Predictors and reduction techniques for irreducible reverse intertrochanteric fractures

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Abstract

Background: Reverse intertrochanteric fractures are usually initially treated with closed reduction. However, sometimes these fractures are not amenable to closed reduction and require open reduction. To date, few studies have been conducted on predictors of and reduction techniques for irreducible reverse intertrochanteric fractures. Therefore, this study aimed to summarize the displacement patterns of irreducible reverse intertrochanteric fractures and corresponding reduction techniques, and explore predictors of irreducibility.

Methods: We reviewed 1174 cases of trochanteric fractures treated in our hospital from January 2006 to October 2018, 113 of which were reverse intertrochanteric fractures. An irreducible fracture was determined according to intra-operative fluoroscopy imaging after closed manipulation. Fractures were assessed for displacement patterns, radiographic features of irreducibility, and reduction techniques. Logistic regression analysis was performed on potential predictors for irreducibility, including gender, age, body mass index, AO Foundation/Orthopaedic Trauma Association (AO/OTA) classification, and radiographic features.

Results: Seventy-six irreducible fractures were identified, accounting for 67% of reverse intertrochanteric fractures. Six patterns of fracture displacement after closed manipulation were identified; the most common pattern was medial displacement and posterior sagging of the femoral shaft relative to the head-neck fragment. Multivariate logistic regression analysis identified three predictors of irreducibility: a medially displaced femoral shaft relative to the head-neck fragment on the anteroposterior (AP) view (odds ratio [OR], 8.00; 95% confidence interval [CI], 3.04–21.04; $P < 0.001$), a displaced lesser trochanter (OR, 3.61; 95% CI, 1.35–9.61; $P = 0.010$), and a displaced lateral femoral wall (OR, 2.92; 95% CI, 1.02–8.34; $P = 0.046$).

Conclusions: A high proportion of reverse intertrochanteric fractures are not amenable to closed reduction. Six patterns of fracture displacement after closed manipulation were identified. Different reduction techniques are required for different displacement patterns. Predictors of irreducibility include a medially displaced femoral shaft relative to the head-neck fragment on the AP view, a displaced lesser trochanter, and a displaced lateral femoral wall. These patients warrant special consideration in terms of recognition and management.

Keywords: Intertrochanteric hip fractures; Irreducible; Predictors; Reduction techniques; Reverse oblique

Introduction

Trochanteric fractures are becoming increasingly common as the population ages and are usually treated surgically by closed reduction and internal fixation.[1] However, some trochanteric fractures are difficult to reduce satisfactorily by closed manipulation and require various types of open reduction. These fractures are defined as irreducible fractures.[2-4] The radiographic features of and treatment strategies for irreducible pertrochanteric fractures have been reported in some studies.[2-5] However, few studies have been conducted on irreducible reverse intertrochanteric fractures. Reverse intertrochanteric fractures are classified as AO Foundation/Orthopaedic Trauma Association (AO/OTA) 31-A3 according to the Orthopaedic Trauma Association classification system. The major fracture line in AO/OTA 31-A1 and A2 fractures runs obliquely from the proximal greater trochanter to the distal lesser trochanter. However, AO/OTA 31-A3 fractures have the opposite configuration, with the major fracture line running from distolateral to proximomedial. Since reverse intertrochanteric fractures are unstable fractures with unique anatomic and mechanical characteristics, the radiographic features, displacement patterns,

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and reduction techniques are different from those of pertrochanteric fractures.[6-8]

We retrospectively analyzed 113 cases of reverse intertrochanteric fractures to summarize the radiographic features and displacement patterns of irreducible reverse intertrochanteric fractures and corresponding reduction techniques and to explore predictors of irreducibility. We hope to help surgeons recognize irreducible fractures pre-operatively and provide some reduction techniques for different displacement patterns.

Methods

Ethical approval

The study was approved by the Ethical Committee of Peking University Third Hospital and was conducted in accordance with the *Declaration of Helsinki*. Since this retrospective study and data analysis were performed anonymously, this study was exempt from requiring informed consent from patients.

Patient data

The medical records of 1174 adult patients who underwent surgery for trochanteric fractures at our institution between January 2006 and October 2018 were retrospectively reviewed. The inclusion criterion was reverse intertrochanteric fractures. The exclusion criteria were: (1) pathological fracture, delayed fracture, or periprosthetic fracture and (2) AO/OTA 31-A1 and A2-type fracture, subtrochanteric fracture, or femoral shaft fracture.

According to the reduction quality of fractures after closed manipulation, the patients were divided into reducible and irreducible groups. The evaluation for reduction quality included two aspects. The reduction quality of alignment was based on the method proposed by Baumgaertner and Solberg,[9] which includes the following two aspects: (1) normal or slightly valgus neck-shaft angle on the anteroposterior (AP) view; (2) less than 20° of angulation on the lateral view. The reduction quality of displacement was based on the method proposed by Kim et al,[5] which includes the following two aspects: (1) displacement less than the medial cortical thickness on the AP view; (2) displacement less than the anterior cortical thickness on the lateral view. A "good" reduction met both criteria of alignment and both criteria of displacement. An "accept-able" reduction met both criteria of alignment and only one criterion of displacement. A "poor" reduction met only one or neither criterion of alignment or neither criterion of displacement. After closed manipulation, a "good" reduction was assigned to the reducible group, and an "acceptable" or a "poor" reduction was assigned to the irreducible group.

