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Appropriate treatment for nail breakage following femur intertrochanteric fractures without additional reduction: case series and literature review

Hong Man Cho[1*], Haeryong Heo[1], Myung Cheol Jung[1], Woochull Chung[2], Eunho Choi[2], Young Lee[3] and Yoon Suh Cho[4]

Abstract

Background Intramedullary nail breakage is an uncommon complication in patients with femoral intertrochanteric fractures treated with proximal femoral nail antirotation. Salvage surgery for nail breakages associated with delayed union or nonunion is challenging, particularly when breakage occurs within an acceptable reduction range, complicating implant selection. This study evaluated outcomes in patients with proximal femoral nail antirotation breakage, acceptable reduction, and fixation treated with the long proximal femoral nail antirotation change with distal screw dynamization and lateral cortical notching procedure.

Methods Eleven patients who underwent the long proximal femoral nail antirotation change with distal screw dynamization and lateral cortical notching procedure between May 2013 and May 2023 with no additional fracture reduction required during salvage surgery and with a helical blade screw resinserted at the same position after removal were observed for > 1 year.

Results The average time to full weight-bearing was 8.44 ± 0.82 weeks (mean ± standard deviation) and to return to normal activities was 18.05 ± 0.89 weeks. The Harris Hip Score was 78.64 ± 1.03 at 12 months; all patients resumed independent walking at the final follow-up. The average fracture union time was 21.49 ± 1.75 weeks. In seven cases with a fracture gap at the time of breakage, significant change was observed in the tip-apex distance ($P = 0.016$) or lateral extension of the proximal femoral nail antirotation blade ($P = 0.005$) between the immediate post-surgery and final follow-up results, with the gap healing radiographically at 21.50 ± 1.65 weeks.

Conclusion Patients with high functional demands, good femoral head bone stock, no acetabular disease, and isolated nail breakage due to nonunion or delayed union in the intertrochanteric area treated with proximal femoral nail antirotation are suitable candidates for osteosynthesis. When reduction is within an acceptable range and the lag screw is centrally placed, long proximal femoral nail antirotation with lateral notching and dynamization offers a minimally invasive approach that reduces soft tissue injury and can yield successful outcomes.

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Clinical trial number Not applicable.

Keywords Femur head, Fracture fixation, Internal hip fractures, Bone screws

Background

Proximal femoral nail anti-rotation (Synthes, Davos, Switzerland) provides a significant advantage in patients with severe osteoporosis and intertrochanteric femoral fractures. Despite its numerous advantages and successful clinical outcomes, implant breakage, can occur [1, 2]. This complication typically arises from material fatigue caused by excessive shear and bending forces in the context of delayed union or nonunion, where the fracture fails to heal [1, 2]. If the patient's health and the condition of the femoral head are favorable, salvage surgery may be performed. However, when the fracture reduction status and proximal femoral nail antirotation position, except for the residual fracture gap, are satisfactory, selecting an appropriate salvage surgery method remains challenging [3–5]. Various implants, including angled blade plates, locking plates, and proximal femoral nails, have been used for salvage surgery, with reported outcomes [3–5]. However, these procedures are relatively invasive and technically demanding. While experimental studies have investigated the stability of screws reinserted at the same position in the femoral head, clinical studies on this approach have not yet been reported [6].

We aimed to report cases of intertrochanteric femoral fractures initially treated with proximal femoral nail antirotation that resulted in delayed union or nonunion, ultimately leading to implant breakage. In these cases, salvage surgery involved using a longer proximal femoral nail antirotation while re-inserting a helical blade screw in the same position within the femoral head. Additionally, the procedure included lateral cortical notching beneath the helical blade insertion site and distal screw dynamization, referred to as the "long proximal femoral nail antirotation change with distal screw dynamization and lateral cortical notching" procedure. The authors present the outcomes of this surgical technique, accompanied by a review of the relevant literature.

Materials and methods

From May 2013 to May 2023, a total of 1,552 patients (1,677 hips) with intertrochanteric femoral fractures underwent surgical treatment using proximal femoral nail antirotation. Among these, 17 patients (17 hips) experienced proximal femoral nail antirotation breakage regardless of the implant position. Among these, two cases exhibited self-dynamization with a distal locking screw fracture and achieved union without additional surgery.

In the remaining 15 cases, breakage occurred at the proximal aperture of the helical blade nail. Among these, excluding two cases treated with the long proximal femoral nail antirotation change with distal screw dynamization and lateral cortical notching procedure, one case with severe femoral head damage underwent total hip arthroplasty, while another was treated with a 130-degree angled blade plate. Additional two cases were excluded despite undergoing the long proximal femoral nail antirotation change with distal screw dynamization and lateral cortical notching procedure: one required correction from varus to valgus alignment after osteotomy, and another had the helical blade position adjusted from center-inferior to center-center. Thus, a total of 11 cases were included in this study (Fig. 1). The inclusion criteria were as follows: [1] no additional fracture reduction surgical procedure required during salvage surgery [2], long proximal femoral nail antirotation PFNA change with distal screw dynamization and lateral cortical notching procedure, and [3] reinsertion of a helical blade screw at the same center-center position after removal. All salvage surgeries were performed by a single orthopedic surgeon with over 15 years of experience and an annual hip surgery volume of more than 300.

Preoperative data analysis prior to salvage surgery

A retrospective revision of computerized medical records was performed for all 11 patients. In all cases, we collected demographic data (age and sex), injury data (mechanism and type of fracture), surgical data, and postoperative radiographic findings. Initial fractures were classified according to the Arbeitsgemeinschaft für Osteosynthesefragen/Orthopedic Trauma Association classification of proximal femoral fractures using radiographic images. We also collected data from the salvage procedure, including the time to implant breakage, location of breakage, and reason for failure. Additionally, radiographs obtained after the primary surgery assessed the tip-apex distance [7] and reduction quality. The state of the reduction was evaluated both postoperatively and at the last follow-up by observing the alignment and displacement using the method described by Fogagnolo et al. [8]. To be considered as anatomical, the alignment was supposed to be at a normal cervico-diaphyseal angle or in slight valgus in the anteroposterior view and have < 20° of angulation in the lateral view. The displacement of the main fragments was evaluated according to two criteria: > 80% of overlap in both planes and < 5 mm of shortening. Cases that met both criteria were designated as good. The other cases were considered acceptable if only one criterion was met or poor if neither of the criteria was met. The reduction of the anterior cortical bone was evaluated

