Radiographic Outcomes of Treatment of Complex Femoral Shaft Fractures by Intramedullary Nailing: A Retrospective Analysis of Different Techniques

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Research Article

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Abstract

Background

This study aimed to determine whether the outcomes of femoral diaphyseal fractures (AO/OTA/32-C) were dependent on the treatment technique (closed vs. open reduction and internal fixation with an interlocking nail).

This retrospective study was conducted at a level III trauma center. A total of 47 consecutive patients with femoral diaphyseal fractures (AO/OTA/32-C) were included. All patients underwent reduction and fixation and were divided into two groups according to the surgical techniques used: closed reduction and open reduction groups. The radiographic union score of the femur, mean union time, re-operation rate, and complication rate were assessed.

Results

At 12 postoperative months, the union rate was 80.76% in the open reduction group and 82.35% in the closed reduction group; however, the difference was not significant (p=0.787). The rate of anatomical-to-small gaps was 96.15% and 47.05% in the open and closed reduction groups, respectively (p=0.01). The radiographic union score of the femur at 6 postoperative months (9.30 vs. 7.76, p=0.02) and postoperative months (9.94 vs. 10.80, p=0.03) was significantly higher in the open reduction group. Further, the required time to union in the open reduction group was significantly shorter (7.39 vs. 9.18 months, p=0.025). The difference in the need for revision surgery was not significant between the two groups (19.23% vs. 23.52%, p=0.964).

Conclusions

Compared to closed reduction, intramedullary nailing of severe comminuted femoral shaft fractures with open reduction has similar outcomes and carries no increased risk of complications. Surgeons should consider open reduction if the outcomes of closed reduction are not satisfactory. This will aid in restoring anatomical reduction, enable primary bone grafting, and result in an optimal union rate, better strength of union, and shorter time to union.

Background

Intramedullary nailing (IMN) is considered the gold standard treatment for femoral diaphyseal fractures. Specifically, closed reduction and internal fixation with an interlocking nail is the standard treatment and is used for most shaft fractures of the proximal or distal femur [1, 2].

Nonetheless, the management of complex femoral diaphyseal fractures remains challenging and often results in delayed union or nonunion. The recommended surgical techniques for these fractures are currently controversial [3, 4]. While some studies have recommended closed reduction with internal fixation without destruction of soft tissue attachments and the blood supply [5], other studies have suggested that the displacement of residual fragments and the size of fragments influence the prognosis [6].

The present study evaluated the radiographic outcomes of IMN for complex femoral diaphyseal fractures and analyzed the influence of different surgical strategies on prognosis. We hypothesized that open reduction may result in better outcomes than closed reduction following internal fixation with intramedullary nails in complex fractures of the femoral diaphysis.

Methods

Patients

A retrospective cohort of patients with complex femoral diaphyseal fractures (AO/32-C) who were treated using antegrade intramedullary nails by the same team of surgeons from January 2008 to December 2018 was included. The exclusion criteria were periprosthetic fracture, pathologic fracture, staged operation following initial external skeletal fixation, and fat embolism in patients with femoral diaphyseal fractures. This study was conducted in accordance with the principles embodied in the Declaration of Helsinki. The study design was approved by the Institutional Review Board of the authors' affiliated hospital (FEMH No. 110059-E).

Data on age, sex, mechanism of injury, comorbidities, smoking, and alcohol use were obtained from patients' medical records. Femoral diaphyseal fracture was defined as a fracture of the femur between a 5-cm distal point from the lesser trochanter and an 8-cm proximal point from the adductor tubercle [7]. The fracture pattern was classified according to the AO/OTA classification [8].

Surgery

All fractures were managed by senior attending surgeons or fellowship-trained orthopedic traumatologists in the orthopedic department of a single trauma center. The enrolled patients were subdivided into the closed and open reduction groups, based on their medical records and the surgical techniques used.

In the closed reduction group, the patients underwent reamed antegrade locked IMN, performed using the standard closed technique. Briefly, a patient was placed in the supine position on a fracture table. The canal in an adult was prepared by reaming the diameter to 1.0 mm more than the anticipated nail diameter, which was determined using a radiograph. All reduction attempts were performed using closed methods, including manipulation with crutches, cooled mallets, reduction levers, and distraction devices [9], or manipulation using the fingers or percutaneously placed half pins with a small incision [10].