Patient demographics and clinical characteristics were recorded, including age at the time of surgery, gender, body mass index (BMI) categorized as low at <18.5 kg/m^2, normal at 18.5 to 23.9 kg/m^2, overweight at 24.0 to 27.9 kg/m^2 or obese at 28.0 kg/m^2,[10] and the mechanism of injury (low energy or high energy).

This study evaluated the following radiological parameters that may impede closed reduction: AO/OTA classification; the type of fracture line: transverse or oblique; lesser trochanter location: attached to the proximal fragment, attached to the distal fragment or displaced; status of the lateral femoral wall fragment: attached to the great trochanter or displaced; and femoral shaft displacement relative to head-neck fragment on the AP view: no displacement, lateral or medial. All radiological parameters mentioned above were evaluated according to pre-operative X-rays.

For the irreducible group, we additionally recorded the fracture displacement patterns after closed manipulation, the reduction techniques, and the final reduction quality.

Operative and reduction protocols

Five experienced orthopedic surgeons performed all of the surgeries. Spinal anesthesia or general anesthesia was used. Reduction and internal fixation were performed with the patients in the supine position on a fracture table using an image intensifier. After closed manipulation, immediate intra-operative images were used to evaluate the reduction quality of the fracture. If the quality was good, then internal fixation was undertaken. If the quality was acceptable or poor, then limited open reduction techniques were performed, including using a bone hook to pull the femoral shaft laterally, a clamp to reduce the fragments, a periosteum elevator to push the head-neck fragment, a Schanz screw as a joystick and a mallet on the thigh to push the distal femur into position. Then, the patients under-went routine procedures for implantation of extra-medullary or intra-medullary devices [Table 1].

Statistical analysis

All statistical analyses were performed using SPSS version 22.0 (SPSS, Inc., Chicago, IL, USA). All variables were evaluated with an unconditional univariate logistic regression analysis. Odds ratios (ORs) and 95% confidence intervals (CIs) were obtained. All variables with $P < 0.05$ in the univariate analysis were included in a subsequent multivariate model. Statistical significance was defined as $P < 0.05$.

Results

Overall, 113 reverse intertrochanteric fractures met the inclusion criterion for the study, accounting for 9.6% of trochanteric fractures. Forty-eight males and 65 females with an average age of 73.9 years (37–92 years) were assessed, and 15 type 31-A3.1 fractures, 21 type 31-A3.2 fractures, and 77 type 31-A3.3 fractures were identified. The mechanisms of injury were low energy (fall from standing height, 84 cases) and high energy (car accident or fall from a high place, 29 cases).

Seventy-six irreducible fractures were identified, accounting for 67% of reverse intertrochanteric frac-tures. Thirty-four males and 42 females with an average age of 68.1 years (19–92 years) were assessed, and eight

Table 1: Implant types of the extra-medullary or intra-medullary devices.

| Implants	Numbers
Extra-medullary fixation	28
Contralateral distal femoral locking plate (LISS; Synthes USA, Paoli, PA)	20
Periarticular proximal femoral locking plates (PERI-LOC®PFP; Smith & Nephew, Inc., Memphis, TN, USA)	6
Dynamic hip screw (DHS; Synthes USA, Paoli, PA) and trochanteric stabilizing plate (TSP; Synthes USA, Paoli, PA)	1
Dynamic hip screw (DHS; Synthes USA, Paoli, PA) and anti-rotation screw (Synthes USA, Paoli, PA)	1
Intra-medullary fixation	48
Proximal femoral nail anti-rotation-II (PFNAII; Synthes USA, Paoli, PA)	32
TRIGEN InterTan nail (Smith & Nephew, Inc.; Memphis, USA)	6
Gamma 3 (Stryker, Mahwah, NJ, USA)	4
Proximal femoral nail anti-rotation (PFNA; Synthes USA, Paoli, PA)	4
TRIGEN Tan nail (Smith & Nephew, Inc.; Memphis, TN, USA)	2
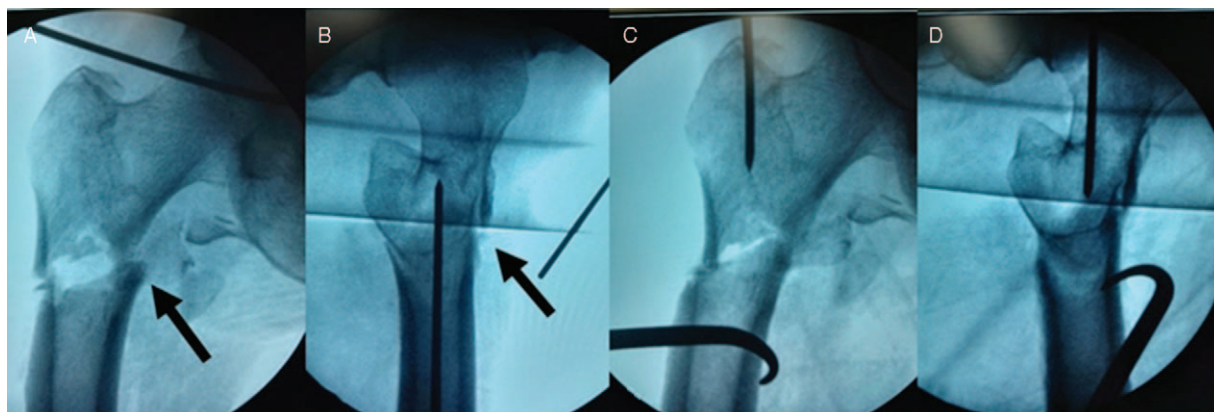
Figure 1: Intra-operative images of a patient in group 1. AP image (A) showing a medially displaced femoral shaft relative to the head-neck fragment (black arrow). Lateral view (B) showing posterior sagging of the femoral shaft (black arrow). A bone hook was used to pull the femoral bone laterally (C). A mallet was used to elevate the thigh (D). AP: Anteroposterior.