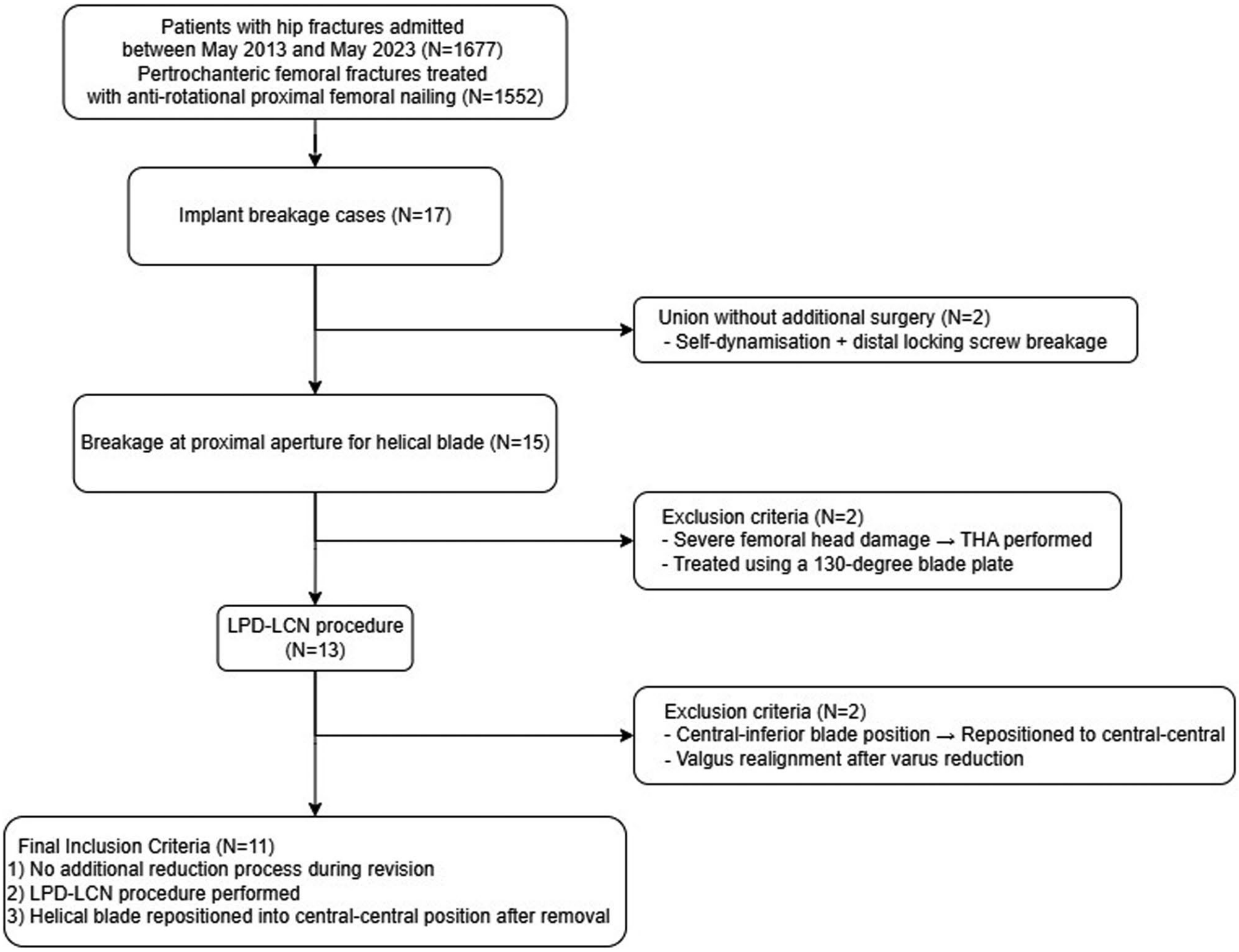

Fig. 1 Flow chart to identify patients who met the inclusion criteria for this study

and classified into three types (extramedullary, neutral, and intramedullary) [7]. Furthermore, the femoral neck-shaft angle, defined as the angle between the central axis of the femoral shaft and neck, was measured immediately after the primary surgery. The position of the helical blade within the femoral head was evaluated using the Cleveland index, which divides the femoral head into nine zones: superior, middle, and inferior regions on the anteroposterior view and anterior, middle, and posterior regions on the lateral view [9]. The characteristics of the nails used during the initial proximal femoral nail antirotation surgery, including the centrum-collum diaphyseal angle (125° or 130°), nail diameter and length, and helical blade length, were also recorded. Finally, the presence of a fracture gap at the time of implant failure was assessed. When a gap was identified, the largest cortical gap was measured in both the anteroposterior and lateral views and was monitored during subsequent follow-up [10].

Radiographic measurements were performed using a picture archiving and communication system (MaroView; Marotech, Seoul, Korea). During the follow-up imaging, the lower limbs were fixed in a frame to maintain consistency throughout the study and ensure the same position was used for each radiographic capture. Additionally, to account for the potential rotation of the hip joint or changes in image magnification, the entire lengths of the helical blade and helical portion were measured. These measurements were then compared with the actual length of the helical blade and adjusted accordingly using a correction factor.

Salvage surgery procedure (long proximal femoral nail antirotation change with distal screw dynamization and lateral cortical Notching procedure)

The patient was positioned supine on a fracture table for routine proximal femoral fracture surgery. Under anesthesia, the broken proximal nail, helical blade, and distal locking screws were removed through incisions (using preexisting incisions whenever possible). Various extraction techniques involving specially designed instruments such as hooks, screws, or guidewires are used to extract the remaining distal nail fragment [11]. After completely removing the initially fixed proximal femoral nail antirotation, a new proximal femoral nail antirotation was inserted with the same diameter and centrum-collum diaphyseal angle as the original proximal femoral nail antirotation. The new nail was longer (260–340 mm) and passed through the original distal locking screw hole. In cases where varus deformity occurred at the fracture site following nail breakage compared to the initial surgery, varus deformity was corrected by the complete removal of the old proximal femoral nail antirotation and traction of the lower limb using the fracture bed. Notably, no additional surgical procedures were required for deformity correction. Following the removal of the guide wire for the nail, a guide pin for the insertion of the new proximal femoral nail antirotation blade was placed along the existing pathway from the lateral cortex opening in the femur originally formed for the previous helical blade toward the femoral head. To confirm that the new proximal femoral nail antirotation had the same cephalo-diaphyseal angle as the old one, the sleeve assembly (buttress, compression nut, protection sleeve, 11.0 mm drill sleeve, and 3.2 mm trocar) was attached to the insertion handle. The 11.0 mm drill bit was then slowly advanced through the existing opening in the lateral cortex to insert the proximal femoral nail antirotation blade, ensuring no resistance until the blade was fully inserted (Fig. 2). Resistance was encountered in cases where varus deformity had been caused by nail breakage. To address this, lower limb traction using the fracture bed was performed until the resistance was eliminated, allowing the restoration of the same cephalo-diaphyseal angle as the old proximal femoral nail antirotation. Subsequently, reaming was performed in the femoral head for the helical blade, followed by blade insertion. The blade length was determined using the standard method, independent of the old proximal femoral nail antirotation. Particular attention was given to ensure that the lateral end of the blade did not remain within the inner aspect of the lateral cortex.