In the open reduction group, the patient was placed in the supine position on a fracture table or in the lateral decubitus position on the table, depending on the surgeon's preference. The incision on the fracture site was made close to the fragments in order to enable reduction and fixation with wiring of fragments; primary reamed bone grafting was also performed. The reamed antegrade IMN principle used here was similar to that used in the closed reduction group.

ROM was initiated immediately after surgery. The patients were not allowed to bear weight for four postoperative weeks. Touch-down weight-bearing with a walker was initiated after callus formation was observed, and the level of ambulation was progressively increased.

Radiographic assessment and outcomes

Preoperative radiographs were obtained from patients at the time of admission, whereas immediate postoperative films were was obtained after surgery on the same day. Anteroposterior and lateral radiographs were acquired at every follow-up visit in the outpatient department (every month for at least 24 months or until bone union was achieved). The quality of reduction was assessed by reviewing the postoperative radiographs and measuring the average gap between the fragments. The numerical value for the gap between the fragments was calculated using Lin et al.'s method[6]. Reduction was categorized into three different groups: anatomical reduction (<2 mm), small gap (2-10 mm), and large gap (>10 mm) [11].

The main outcome was the radiographic union score at 6, 9, and 12 postoperative months and when bone union was achieved (at the last visit). One author (YH Chen) interpreted all radiographs twice in a blinded fashion; this was repeated by a senior staff (TY Lan) to ensure reliability. The radiographic union score of the femur (RUSF) was assessed using each follow-up radiograph, which was based on the assessment of healing at each of the four cortices visible on these projections (i.e., medial and lateral cortices on the anteroposterior plain film as well as anterior and posterior cortices on the lateral film). The scoring system was modified from the "radiographic union score of the tibia" system described by Whelan et al. [12] and had been applied to present quantitative criteria for radiographic union [6]. This scoring system implicates better biomechanical strength in high-scoring cases [13].

The outcomes of treatment, including the bone union rate, RUSF, union time, and revision rate, were assessed. Radiographic union was defined as restoration of the continuity by a bridging callus at the fracture gap with consolidation. Nonunion was defined as a disturbed consolidation of a fracture that required re-operation or prolonged bone healing >12 months [14, 15]. Revision operation was performed if there were no visible progressive signs of healing for three consecutive months, nonunion, failure of internal fixation, infection, or surgical complications. The re-operation techniques included secondary autogenous/allogenous bone grafting, dynamization, or change in the interlocking nail.

Data analysis

Statistical correlation was analyzed using the Mann–Whitney U test and chi-square test. The level of statistical significance was set at $p<0.05$. Statistical analyses were performed using SPSS version 22 (IBM Corp., Armonk, NY, USA).

Results

A total of 47 patients with complex femoral shaft fractures were considered eligible. Four patients were excluded due to a short follow-up duration and loss to follow-up. Therefore, 43 (33 male, 10 female) patients were included. There were 26 (21 male, 5 female) and 17 (12 male, 5 female) patients in the open reduction and closed reduction groups, respectively.

Demographic characteristics

The mean age of patients was 34.3 and 29.6 years in the closed and open reduction groups, respectively. There was no significant difference in the demographic characteristics between the two groups (Table 1).

Reduction outcome

In the open reduction group, 25 (96.15%) patients had anatomical-to-small gaps, and only one (3.85%) patient had a large gap. In the closed reduction group, eight patients (47.05%) had small gaps and nine (52.95%) patients had large gaps. The difference in reduction quality was significant between the two groups (p=0.001; Table 2).

Bone healing outcome

The overall union rate at 12 postoperative months was 81.39%, with 35 patients with union and eight with nonunion. The union rate of the close reduction and open reduction groups at 12 postoperative months was 80.76% and 82.35%, respectively (p=0.787). One patient in each group underwent early dynamization and achieved union at 12 postoperative months (Table 3). The mean (standard deviation) time to union in the closed reduction group was 9.18 (2.04) months and 7.39 (2.78) in the open reduction group; the difference was significant (Table 2).

Radiographic union score of the femur

The mean RUSF at 6 postoperative months was 7.76 and 9.30 in the closed and open reduction groups, respectively (p=0.02). The difference persisted until 9 postoperative months (9.94 vs. 10.80, p=0.03). The difference in mean RUSF between the closed and open reduction groups was not significant at 12 postoperative months (11.41 vs. 11.19, p=0.237; Table 2).