type 31-A3.1 fractures, eight type 31-A3.2 fractures, and 60 type 31-A3.3 fractures were identified. The mechanisms of injury were low energy (fall from standing height, 54 cases) and high energy (car accident or fall from a high place, 22 cases).

Patterns of displacement

According to intra-operative fluoroscopy images after closed manipulation, these irreducible fractures could be grouped into six patterns.

Medial displacement and posterior sagging of the femoral shaft relative to the head-neck fragment

Thirty patients showed this kind of pattern [Figure 1]. Intra-operative images showed a medially displaced femoral shaft relative to the head-neck fragment on the AP view [Figure 1A] and posterior sagging of the femoral shaft on the lateral view [Figure 1B]. Attempts at closed reduction were unsuccessful. A bone hook was used to pull the femoral shaft laterally [Figure 1C and 1D], and a mallet was used to elevate the femoral shaft. Both the anterior and medial cortices were reduced. Keeping the bone hook *in situ*, the fracture was fixed using an intra-medullary fixation device.

Posterior sagging of the femoral shaft relative to the head-neck fragment

Eleven patients showed this kind of pattern [Figure 2]. The AP fluoroscopic image showed a relatively simple long oblique intertrochanteric fracture that seemed well reduced [Figure 2A]. However, the lateral fluoroscopic image showed that the sagittal geometry was unstable, and that the femoral shaft sagged posteriorly [Figure 2B]. For this pattern, we tried to elevate the thigh with a mallet, which was successful in most cases. Occasionally, achieving a good reduction with the mallet was difficult because we could not precisely control the femoral shaft. Then, we discovered that we could use a Schanz screw as a joystick, with a T-handle hanging on the G-arm [Figure 3C]. We stood behind the X-ray barrier and used a remote device to control the G-arm to reduce the fracture exactly. Both the anterior and medial cortices were reduced [Figure 3D and 3E]. However, the Schanz screw impeded intra-medullary nail insertion, therefore, we used a locking compression plate as the final fixation.

Malalignment of the lateral femoral wall

Eleven patients showed this kind of pattern [Figure 3]. These fractures showed good contact of the medial cortices and anterior cortices [Figure 3A and 3B]. However, the AP
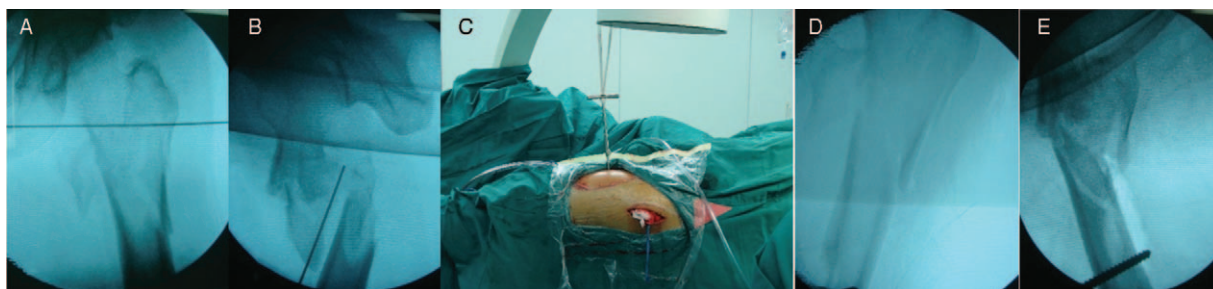
Figure 2: AP fluoroscopic image of a patient in group 2 showing a relatively simple long oblique intertrochanteric fracture that looks well reduced (A). The lateral fluoroscopic image shows that the sagittal geometry is unstable, and that the femoral shaft sags posteriorly (B). Image showing a hanging system with a Schanz screw on the femoral shaft (C). The G-arm was controlled with a remote device, and the AP and lateral views showed a good reduction (D and E). AP: Anteroposterior.
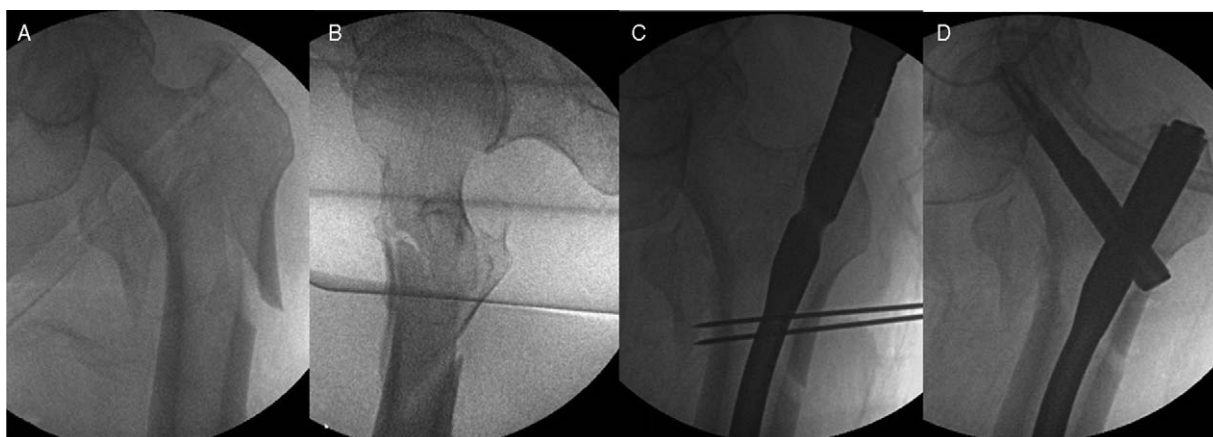