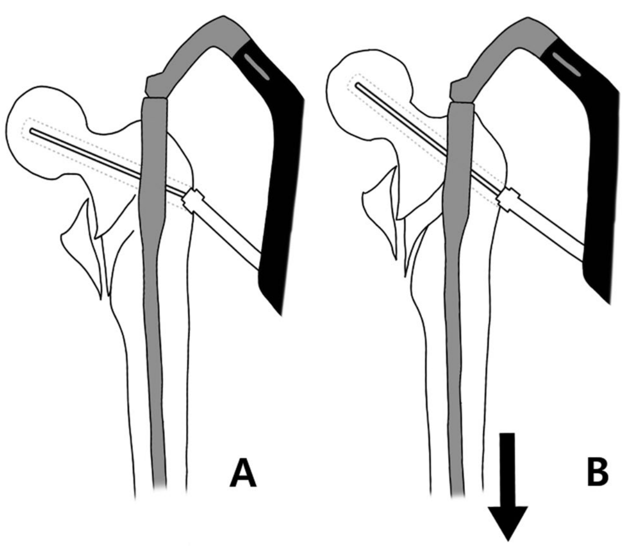

Fig. 2 Schematic Diagram of surgical procedure shows the 11.0 mm drill bit was then slowly advanced through the existing opening in the lateral cortex for proximal femoral nail antirotation blade insertion, ensuring that it passed through without resistance until fully inserted. (**A**) The insertion of an 11.0 mm drill bit is hindered by the varus deformity of the (**A**) fracture and the lateral cortex, where the old blade was removed, for proximal femoral nail antirotation (PFNA) blade insertion. (**B**) The lower limb is tractioned on the fracture table to ensure that the 11.0 mm drill bit is inserted without resistance. After reaming, the blade is inserted

In selecting the new helical blade, the length of the old blade was not considered. Instead, the selection was primarily determined by considering an appropriate tip-apex distance, similar to primary proximal femoral nail antirotation. Additionally, it was ensured that the medial end of the new helical blade was not inserted less than the medial end of the old helical blade. The lateral end of the new helical blade was positioned based on the criterion that it should not be located medial to the outer boundary of the cortical bone. After securing the blade, a single distal locking screw was placed in the dynamic hole of the intramedullary nail for fixation. Subsequently, a small osteotomy was performed immediately below the sleeve of the helical blade on the lateral side using a chisel. The osteotomy must be as broad as the sleeve and extend by approximately 1.5 cm craniocaudally. The osteotomy should be sufficiently deep to ensure sufficient bone resection and allow direct visualization of the nail. Therefore, the cortical support underneath the lag screw is removed, and gliding of the nail along the femoral shaft axis is no longer blocked by the lateral cortex [12] (Fig. 3).

Data analysis after salvage surgery

A retrospective analysis of the patients' medical records was conducted to evaluate the type of anesthesia, operation time, blood loss, need for blood transfusion, and amount of transfusion. The operation time was measured from the start to the end of anesthesia, whereas blood loss was calculated by measuring the volume collected in the suction device and the amount of gauze used, accounting for the volume of irrigation fluid used during the procedure. The usage time of the C-arm fluoroscopy device was determined from the radiation exposure time stored in the machine after surgery. The total hospital stay was also recorded. The clinical evaluation included determining when full weight-bearing ambulation was achieved. The Harris Hip Score [13] assessed functional recovery up to one year post-surgery through regular follow-ups at 3, 6, and 12 months and then annually thereafter. Patients were also asked when they felt they had fully returned to their daily activities. Radiological evaluations were performed using standard anteroposterior and lateral radiographs obtained at each