Complications

Overall, eight patients had nonunion (3 [17.64%] in the closed reduction group and 5 [19.23] in the open reduction group); the difference was not significant. No patient has a postoperative infection (Table 4).

In the open reduction group, two patients underwent early dynamization at 6 and 7 postoperative months; one of them achieved union at 12 postoperative months. The other patient had nonunion and underwent a revision surgery (nail change and secondary bone grafting) at 12 postoperative months. Three patients had nonunion. Two patients had a failed implant with a broken nail at seven and 12 postoperative months; they underwent a revision operation. The other patient had a failed union and underwent a revision operation (nail exchange and bone grafting), which was performed after one year of follow-up. All of these patients eventually achieved union (Table 3).

In the closed reduction group, there were four patients with complications. One patient underwent a prompt revision operation, which was indicated for femoral malrotation on the third day after the first operation. Two patients had nonunion and were managed by dynamization and secondary bone grafting in the fourth and sixth postoperative months, respectively. One patient had nonunion and a reversed fragment; he underwent a revision reduction and fixation with wiring and secondary bone grafting at the fifth postoperative month (Fig. 1). All patients achieved union by the last follow-up session (Table 3).

Discussion

We conducted a retrospective analysis of 47 patients and compared two techniques: open reduction and closed reduction, following internal fixation. To the best of our knowledge, this is the first study that compares the two techniques in complex femoral diaphyseal fractures, AO/OTA type-32C. Open reduction achieved a better anatomical reduction and improved bone union in complex femoral diaphyseal fractures.

The rate of nonunion after IMN of femoral shaft fractures ranges from 1–20% [16]. Delayed union or nonunion after IMN is more frequent in complex fractures [16]. In our study, the overall rate of union was 81.39% at 12 postoperative months, corresponding to the rate in the previous study. Additionally, early intervention with dynamization or secondary bone grafting for the management of delayed union is helpful in facilitating bone union.

Some disadvantages of the open technique have also been described, which include higher complication rates, increased infection rates, and decreased union rates [17]. Traditionally, closed reduction is said to preserve the soft tissue integrity and blood supply, leading to satisfactory prognoses [2, 18–20]. However, several studies have shown that open reduction has similar to superior outcomes [6, 21–23]. In our study, the open reduction group had a shorter time to union (7.39 vs. 9.18 months, $p = 0.025$) and significantly better strength of union in the early postoperative stage. The open reduction group had a higher RUSF at 6 postoperative months (9.30 vs. 7.76, $p = 0.02$) and 9 postoperative months (10.80 vs. 9.94, $p = 0.03$); there was no statistical difference between the two groups at 12 postoperative months (11.19 vs. 11.41, $p = 0.37$).

Regarding adverse outcomes, the overall risk of nonunion or infection was different between the two groups in this study. The difference in the revision surgery rate was not significantly different between the groups. Besides, the revision surgery rate in the closed reduction group was slightly higher (19.23% vs. 23.52%, $p = 0.964$). Therefore, open reduction and IMN of femoral shaft fractures did not significantly disturb union processing or predispose to complications. These results suggested that preservation of soft tissue integrity in complex femoral diaphyseal fractures was limited, due to the compromised vascular bed and severe soft tissue injury following high-energy trauma in such cases.

We speculate that a properly executed open reduction technique may result in better postoperative outcomes than a poorly performed open reduction, which leads to a large gap with a great predisposition to complications. In our study, the rate of anatomical-to-small gaps in the open reduction group was 96.15%, which was higher than that in the closed reduction group (96.15% vs. 47.05%, $p = 0.01$). In addition, three out of four patients with complications in the closed reduction group had large gaps; furthermore, one patient had a femoral malrotation due to poor reduction and biomechanical abnormalities and required re-operation in the acute postoperative phase. The effect of the presence of a third fragment and residual gap has been investigated in several studies [6, 21, 22]. The residual gap persists after closed reduction [3, 4], indicating a worse bone environment from huge fragment diastasis, potential soft tissue interposition, and poor axial load-bearing ability [2, 3]. Furthermore, the excessive fragmentary motion between the large gap has a negative effect on callus formation [24, 25]. The vascular supply to the reversed fragments may be strangulated and become compromised in the setting of an altered morphology [6]. Hamahashi et al. concluded that among the risk factors of delayed union, displacement is the only risk factor that could be modified with intraoperative reduction [21]. Achieving a quality reduction, eliminating the third-fragment effect, and facilitating bone union are more likely with the open reduction technique than with closed reduction.