Figure 3: Intra-operative AP fluoroscopic image of a patient in group 3 showing a long oblique intertrochanteric fracture with contact of the medial cortices but malalignment of the lateral femoral wall (A). The lateral fluoroscopic image shows good contact of the anterior cortices (B). The image shows that the lateral femoral wall is reduced and provisionally fixed with K-wires (C). Final fixation is applied using an intra-medullary fixation device (D). AP: Anteroposterior.

fluoroscopic image showed a displaced lateral femoral wall. For displaced lateral femoral walls with a relatively large tilting angle, we tried to reduce and provisionally fix them with K-wires [Figure 3C]. Then, the fracture was fixed using an intra-medullary fixation device [Figure 3D].

Separation of the lateral femoral wall on the sagittal plane

Nine patients showed this kind of pattern [Figure 4]. A coronal fracture line of the lateral femoral wall was always present. These fractures showed good contact of the medial cortices and anterior cortices [Figure 4A and 4B]. However, the lateral fluoroscopic image showed a separation of the lateral femoral wall on the sagittal plane. For fractures with evident displacement of the lateral femoral wall, we tried to use a clamp to reduce the fragments and cannulated screws to fix them [Figure 4C–4F]. Finally, the fracture was fixed with a locking compression plate [Figure 4G and 4H].

Lateral displacement and posterior sagging of the femoral shaft relative to the head-neck fragment

Nine patients showed this kind of pattern [Figure 5]. Intra-operative images showed a laterally displaced femoral shaft relative to the head-neck fragment on the AP view

[Figure 5A] and posterior sagging of the femoral shaft on the lateral view [Figure 5B]. Attempts at closed reduction were unsuccessful. A periosteum elevator was used to push the head-neck fragment posteriorly [Figure 5C and 5D], and a mallet was used to lift up the femoral shaft. Keeping the bone hook and mallet *in situ*, the fracture was fixed using an intra-medullary device.

Medially displaced femoral shaft relative to the head-neck fragment

Six patients showed this kind of pattern [Figure 6]. Intra-operative images showed a medially displaced femoral shaft relative to the head-neck fragment on the AP view [Figure 6A], while good alignment was observed on the lateral view [Figure 6B]. A bone hook was used to pull the femoral shaft laterally [Figure 6C]. Both the anterior and medial cortices were reduced [Figure 6C and 6D]. Keeping the bone hook *in situ*, the fracture was fixed using an intra-medullary device.