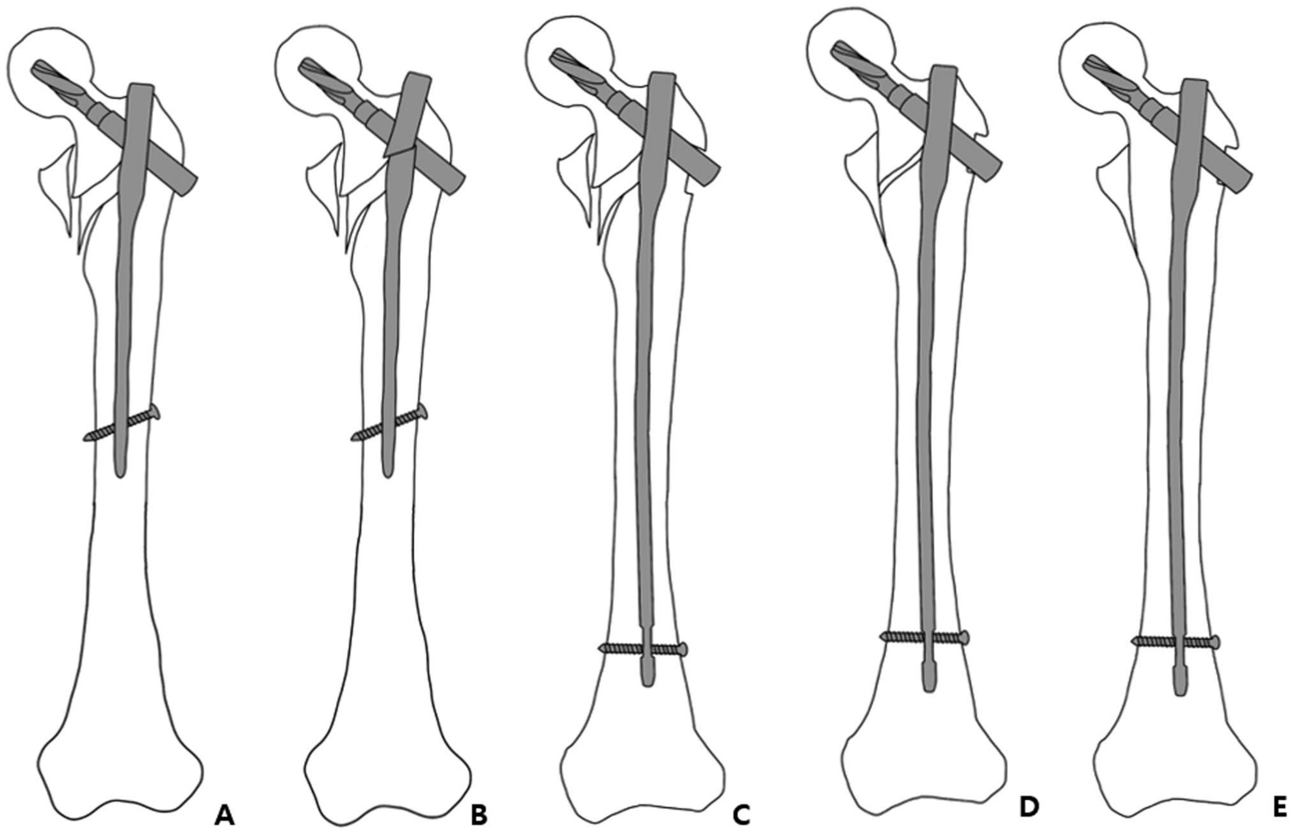

Fig. 3 Schematic Diagram of surgical procedure (long proximal femoral nail antirotation with lateral notching and dynamization). (**A**) Arbeitsgemeinschaft für Osteosynthesefragen/Orthopedic Trauma Association 31-A2 trochanteric fracture treated with proximal femoral nail antirotation, showing acceptable fracture reduction, helical blade position, and fracture gap. (**B**) Illustration shows nail breakage at the proximal aperture of the proximal femoral nail antirotation blade with trochanteric fracture nonunion due to fracture gap. (**C**) In cases where resistance was encountered, it was due to varus deformity caused by nail breakage. To address this, traction of the lower limb using the fracture bed was performed until resistance was eliminated, allowing the restoration of the same cephalo-diaphyseal angle as the old proximal femoral nail antirotation (**D**) long proximal femoral nail antirotation with lateral notching and distal screw dynamization and helical blade re-insertion at the same position of femoral head (center-center). (**E**) compressed fracture site and distal screw dynamization. (**F**) fracture is healed completely without a fracture gap

visit during the follow-up period. During the follow-up period after salvage surgery, implant positional changes were examined for changes in the tip-apex distance [7] (Fig. 4), and the lateral extension distance was examined for screw back-up. The lateral extension distance [14] was compared with the length measured on images obtained immediately after salvage surgery and at postoperative 1 year. The lateral extension distance (for screw backup) was measured between the lateral end of the screw and lateral edge of the intramedullary nail [14] (Fig. 4). The persistence of a fracture gap due to nonunion or delayed union can contribute to nail breakage. Therefore, patients with a prominent gap observed on a simple radiograph were identified. In patients with a gap at the time of failure, the largest cortical gap was measured on anteroposterior or lateral radiographs, and the time at which the gap resolved after salvage surgery was recorded (Fig. 4). Fracutre union was defined clinically as the absence of tenderness or false motion at the fracture site and radiographically as the presence of a bridging callus across at least two cortical bones or restoration of cortical continuity [15]. Nonunion was defined as the absence of callus formation on radiographs in both the anteroposterior and lateral views at the 6-month follow-up. Radiological measurements and evaluations were performed by two orthopedic surgeons based on anteroposterior and lateral radiographs of the hip joint. Kappa coefficient tests were used to measure the inter-observer reliability of the two observers, and an almost perfect agreement was found (kappa = 0.88).

Complications related to the surgery, including femoral head perforation, varus deformity due to a change in the neck-shaft angle of 10° or more, sliding of the screw by 15 mm or more, implant failure, or the need for reoperation, were also documented.

Statistical analyses

Patient characteristics are presented as numbers with percentages for categorical variables and as mean ± standard deviation for continuous variables. Due to the

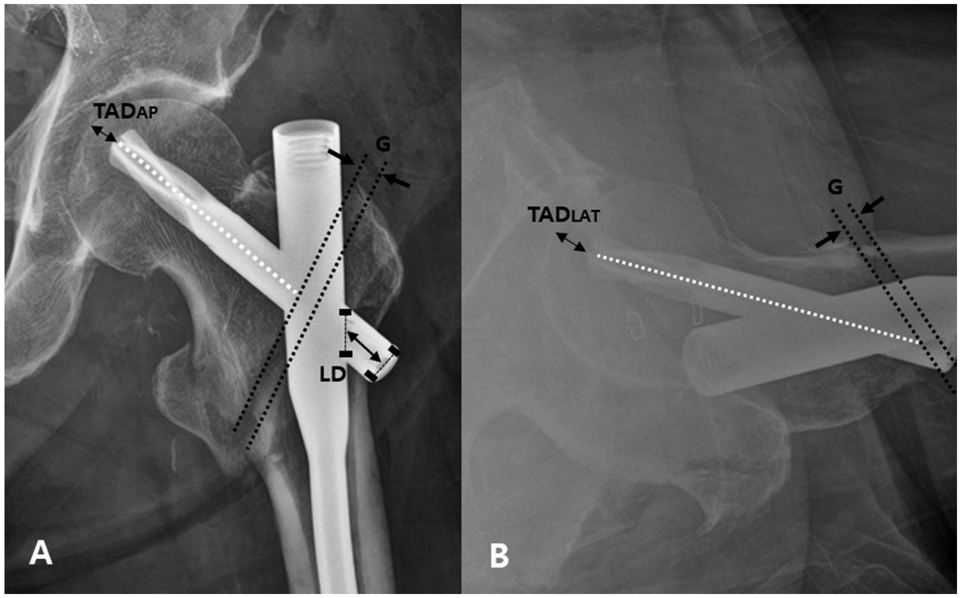

Fig. 4 Radiographic measurements performed in this study. (**A**) (**B**) The tip-apex distance is measured as the sum of the distance, in millimeters, from the tip of the lag screw to the apex of the femoral head in the anteroposterior and lateral view of the radiographs. The lateral extension distance (for screw back-up) was measured between the lateral end of the screw and lateral edge of the intramedullary nail. The gap of the cortical bone (G) was measured as the maximum value of the gap observed in the anteroposterior or lateral view

small sample size, non-parametric methods were used. Differences between the groups were tested using the Mann-Whitney U test for continuous variables and Fisher's exact test for categorical variables. Differences in tip-apex and lateral extension distances between values obtained immediately after surgery and at one year post-surgery were analyzed using the Wilcoxon signed-rank test. Radiologic measurements and evaluations were supervised by two orthopaedic surgeons based on anteroposterior and lateral radiographs of the hip joint. Kappa coefficient tests were applied to measure the intra-observer (K1) and inter-observer (K2) reliabilities of the two observers; both sets of results were at reliable levels (K1 = 0.88, K2 = 0.81). All statistical analyses were performed using R software, version 4.1.2 (R Foundation for Statistical Computing, Vienna, Austria; http://www.R-project.org).