Primary bone grafting can be performed through the incisional wound and help to achieve a better quality of reduction. Although this issue is controversial, primary bone grafting for complex long bone diaphyseal fractures is recommended [26–28]. Among these orthobiologic agents of bone enhancement, the evidence supporting the use of bone grafts is strong, whereas the evidence for the use of demineralized bone matrix and synthetic ceramics is moderate [29, 30]. In our open reduction group, primary bone grafting with reamed intramedullary autografts was performed in all patients. In this study, the time to union was significantly shorter in the open reduction group than in the closed reduction group (7.39 vs. 9.18 months, $p = 0.025$), suggesting that open reduction may result in a better quality of reduction and enhance additional bone healing.

The difference in outcomes between closed and open nailing in femoral diaphyseal fractures is controversial [31–33]. Therefore, individualizing treatment will be a better approach. Syed et al. suggested that in cases where closed reduction is difficult, i.e., it cannot be achieved in 15 minutes, it is better to use open reduction [17]. From our study, open reduction may be beneficial in complex femoral diaphyseal fractures (AO/OTA type 32C), by restoring the anatomical gap and facilitating primary bone grafting.

The limitations to this study, including the relatively small sample size and the short follow-up duration, may have an impact on the outcomes and led to different conclusions. Additionally, only radiographic outcomes were presented. Further studies on clinical outcomes and radiographic findings are mandatory to confirm our findings.

Conclusions

Compared to closed reduction, IMN of severe comminuted femoral shaft fractures with open reduction has similar outcomes and carries no increased risk of complications. Surgeons should consider open reduction if the outcomes of closed reduction are not satisfactory. This will aid in restoring anatomical reduction, enable primary bone grafting, and result in an optimal union rate, better strength of union, and shorter time to union.

Abbreviations

IMN: Intramedullary nailing

RUSF: Radiographic union score of the femur

Declarations

Ethics approval and consent to participate

The protocol has been approved by the Institutional Review Board of the Far Eastern Memorial Hospital (FEMH No. 110059-E). This study was conducted in accordance with the principles embodied in the Declaration of Helsinki. The need for informed consent was waived by the Institutional Review Board of the Far Eastern Memorial Hospital due to the retrospective nature of the study.

Consent for publication

Not applicable.

Availability of data and materials

The datasets are not publicly available as they will be used for further research but are available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

C-YH and L-TY participated in the study design, in collecting the data, the statistically analyses and drafting of the manuscript. L-SM participated in the study design. C-CH advised and assisted drafting of the manuscript. All authors read and approved the final manuscript.

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References

1. Klemm KW, Börner M. Interlocking nailing of complex fractures of the femur and tibia. Clin Orthop Relat Res. 1986;212:89-100.
2. Wiss DA, Fleming CH, Matta JM, Clark D. Comminuted and rotationally unstable fractures of the femur treated with an interlocking nail. Clin Orthop Relat Res. 1986;212:35-47.
3. Winquist RA, Hansen ST Jr. Comminuted fractures of the femoral shaft treated by intramedullary nailing. Orthop Clin North Am. 1980;11:633-48.
4. Salminen ST, Pihlajamäki HK, Avikainen VJ, Böstman OM. Population based epidemiologic and morphologic study of femoral shaft fractures. Clin Orthop Relat Res. 2000;372:241-9.
5. Winquist RA, Hansen ST Jr, Clawson DK. Closed intramedullary nailing of femoral fractures. A report of five hundred and twenty cases. J Bone Joint Surg Am. 1984;66:529-39.
6. Lin SJ, Chen CL, Peng KT, Hsu WH. Effect of fragmentary displacement and morphology in the treatment of comminuted femoral shaft fractures with an intramedullary nail. Injury. 2014;45:752-6.
7. Böstman O, Varjonen L, Vainionpää S, Majola A, Rokkanen P. Incidence of local complications after intramedullary nailing and after plate fixation of femoral shaft fractures. J Trauma. 1989;29:639-45.
8. Fracture and dislocation compendium. Orthopaedic Trauma Association Committee for Coding and Classification. J Orthop Trauma. 1996;10 Suppl 1:v-ix, 1-154.
9. McFerran MA, Johnson KD. Intramedullary nailing of acute femoral shaft fractures without a fracture table: technique of using a femoral distractor. J Orthop Trauma. 1992;6:271-8.
10. Georgiadis GM, Burgar AM. Percutaneous skeletal joysticks for closed reduction of femoral shaft fractures during intramedullary nailing. J Orthop Trauma. 2001;15:570-1.