Reduction quality and follow-up

After applying the above reduction techniques, the reduction quality of fractures was substantially improved. According to the grade of reduction quality, 53 cases had
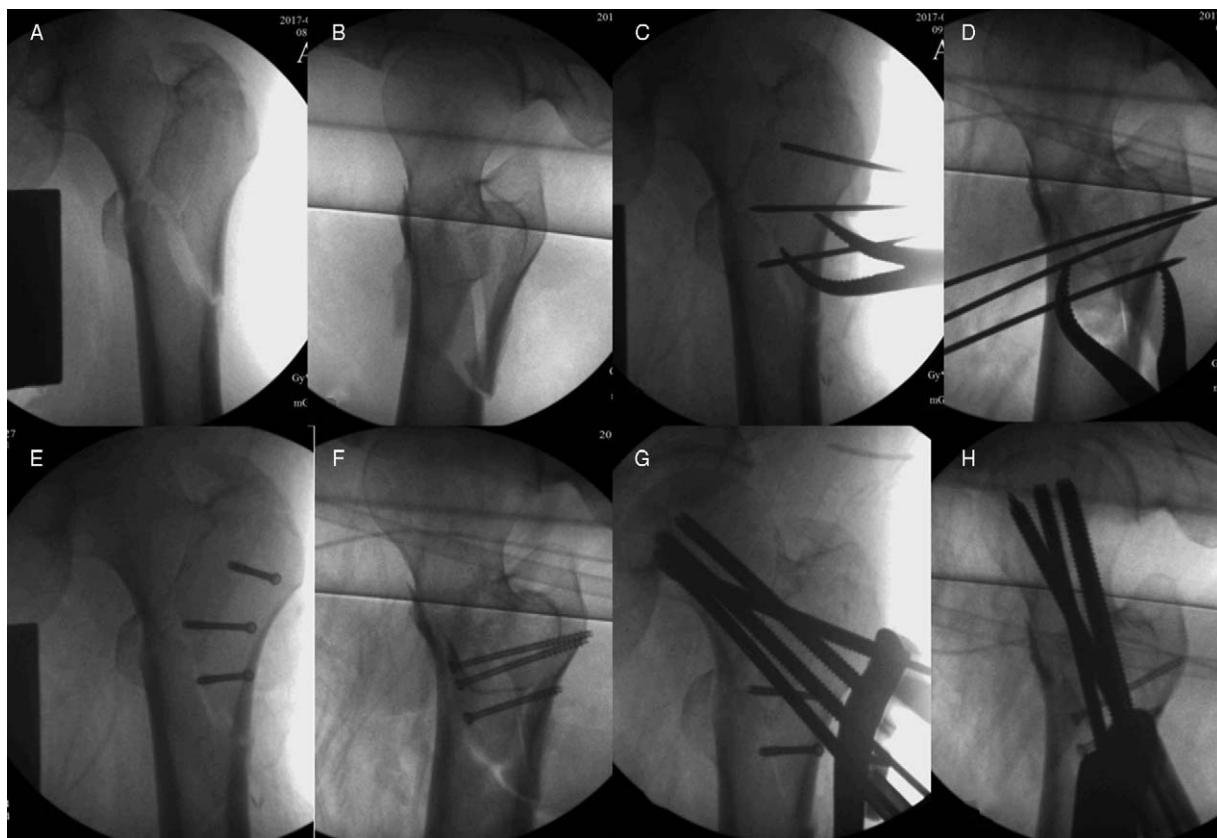
Figure 4: Intra-operative images of a patient in group 4 with an oblique intertrochanteric fracture showing a coronal fracture line on the lateral view. AP fluoroscopic image and lateral image showing good contact of the medial cortices and anterior cortices (A) but with separation of the lateral femoral wall (B). Reduction of the fragments with a clamp and provisional fixation with K-wires (C and D). Fixation of the lateral wall with cannulated screws (E and F). Final fixation of the fracture with a proximal femoral locking compression plate (G and H). AP: Anteroposterior.
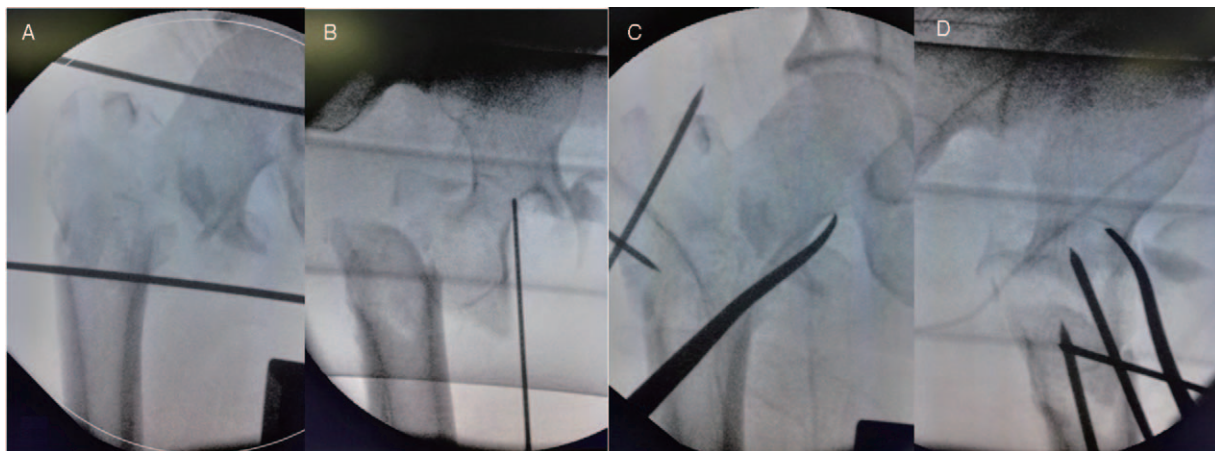

Figure 5: Intra-operative images of a patient in group 5. AP image (A) showing a laterally displaced femoral shaft relative to the head-neck fragment. Lateral view (B) showing posterior sagging of the femoral shaft. A periosteum elevator was used to push the head-neck fragment posteriorly, and a mallet was used to lift up the femoral shaft (C and D). AP: Anteroposterior.