Results

Patient demographic data

Among the 11 cases, two were female, and nine were male, with an average age of 75.00 ± 4.43 years. Proximal femoral nail antirotation was used for all patients who were independently ambulant before the fracture. Three patients each had diabetes and hypertension, while one had ischemic heart disease and bronchial asthma. Six patients were classified as American Society of Anesthesiologists grade 2, and five were classified as American Society of Anesthesiologists grade 1. One patient sustained a fracture in a high-velocity motor vehicle accident, one sustained sports injury during mountain climbing, and nine sustained a trivial fall. The fracture types included 31A1.3 (1 case), 31A2.1 (2 cases), 31A2.2 (6 cases), and 31A2.3 (2 cases), with 31A2.2 being the most prevalent. The reduction quality was good in seven cases and acceptable in four cases, while anterior cortical bone reduction was extramedullary (6 cases) or neutral (5 cases). The position of the helical blade within the femoral head was central-to-central in all cases. The tip-apex diameter was 21.93 ± 1.12 mm, and the femoral neck-shaft angle was 130.09° ± 5.30 (Table 1).

Nail breakage

The time to breakage was 5.82 ± 1.16 months. Breakage occurred at the proximal aperture of the helical blade. The centrum-collum diaphyseal angles of the proximal femoral nail antirotation nails were 125° (3 cases) and 130° (8 cases); diameters were 9 mm (3 cases), 10 mm (5 cases), and 11 mm (3 cases); and lengths were 170 mm (9 cases) and 200 mm (2 cases). Blade lengths were 85–100 mm. Failure was attributed to delayed union or nonunion, with fracture gaps of 1.40 ± 0.17 mm in seven cases (Table 2). The seven cases with a fracture gap were radiographically suspected to have oligotrophic non-union due to the persistent gap, which did not compress during surgery and/or with natural sliding of the helical blade during postoperative ambulatory periods. One of the 11 patients included in this study experienced persistent hip pain following the initial surgery. As the pain worsened, the patient visited a private clinic; however,

Table 1 Patient characteristics before and after long proximal femoral nail antirotation with lateral Notching and dynamization

Case	Sex	BMI	Mechanism	Fx type	Primary operation								
					TAD	QR	AC	NSA (degree)	CI	CCD (degree)	ND (mm)	NL (mm)	BL (mm)
1	M	23.8	slip down	31A2.2	22.8	good	positive	133	5	130	10	170	100
2	M	24.1	slip down	31A2.2	20.7	acceptable	neutral	122	5	125	10	200	85
3	F	19.9	slip down	31A2.3	22.7	good	neutral	130	5	130	11	170	85
4	M	24.8	slip down	31A2.2	23.6	good	neutral	139	5	130	10	170	95
5	F	18.1	sport injury	31A2.3	22.8	acceptable	positive	135	5	125	9	170	90
6	M	21.9	slip down	31A1.3	20.3	acceptable	positive	123	8	130	11	170	90
7	M	24.8	autobike	31A2.2	20.5	good	neutral	131	5	130	9	170	90
8	M	22.9	slip down	31A2.2	22.7	good	neutral	130	5	130	11	170	100
9	M	23.1	auto bike	31A2.2	21.1	acceptable	positive	124	8	125	9	170	85
10	M	27.7	slip down	31A2.1	21.8	good	positive	134	5	130	10	200	95
11	M	22.1	slip down	31A2.1	22.2	good	positive	130	5	130	10	170	90

BMI, Body Mass Index; Fx, Fracture; TAD, Tip-Apex Distance; QR, Quality of Reduction; AC, Anterior Cortex Position; NSA, Neck Shaft Angle; CI, Cleveland Index; CCD, centrum-collum diaphyseal angle; ND, Nail Diameter; NL, Nail Length; BL, Blade Length

the breakage of the intramedullary nail was overlooked. Two weeks later, the patient developed severe pain while walking and presented to the emergency department of our hospital (Fig. 5).

Clinical and radiological results after salvage surgery

General anesthesia was administered in three cases and spinal anesthesia in eight cases. The surgical time was 99.00 ± 7.75 min, and the blood loss volume was 369.09 ± 38.91 cc. Blood transfusion was required in four cases, with transfusion of 2.5 pints (range: 2–4 pints) of blood. The duration of C-arm fluoroscopy use was 2.72 ± 0.35 min. The hospital stay was 20.64 ± 2.46 days (Table 2), and the time until full weight-bearing ambulation was possible was 8.44 ± 0.82 weeks. The Harris Hip Score at regular follow-up intervals was 65.82 ± 3.19 at 3 months, 72.45 ± 2.02 at 6 months, 76.18 ± 0.87 at 9 months, and 78.64 ± 1.03 at 12 months, indicating gradual improvement. All patients resumed independent walking at the final follow-up, which was the same as that before the fracture. The time for patients to return to normal daily activities was 18.05 ± 0.89 weeks. The time for fracture union was 21.49 ± 1.75 weeks, and in the seven cases with a fracture gap at the time of breakage, the tip-apex diameter was 22.32 ± 0.89 mm immediately after salvage surgery. At 12 months following surgery, the TAD was 23.06 ± 0.75 mm, and a significant change occurred between the tip-apex diameter immediately after salvage surgery and at the final follow-up ($P = 0.016$; Table 3). The lateral extension distance [14] of the proximal femoral nail antirotation blade, compared between the image taken immediately (3.54 ± 1.15 mm) after salvage surgery and at the last follow-up (4.15 ± 1.20 mm) showed a significant difference ($P = 0.005$; Table 4). The gap completely healed radiographically at 21.50 ± 1.65 weeks (Table 3). No significant differences were observed in the timing of nail breakage, intraoperative data related to salvage surgery, or postoperative clinical and radiographic recovery when the seven cases with a prominent gap on the conventional radiographs were compared with the four cases without a prominent gap (Table 5). No nonunions were observed, and one patient experienced hematoma at the helical blade insertion site, which improved with conservative treatment, including compression dressing, without requiring additional surgical intervention.