11. Marsh JL, Buckwalter J, Gelberman R, Dirschl D, Olson S, Brown T, et al. Articular fractures: does an anatomic reduction really change the result? J Bone Joint Surg Am. 2002;84:1259-71.
12. Whelan DB, Bhandari M, Stephen D, Kreder H, McKee MD, Zdero R, et al. Development of the radiographic union score for tibial fractures for the assessment of tibial fracture healing after intramedullary fixation. J Trauma. 2010;68:629-32.
13. Panjabi MM, Walter SD, Karuda M, White AA, Lawson JP. Correlations of radiographic analysis of healing fractures with strength: a statistical analysis of experimental osteotomies. J Orthop Res. 1985;3:212-8.
14. Bellabarba C, Ricci WM, Bolhofner BR. Results of indirect reduction and plating of femoral shaft nonunions after intramedullary nailing. J Orthop Trauma. 2001;15:254-63.
15. Marsh D. Concepts of fracture union, delayed union, and nonunion. Clin Orthop Relat Res. 1998;355 Suppl:S22-30.
16. Gelalis ID, Politis AN, Arnaoutoglou CM, Korompilias AV, Pakos EE, Vekris MD, et al. Diagnostic and treatment modalities in nonunions of the femoral shaft: a review. Injury. 2012;43:980-8.
17. Ghouri SI, Alhammoud A, Alkhayarin MM. Does open reduction in intramedullary nailing of femur shaft fractures adversely affect the outcome? A retrospective study. Adv Orthop. 2020;2020:7583204.
18. Winquist RA. Locked femoral nailing. J Am Acad Orthop Surg. 1993;1:95-105.
19. Singh D, Garg R, Bassi JL, Tripathi SK. Open grade III fractures of femoral shaft: outcome after early reamed intramedullary nailing. Orthop Traumatol Surg Res. 2011;97:506-11.
20. Kempf I, Grosse A, Beck G. Closed locked intramedullary nailing. Its application to comminuted fractures of the femur. J Bone Joint Surg Am. 1985;67:709-20.
21. Hamahashi K, Uchiyama Y, Kobayashi Y, Ebihara G, Ukai T, Watanabe M. Clinical outcomes of intramedullary nailing of femoral shaft fractures with third fragments: a retrospective analysis of risk factors for delayed union. Trauma Surg Acute Care Open. 2019;4:e000203.
22. Lee JR, Kim HJ, Lee KB. Effects of third fragment size and displacement on non-union of femoral shaft fractures after locking for intramedullary nailing. Orthop Traumatol Surg Res. 2016;102:175-81.
23. Burç H, Atay T, Demirci D, Baykal YB, Kirdemir V, Yorgancigil H. The intramedullary nailing of adult femoral shaft fracture by the way of open reduction is a disadvantage or not? Indian J Surg. 2015;77:583-8.
24. Claes L, Eckert-Hübner K, Augat P. The effect of mechanical stability on local vascularization and tissue differentiation in callus healing. J Orthop Res. 2002;20:1099-105.
25. Lienau J, Schell H, Duda GN, Seebeck P, Muchow S, Bail HJ. Initial vascularization and tissue differentiation are influenced by fixation stability. J Orthop Res. 2005;23:639-45.
26. Gogus A, Ozturk C, Tezer M, Camurdan K, Hamzaoglu A. "Sandwich technique" in the surgical treatment of primary complex fractures of the femur and humerus. Int Orthop. 2007;31:87-92.
27. Marongiu G, Capone A. Atypical periprosthetic acetabular fracture in long-term alendronate therapy. Clin Cases Miner Bone Metab. 2016;13:209-13.
28. Kashayi-Chowdojirao S, Vallurupalli A, Chilakamarri VK, Patnala C, Chodavarapu LM, Kancherla NR, et al. Role of autologous non-vascularised intramedullary fibular strut graft in humeral shaft nonunions following failed plating. J Clin Orthop Trauma. 2017;8:S21-30.