good reduction quality (70%), 15 cases had acceptable reduction quality (20%), and eight cases had poor reduction quality (11%) [Table 2]. The mean follow-up time was 24.3 months (range, 3–75 months). Overall, implant failure occurred in ten (13%) of 76 patients. Of the 53 cases with good reduction quality, implant failure occurred in five cases (9%). Two cases of screw breakage, one case of helical blade cut-out, one case of helical blade perforation, and one case of main nail breakage occurred. Of the 15 cases with acceptable reduction, quality implant failure occurred in two cases (2/15). One case of helical blade cut-out and one case of screw breakage occurred. Of the eight cases with poor reduction quality, implant failure occurred in three cases (3/8). One case of helical blade cut-out, one case of screw breakage, and one case of main nail breakage occurred.
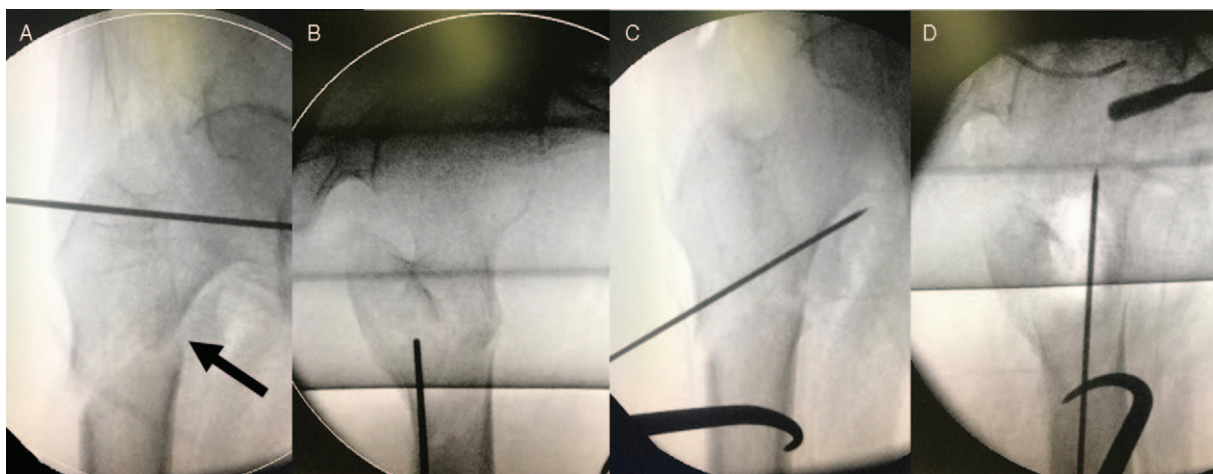
Figure 6: Intra-operative images of a patient in group 6. AP image (A) showing a medially displaced femoral shaft relative to the head-neck fragment (black arrow). Lateral view (B) showing that the anterior cortices were reduced. A bone hook was used to pull the femoral bone laterally (C). A K-wire was used to push the head-neck fragment medially (D). AP: Anteroposterior.

Table 2: Evaluation of the reduction quality of irreducible reverse intertrochanteric fractures (n = 76).

Reduction quality	After closed manipulation, n (%)	After using reduction techniques, n (%)
Good	0	53 (70)
Acceptable	20 (26)	15 (20)
Poor	56 (74)	8 (11)

The initial univariate analysis revealed that four factors were associated with fracture irreducibility, including a medially displaced femoral shaft relative to the head-neck fragment on the AP view (OR, 7.62; 95% CI, 3.16–18.39; $P < 0.001$), a displaced lesser trochanter (OR, 3.29; 95% CI, 1.45–7.51; $P = 0.005$), a displaced lateral femoral wall (OR, 3.86; 95% CI, 1.51–9.85; $P = 0.005$), and a BMI <18.5 kg/m^2 (OR, 0.20; 95% CI, 0.06–0.67; $P = 0.010$) [Table 3].

After controlling for confounding variables using multivariable analysis, three factors were identified as predictors of irreducibility: a medially displaced femoral shaft relative to the head-neck fragment on the AP view (OR, 8.00; 95% CI, 3.04–21.04; $P < 0.001$), a displaced lesser trochanter (OR, 3.61; 95% CI, 1.35–9.61; $P = 0.010$), and a displaced lateral femoral wall [Table 4] (OR, 2.92; 95% CI, 1.02–8.34; $P = 0.046$).

Discussion

Trochanteric fractures usually require surgical treatment. As most patients are elderly and have many comorbidities, minimizing surgical trauma, reducing intra-operative blood loss, and shortening the duration of the operation are important. Despite improved techniques and various implant modifications, implant failure remains a challenging problem for unstable fractures.[11-13] Many factors are associated with implant failure, including osteoporosis, age at the time of surgery, fracture classification, and reduction quality. However, reduction quality is a controllable factor for doctors.[14,15] The quality of fracture reduction determines the fracture prognosis to a large extent. A satisfactory fracture reduction ensures early rehabilitation exercise; therefore, reducing the complications caused by a long-term bedridden status.[15] Intertrochanteric fractures are usually initially treated with closed reduction.[6] However, for some intertrochanteric fractures, achieving satisfactory reduction by closed manipulation is difficult, and various types of open reduction are, therefore, required. These fractures are defined as irreducible fractures.[2-4] However, to the authors' knowledge, few studies have been conducted on predictors of and reduction techniques for irreducible reverse intertrochanteric fractures. We therefore retrospectively analyzed 113 cases of reverse intertrochanteric fractures to summarize the radiographic features and displacement patterns of irreducible reverse intertrochanteric fractures and corresponding reduction techniques and to explore predictors of irreducibility.

No precise definition of an irreducible reverse intertrochanteric fracture currently exists. We used the reduction quality of fractures after closed manipulation to identify irreducible fractures. However, no useful reference for evaluating intra-operative reduction on fluoroscopy during surgery is available. Baumgaertner and Solberg[9] assessed reduction quality with respect to the amount of displacement and neck-shaft alignment on immediate post-operative AP and lateral radiographs, which was categorized as good, acceptable or poor. A "good" reduction displays normal or slightly valgus neck-shaft alignment on the AP radiograph, under 20° of angulation on the lateral view and a displacement of less than 4 mm on either view. "Acceptable" reductions meet the requirements regarding alignment or displacement, but not both, whereas "poor" reductions do not meet any of the requirements. However, the extent of displacement is a parameter that cannot be measured intra-operatively with a fluoroscope. Kim et al[5] described displacement of the proximal medial cortex with respect to the distal fragment on the AP view and the anterior cortex on the lateral view in terms of cortical

Table 3: Univariate analyses of factors associated with irreducible fractures ($n = 113$).