Discussion and conclusions

Intramedullary nail breakage due to nonunion or delayed union in pertrochanteric fractures is a rare complication, with a reported prevalence of 0.87–0.88% in previous studies [16, 17]. In this study, among 1,677 cases treated with proximal femoral nail antirotation, 15 experienced implant breakage, yielding an incidence of 0.89%. The

Table 2 Nail breakage and intra-operative data related to salvage surgery

Case	Nail Breakage		Gap	GD (mm)	Salvage Operation						
	Period (Months)	Site			Anesthesia	Surgical time (min)	Bleeding (ml)	Transfusion	PRBC (pints)	FT (min)	HP (days)
1	6.4	PAHB	yes	1.6	Spinal	115	380	no	0	3.2	19
2	7.2	PAHB	no	0	Spinal	95	320	yes	2	2.5	18
3	5.6	PAHB	no	0	General	105	360	no	0	3.3	19
4	4.9	PAHB	yes	1.6	Spinal	100	405	yes	2	3.1	22
5	7.8	PAHB	yes	1.5	Spinal	95	295	no	0	2.6	21
6	4.8	PAHB	no	0	Spinal	94	410	no	0	2.6	20
7	5.5	PAHB	no	0	Spinal	95	360	no	0	2.6	23
8	4.6	PAHB	yes	1.2	Spinal	90	420	yes	4	2.7	18
9	4.2	PAHB	yes	1.2	Spinal	95	360	no	0	2.3	26
10	6.9	PAHB	yes	1.3	General	110	400	yes	2	2.8	19
11	6.1	PAHB	yes	1.4	General	95	350	no	0	2.2	22

PAHB, Proximal Aperture of Helical Blade; GD, Gap Diameter; PRBC, Packed RBC concentrate; FT, Fluoroscpy Time; HP, Hospital Periods

mean time to implant breakage is reported as 9 months (range, 3–24 months) [18, 19]. In this study, the mean time was 5.82 ± 1.16 months. All the 11 patients in this study experienced persistent pain during the follow-up period, which worsened at the time of implant breakage. In one of the cases included in this study, nail breakage was initially overlooked. Therefore, in patients with persistent pain at 6 months of follow-up, suboptimal reduction, lack of consolidation signs, and comorbidities, revision osteosynthesis with grafting should be considered to avoid implant breakage [20]. Most nail breakages are associated with nonunion. Li et al. reported that among 70 cases, nail breakage occurred in 65 (92.9%) of pertrochanteric fractures that exhibited nonunion, as "fracture healing is a race between the bony union and implant failure" [21]. The fracture gap between the main bone fragments remaining after intramedullary nailing is recognized as one of the major risk factors for delayed union and nonunion [22]. In this study, seven patients with implant breakage showed fracture gaps on standard radiographs taken at the time of primary surgery.

Management of this complication includes conversion to hip arthroplasty or revision with new osteosynthesis [23]. The decision to perform revision surgery to replace a broken nail should be based on the patient's individual characteristics. As recommended by Tomás-Hernández et al. [16], factors such as the type of previous fracture, quality of remaining bone stock in the trochanteric area and femoral head, patient's age and functional demands, ease of removing broken implants, and surgeon's expertise must be considered. All the cases in the present study involved relatively healthy patients who were community ambulators with good femoral head and proximal femoral bone quality. Additionally, the broken nail could be removed without difficulty. Therefore, salvage surgery was prioritized over primary arthroplasty. Possible revision methods include re-fixation with nails, locking plates, and angle blade plates [3]. Re-nailing is challenging, especially since nailing contributes independently to nonunion. Locking plates, although an option, do not achieve dynamic compression [4]. Moreover, using locking plates would require a larger surgical field to accommodate the longer plates, making the procedure more invasive. Additionally, as plates are mechanically weaker than nails, a period of non-weight-bearing would likely be required postoperatively. Angled blade plates are useful for revision surgery because they can refine varus deformity and target the inferior portion of the femoral head, typically unaffected by prior fixation devices [5]. Furthermore, angled blade plates do not provide dynamic compression at the fracture site.

In cases of nail breakage, even when reduction is within the acceptable range, the helical blade may remain stably fixed in the center of the femoral head, the tip-apex distance may be appropriately placed, and implant failure due to delayed union or nonunion can still occur. These cases typically arise when a gap exist at the fracture site and sliding has not been achieved. When performing salvage surgery in such cases, if the reoperation involves reusing the intramedullary nail, no additional reduction is required after nail removal. However, the following two critical steps must be taken: [1] reducing the fracture gap and ensuring sliding at the fracture site to address the cause of delayed union or nonunion and [2] re-inserting the helical blade at the same location in the femoral head, which presents challenges in selecting the appropriate screw type.

Surgical methods, such as osteotomy or bone grafting, aimed at reducing the fracture gap and achieving contact between bone fragments, are highly invasive. Therefore, less invasive alternatives are needed. Surgical methods, such as osteotomy or bone grafting, aimed at reducing the fracture gap and achieving contact between bone fragments, are highly invasive. Therefore, less invasive