Parameters	Reducible fractures ($n = 37$), n (%)	Irreducible fractures ($n = 76$), n (%)	Odds ratio (95% CI)	P
Gender			0.750 (0.340–1.680)	0.487
Male	14 (38)	34 (45)		
Female	23 (62)	42 (55)		
Age			0.400 (0.160–1.030)	0.058
<65 years	7 (19)	28 (37)		
≥65 years	30 (81)	48 (63)		
BMI				0.019
<18.5 kg/m^{2*}	10 (27)	5 (7)	0.200 (0.060–0.670)	0.010
18.5–23.9 kg/m^2	15 (41)	38 (50)		
≥24.0 kg/m^{2*}	12 (32)	33 (43)	1.090 (0.450–2.650)	0.857
Mechanism of injury			1.750 (0.670–4.560)	0.255
Low energy	30 (81)	54 (71)		
High energy	7 (19)	22 (29)		
AO/OTA classification				
31A-3.1	7 (19)	8 (11)		
31A-3.2	13 (35)	8 (11)	0.540 (0.140–2.060)[†]	0.366
31A-3.3	17 (46)	60 (78)	3.090 (0.980–9.740)[†]	0.054
Displaced lesser trochanter			3.294 (1.450–7.510)	0.005
No	20 (54)	20 (26)		
Yes	17 (46)	56 (74)		
Displaced lateral femoral wall			3.860 (1.510–9.850)	0.005
No	30 (81)	40 (53)		
Yes	7 (19)	36 (47)		
Type of fracture line			0.630 (0.270–1.430)	0.265
Oblique	12 (32)	33 (43)		
Transverse	25 (68)	43 (57)		
Femoral shaft displacement relative to the head-neck fragment			7.620 (3.160–18.390)	<0.001
No displacement or lateral	26 (70)	18 (24)		
Medial	11 (30)	58 (76)		

*BMI (body mass index) 18.5 to 23.9 kg/m^2 as the reference value; †Compared with type A3.1. CI: Confidence interval.

Table 4: Multivariable analysis of factors associated with irreducible fractures ($n = 113$).

Parameters	Odds ratio	95% CI	P
Femoral shaft displaced medially	8.000	3.040–21.040	<0.001
Displaced lesser trochanter	3.610	1.350–9.610	0.010
Displaced lateral femoral wall	2.920	1.020–8.340	0.046

CI: Confidence interval.

thickness. A displacement of <1 cortical thickness implies contact between the proximal and distal fragments. We believe that the criteria proposed by Kim are more practical for clinical application to describe the extent of displacement. However, the criteria do not include an evaluation of alignment, which is also important for a good reduction. Consequently, this study adopted modified criteria to evaluate reduction quality.

The incidence of irreducible intertrochanteric fractures has been reported to vary from 3% to 17%.[2,4,16] However, these incidence rates are all related to AO/OTA 31-A1-type and A2-type fractures. To the authors' knowledge, no reports on the incidence of irreducible reverse intertro-

chanteric fractures have been published. In this study, irreducible fractures accounted for 67% of reverse intertrochanteric fractures. In other words, more than half of reverse intertrochanteric fractures are not amenable to closed manipulation. In cases of such fractures, many surgeons may repeatedly adjust the traction table to attempt closed reduction; however, the reduction quality will not be improved. Sometimes, a patient may be draped despite poor reduction quality, leading to an increased implant failure rate.

Reverse intertrochanteric fractures differ from AO31-A1 and A2 pertrochanteric fractures in that the major fracture line runs from distal-lateral to proximal-medial. The reverse fracture line and the function of the adductor muscles may lead to femoral shaft medicalization, which sometimes requires limited reduction maneuvers. Torn dorsal soft tissues and gravity may cause sagging of the shaft on the traction table, resulting in the need for dorsal support. According to intra-operative fluoroscopy images after closed manipulation, these fractures can be grouped into six patterns.

The most common pattern was observed in 30 patients. All of these patients showed a transverse or short oblique main

fracture line with an intact greater trochanter. The lesser trochanter was attached to the femoral shaft fragment. The femoral shaft may displace medially under the function of the iliopsoas and adductor muscles. However, the head-neck fragment may displace laterally and upward under the function of the gluteus medius and gluteus minimus. At the same time, the femoral shaft sagged posteriorly due to gravity. Consequently, increasing the traction force would have only caused aggressive displacement, thus, limited open reduction was then considered. A bone hook can help reduce the medially displaced femoral shaft [Figure 1].

The second pattern was observed in 11 patients. The possible mechanism may be that the femoral shaft sagged posteriorly due to gravity, however, the head-neck fragment was in a balanced state under the function of muscle groups. Chun *et al*[16] reported a kind of percutaneous reduction technique to reduce unstable sagittal intertrochanteric fractures, where a mallet was used to elevate the thigh. We have also tried this method, but achieving a good reduction was sometimes difficult because we could not precisely control the femoral shaft. The technique that we used in this study could not only reduce the fracture exactly but also protect surgeons from radiation.