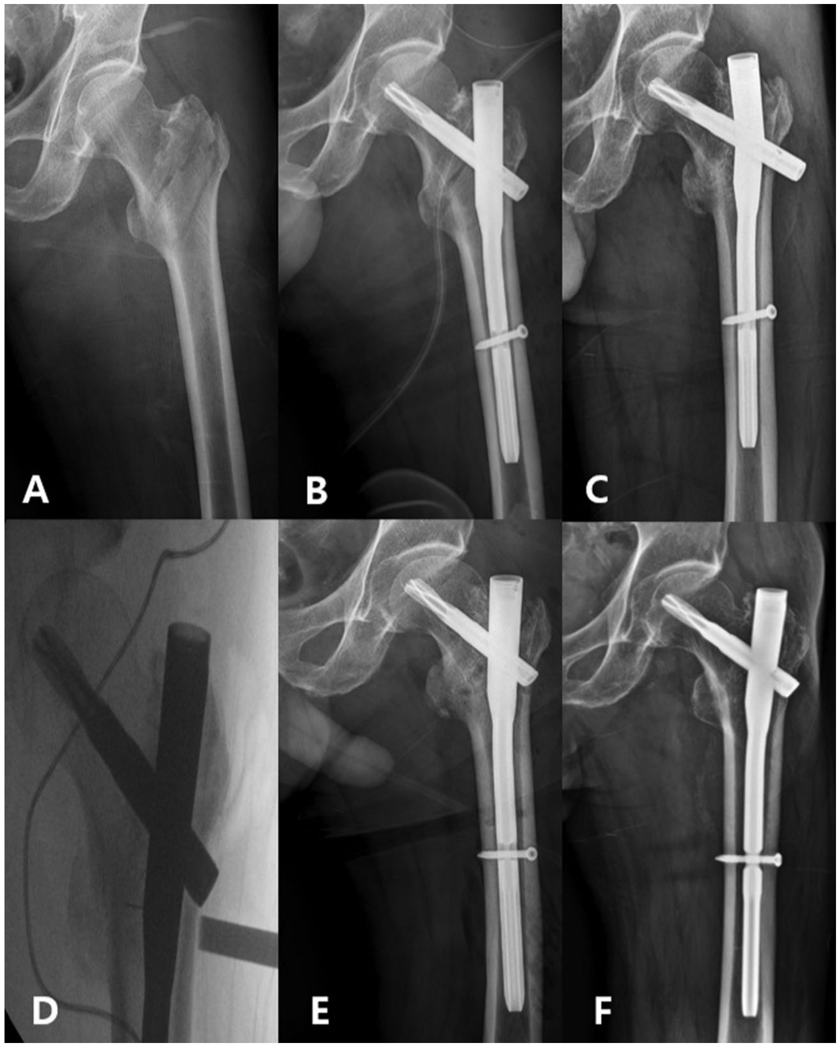

Fig. 5 Pelvis anteroposterior radiographs of an intertrochanteric fracture in a male patient in his 70s. (**a**) Preoperative radiographs show an intertrochanteric fracture (Arbeitsgemeinschaft für Osteosynthesefragen/Orthopedic Trauma Association 31-A2.1). (**b**) Immediate postoperative radiograph after fixation using proximal femoral nail antirotation showing a fracture gap. (**c**) The nail broke at the proximal aperture 6.9 months later due to nonunion. Fracture gap is persistent although compared to the immediate post-operation radiograph. (**d**) Using a chisel we performed a small osteotomy just below the sleeve of the helical blade on the lateral side. (**e**) The long proximal femoral nail antirotation with lateral notching and dynamization was performed after proximal femoral nail antirotation removal. (**f**) The radiograph taken 19.8 months after salvage surgery shows no gap, indicating that there is good bone contact, and the fracture has healed

alternatives are needed. All the seven cases with a fracture gap in this study were considered to have oligotrophic nonunion due to the persistence of the fracture gap. Oligotrophic nonunion is intermediate between atrophic and hypertrophic nonunion types, characterized by biological activity with minimal radiographic evidence of healing. Oligotrophic nonunion primarily occurs due to inadequate fracture surface contact. Therefore, achieving proper fracture contact was considered a key factor in resolving this condition. Long proximal femoral nail antirotation modifications with distal screw dynamization and the long proximal femoral nail antirotation change with distal screw dynamization and lateral cortical notching procedure have been reported as effective approaches for achieving this goal. This procedure offers a less invasive solution while addressing the fracture gap and facilitating healing. Dynamization through the removal of the distal interlocking screw can promote bone healing in intertrochanteric fractures with a medial bone defect, where gliding along the femoral neck axis permitted by the lag screw does not provide sufficient fracture compression [24]. However, in certain intertrochanteric fractures, such as those with a fracture line running at the level of the lag screw, the removal of the distal interlocking screw alone does not facilitate adequate gliding of the nail. This is because gliding is blocked by the contact of the lag screw with the lateral femoral cortex, making dynamic fixation alone insufficient to reduce the fracture

Table 3 Clinical and radiological results after salvage surgery

Case	3HHS	6HHS	9HHS	12HHS	FWB (weeks)	RO (weeks)	2 TAD	3 TAD	2 LE	3 LE	GH	Fx Union
1	58	69	75	77	8.6	19.4	21.4	22.5	2.3	3.1	19.7	24.2
2	62	70	75	78	8.5	19.0	22.8	23.7	3.4	4.6	no	23.9
3	65	71	75	78	8.9	18.8	21.8	23.1	1.8	2.9	no	18.8
4	66	71	76	78	10.0	17.9	22.9	22.8	4.6	5.1	21.4	22.8
5	66	72	76	78	7.3	17.7	23.6	24.1	3.5	4.6	24.2	22.5
6	67	73	76	78	7.2	17.6	22.1	23.6	2.7	2.9	no	22.0
7	68	73	77	79	9.1	17.6	21.8	21.5	5.9	6.8	no	21.0
8	68	74	77	79	7.7	17.2	22.8	22.5	3.2	3.2	20.5	20.9
9	68	74	77	80	8.3	17.2	23.0	23.7	4.4	4.6	22.7	20.8
10	68	75	77	80	8.4	16.9	20.5	22.7	3.1	3.4	19.8	19.8
11	68	75	77	80	8.8	19.2	22.8	23.5	4.0	4.5	22.2	19.7

HHS, Harris Hip Score; FWB, Full Weight Bearing; RO, Return to Ordinary Living; TAD, Tip-Apex Distance; GH, Gap Completely Healed

Table 4 Clinical and radiographic outcomes by the presence or absence of a prominent fracture gap

		Gap - (*n* = 4)	Gap + (*n* = 7)	*p* value
Broken periods (months)		5.78 ± 1.01	5.84 ± 1.32	1
Surgical time (min)		97.25 ± 5.19	100.00 ± 9.13	0.62
Bleeding (ml)		362.50 ± 36.86	372.86 ± 42.41	0.775
FT (min)		2.75 ± 0.37	2.70 ± 0.37	1
HD		20.00 ± 2.16	21.00 ± 2.71	0.702
TAD (salvage surgery)	Immediate	22.12 ± 0.47	22.43 ± 1.08	0.39
	12 months	22.98 ± 1.02	23.11 ± 0.64	1
LD (salvage surgery)	Immediate	3.45 ± 1.76	3.59 ± 0.81	0.648
	12 months	4.30 ± 1.85	4.07 ± 0.81	0.774
HHS	3 months	65.50 ± 2.65	66.00 ± 3.65	0.487
	6 months	71.75 ± 1.50	72.86 ± 2.27	0.34
	9 months	75.75 ± 0.96	76.43 ± 0.79	0.266
	12 months	78.25 ± 0.50	78.86 ± 1.21	0.422
FB (weeks)		8.43 ± 0.85	8.44 ± 0.86	0.788
RO (weeks)		18.25 ± 0.75	17.93 ± 1.00	0.776
Fx union (weeks)		21.43 ± 2.12	21.53 ± 1.68	1