The third pattern was observed in 11 patients. We found that these patients commonly have a long oblique main fracture line. The lateral femoral wall showed abduction and external rotation under the function of the gluteus medius, gluteus minimus, piriformis, and obturator internus. For a displaced lateral femoral wall with a relatively large tilting angle, we tried to reduce and provisionally fix it with K-wires. Then, the fracture was fixed using an intra-medullary fixation device. Intertrochanteric fractures with a fracture of the lateral femoral wall have high rates of implant failure.[17,18] However, to the authors' knowledge, no useful reference for the evaluation of reduction focusing on the lateral femoral wall is available. We suppose that malalignment of the lateral femoral wall represents a pattern of unsatisfactory reduction. However, further research is needed to confirm this hypothesis.

The fourth pattern was observed in nine patients. All of these patients had a coronal fracture line of the lateral femoral wall. For fractures with evident displacement of the lateral femoral wall, we tried to use a clamp to reduce the fragments and cannulated screws to fix them [Figure 4]. However, screws may impede medullary nail insertion. Therefore, we used a locking compression plate instead. In this study, three patients underwent lateral femoral wall fixation with screws. The lateral femoral wall in the remaining six patients was not fixed. None of the patients experienced implant failure.

The fifth pattern was observed in nine patients. All of these patients showed a transverse or short oblique main fracture line with the lesser trochanter attached to the head-neck fragment. The head-neck fragment may displace medially along with external rotation under the function of the iliopsoas muscle, iliofemoral ligament, and pubofemoral ligament. In addition, the gluteus medius and gluteus minimus could not exert the function of abduction because of the comminuted greater trochanter. Then, the femoral shaft displaced laterally relative to the head-neck fragment. At the same time, the femoral shaft sagged posteriorly due to gravity. A periosteum elevator and a mallet may help to reduce the fracture [Figure 5].

The last pattern was observed in six patients, where a medially displaced femoral shaft relative to the head-neck fragment was shown on the AP view, while good alignment was shown on the lateral view. All of these patients showed a transverse or short oblique main fracture line with an intact greater trochanter. The mechanism of this pattern has been explained in the discussion on the first pattern. We used a bone hook to pull the femoral shaft laterally [Figure 6].

Although various reduction techniques were adopted in this study, eight cases (11%) still had poor reduction quality. Among them, seven cases showed the first displacement pattern, and one case showed the fifth displacement pattern. All of these cases had re-displacement after final fixation.

Surgeons must be able to recognize irreducible fractures pre-operatively and may need to prepare for a limited open reduction. Based on other studies[15,19,20] and our experience, we considered age, the mechanism of injury, BMI, AO/OTA classification, the statuses of the lesser trochanter and the lateral femoral wall, the type of fracture line, and femoral shaft displacement relative to the head-neck fragment on the AP view to be factors associated with irreducibility. Therefore, a univariate regression analysis of the above factors was conducted. We found that four factors were related to irreducibility [Table 3]. After controlling for confounding variables via multivariable analysis, three factors were identified as predictors of irreducibility: a medially displaced femoral shaft relative to the head-neck fragment on the AP view, a displaced lesser trochanter, and a displaced lateral femoral wall [Table 4]. As mentioned above, a medially displaced femoral shaft relative to the head-neck fragment may be due to the function of the adductor muscles; in this case, achieving a satisfactory reduction through closed manipulation is difficult. A bone hook may be useful to pull the femoral shaft laterally [Figure 1C]. The characteristic of reverse intertrochanteric fractures is that the greater trochanter is attached to the head-neck fragment. If the lesser trochanter is displaced, then both the gluteus minimus and iliopsoas fail to control the femoral shaft. Consequently, the femoral shaft will sag posteriorly due to gravity. For these fractures, closed reduction may be difficult, and re-displacement is not uncommon.[21] A displaced lateral femoral wall indicates that free bone fragments are present at the junction of the greater trochanter and the lateral femoral wall. A comminuted lateral femoral wall complicates reduction of the fracture.

This study had some limitations. First, the study design was retrospective, causing the analyses to be inherently more susceptible to missing data, biases, and confounding factors compared to a prospective study. Second, this study focused on patterns of displacement, reduction

techniques, and predictors of irreducible reverse inter-trochanteric fractures and did not examine the clinical and functional outcomes of all patients. We believe that this research must be continued by developing clinical trials and well-structured studies to provide strong scientific evidence regarding this topic.

In summary, we retrospectively analyzed 113 cases of reverse intertrochanteric fractures in this study and found that irreducible fractures accounted for 67% of reverse intertrochanteric fractures. According to intra-operative fluoroscopy images after closed manipulation, irreducible fractures can be grouped into six patterns. The most common pattern was medial displacement and posterior sagging of the femoral shaft relative to the head-neck fragment. Various techniques were adopted for different patterns of displacement, including the use of a bone hook to pull the femoral shaft, a clamp to reduce fracture fragments, a periosteum elevator to push the head-neck fragment posteriorly, a mallet to lift up the femoral shaft, and a Schanz screw as a joystick. Compared with A3.1-type and A3.2-type fractures, A3.3-type fractures had a higher incidence of irreducibility. Three predictors of irreducibility were identified: a medially displaced femoral shaft relative to the head-neck fragment on the AP view, a displaced lesser trochanter, and a displaced lateral femoral wall. These patients warrant special consideration in terms of recognition and management.

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Conflicts of interest

None.

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