HHS, Harris Hip Score; FWB, Full Weight Bearing; RO, Return to Ordinary Living; TAD, Tip-Apex Distance

Table 5 Differences in tip-apex distance and lateral distance between measurement times

	Immediate[a]	12 months[a]	Difference	*p* value
TAD (salvage surgery)	22.32 ± 0.89	23.06 ± 0.75	0.75 ± 0.78	0.016
LD (salvage surgery)	3.54 ± 1.15	4.15 ± 1.20	0.62 ± 0.42	0.005

[a]Measurements were performed immediately and at 12 months after salvage surgery. TAD, Tip-Apex Distance; LD, Lateral Extension Distance

gap. Attempts have been made to combine lateral cortical notching with distal screw dynamization to address this issue. This combined approach has been reported to yield successful outcomes in treating nonunion of intertrochanteric fractures. Therefore, lateral cortical notching can promote dynamization of proximal femoral nailing and enable gliding of the intramedullary nail along the femoral shaft axis, leading to compression at the fracture site in certain intertrochanteric fractures [24, 25]. Thus, compared to these revision strategies (angled blade plate, locking plate dynamic compression plate, etc.), long proximal femoral nail antirotation change with distal screw dynamization and lateral cortical notching is a minimally invasive technique with reduced damage to the soft tissue and blood supply at the fracture site. We performed long proximal femoral nail antirotation change with distal screw dynamization and lateral cortical notching in 11 patients with nail breakage after proximal femoral nail antirotation. Despite relatively minimal soft tissue damage and the minimally invasive nature of the procedure, successful outcomes were achieved in all cases. The differences between the the present study and the report by Biber et al. [24] on dynamization via the removal of the distal interlocking screw combined with lateral cortical notching for nonunion of intertrochanteric fractures are as follows. First, in the present study, the same helical blade was used in both the initial and salvage surgeries. Second, dynamization was achieved by replacing the implant with a long nail in all cases and using a distal locking screw in a dynamic hole. Third, this study focused on fractures that were not reverse oblique or subtrochanteric.

In salvage surgery for breakage, while efforts to reduce the fracture gap are important, selecting an appropriate re-fixation device during the re-insertion of the lag screw at the same location is challenging. Among the two main types (conventional and helical) of lag screws inserted into the femoral head, experimental studies have suggested that re-inserting a helical blade lag screw after removal offers the greatest resistance to pull-out or rotation [6]. In our case, similar to the experimental findings, re-inserting the same type of helical blade lag screw at the same location resulted in successful outcomes without fixation loss. Therefore, re-inserting the same type of helical blade screw at the same position does not significantly affect fixation strength.

Rehabilitation after surgical treatment for hip fractures significantly impacts prognosis. Given that controlled compression at the fracture site is crucial in preventing delayed union or nonunion, active rehabilitation remains essential even after salvage surgery. Reports have suggestted that adding education to rehabilitation exercises improves psychological outcomes [26] and that wearable devices can enhance physical activity [27]. Therefore, incorporating structured education and utilizing beneficial devices for patients may be advantageous.

The limitations of this study include the lack of a control group, a small sample size, and the absence of a comparative analysis, which restricts the determination of factors associated with breakage and the reproducibility of treatment outcomes. This is because nail breakage following surgical treatment of intertrochanteric femoral fractures is extremely rare. Furthermore, cases meeting the specific conditions for long proximal femoral nail antirotation change with distal screw dynamization and lateral cortical notching—such as good fracture reduction, appropriate tip-apex diameter and helical blade position, and good bone quality—are even rarer. Intertrochanteric fractures of the femur are a representative osteoporotic fracture in the older adult population and significantly impact quality of life. When treated with proximal femoral nail antirotation, cases of delayed union or nonunion may lead to nail breakage, necessitating secondary surgery. The primary cause of delayed union or nonunion is often the failure of controlled impaction at the fracture site. If the patient's overall health permits and the bone quality of the femoral head and fracture reduction status are favorable, salvage surgery may be considered. However, if the previously inserted nail and blade are positioned appropriately, reimplantation at the same site is required, posing a challenge in selecting the appropriate implant type. Furthermore, additional challenging procedures such as curettage, bone grafting, or osteotomy may be necessary to reduce the fracture gap contributing to the delayed union or nonunion, increasing surgical difficulty. A previous experimental study reported that reinserting a helical blade at the same position after its removal in intertrochanteric femur fractures provides the greatest stability, regardless of whether reaming is performed. The present study includes a limited number of cases; the authors aimed to propose a relatively non-invasive surgical approach to overcome proximal femoral nail antirotation failure caused by delayed union or nonunion due to a fracture gap in such a limited situation.

Conclusion

The primary cause of nonunion was the absence of dynamic compression at the fracture site. In certain intertrochanteric fractures, the gliding of the lag screw within the nail along the femoral neck may be blocked, preventing compression at the fracture site. Therefore, careful attention should be given to minimizing fracture gaps during intertrochanteric fracture surgery. We believe that patients with high functional demands, good bone stock in the femoral head, no acetabular disease, and isolated nail breakage due to nonunion or delayed union in the intertrochanteric area treated with proximal femoral nail antirotation are suitable candidates for new osteosynthesis. If the reduction is within an acceptable range and the lag screw is centrally placed, performing a long proximal femoral nail antirotation with lateral notching and dynamization is a relatively minimal invasive approach that minimizes soft tissue injury and leads to successful outcomes.

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Author contributions

CHM, CEH conceived and coordinated the study. CHM, CEH, HHR and CWC designed the ethical issues. CEH, JMC and CWC acquired the data. CHM, HHR and CWC reviewed the data. CEH JMC and CWC performed the statistical analysis. CHM, HHR, CWC, and CEH prepared the manuscript. YL and CHM performed the statistical analysis. CYS created the figures included in the paper. JMC, CWC, CYS, and CEH provided administrative, technical, or material support. All authors approved the manuscript.

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Data availability

The datasets used and/or analysed during the current study available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

The protocol of this study was approved by Gwangju Veterans Hospital Institutional Review Board (no. 2024-2-1). All data were anonymized, and the requirement for informed consent was waived by the Institutional Review Board due to the retrospective nature of the study design. This research was conducted in accordance with the Declaration of Helsinki.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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