29. Marongiu G, Dolci A, Verona M, Capone A. The biology and treatment of acute long-bones diaphyseal fractures: overview of the current options for bone healing enhancement. Bone Rep. 2020;12:100249.
30. Marongiu G, Contini A, Cozzi Lepri A, Donadu M, Verona M, Capone A. The treatment of acute diaphyseal long-bones fractures with orthobiologics and pharmacological interventions for bone healing enhancement: a systematic review of clinical evidence. Bioengineering (Basel). 2020;7:22.
31. Wu CC, Lee ZL. Treatment of femoral shaft aseptic nonunion associated with broken distal locked screws and shortening. J Trauma. 2005;58:837-40.
32. Taitsman LA, Lynch JR, Agel J, Barei DP, Nork SE. Risk factors for femoral nonunion after femoral shaft fracture. J Trauma. 2009;67:1389-92.
33. Liao JC, Hsieh PH, Chuang TY, Su JY, Chen CH, Chen YJ. Mini-open intramedullary nailing of acute femoral shaft fracture: reduction through a small incision without a fracture table. Chang Gung Med J. 2003;26:660-8.

Tables

Table 1
Demographic data of the open and closed reduction groups

	Open (26)	**Closed (17)**	***p*-value**
Age, years, mean (SD)	29.6 (11.5)	34.3 (18.2)	0.679
Sex (*n*, %)			0.687
Male	21 (80.77)	12 (70.59)	
Female	5 (19.23)	5 (29.41)	
BMI (SD)	22.8 (17.7)	21.4 (19.1)	0.655
Smoking (*n*, %)	4 (15.38)	5 (29.41)	0.470
Site (*n*, %)			0.748
Right	12 (46.15)	7 (41.18)	
Left	14 (53.85)	10 (58.82)	
Subtype			0.977
C1 (spiral)	13	9	
C2 (segmental)	3	2	
C3 (irregular)	10	6	
Multiple trauma (*n*, %)	8 (30.77)	8 (47.06)	0.280
Brain injury (*n*, %)	5 (19.2)	6 (35.29)	0.411
Open fracture (type I/II)	1 (3.85)	3 (42.86)	0.324

SD standard deviation

Table 2
Comparison of the open and closed reduction groups

	Open (26)	**Closed (17)**	***p*-value**
Reduction (*n*, %)			0.001
Anatomical-to-small gap	25 (96.15)	8 (47.05)	
Large gap	1 (3.85)	9 (52.95)	
Union rate at 12 postoperative months	80.76%	82.35%	0.787
Union time (months)	7.39 (2.77)	9.18 (2.04)	0.025*
RUSF			
Score at 6 postoperative months	9.30 (2.34)	7.76 (2.39)	0.02*
Score at 9 postoperative months	10.80 (2.02)	9.94 (1.88)	0.03*
Score at 12 postoperative months	11.19 (1.93)	11.41 (0.87)	0.37

Data are expressed as mean (standard deviation)

RUSF radiographic union score of the femur

*$p < 0.05$

Table 3
Demographic characteristics of patients who underwent re-operation

Open reduction group						
Case no.	**Sex/age (years)**	**Etiology**	**Gap**	**Timing of complications**	**Secondary intervention**	**Time to union (months)**
1	Male/28	Nonunion/broken nail	Small	12th month	Exchange nail and bone grafting	20
2	Female/25	Nonunion/broken nail	Small	7th month	Exchange nail and bone grafting	14
3	Male/20	Nonunion	Small	7th month	Dynamization	12
4	Male/25	Nonunion	Small	6/10th month	Dynamization/exchange nail and bone grafting	20
5	Male/52	Nonunion	Small	12th month	Exchange nail and bone grafting	15
Closed reduction group						
Case no.	**Sex/age (years)**	**Etiology**	**Gap**	**Timing of complications**	**Secondary intervention**	**Time to union (months)**
6	Male/21	Nonunion	Small	4th month	Dynamization	12
7	Male/17	Femoral malrotation	Large	3rd day	De-rotation, adjustment of distal screws	12
8	Female/23	Nonunion and reversed fragment	Large	5th month	Revision reduction and fixation with wiring, secondary bone grafting	12
9	Male/50	Nonunion	Large	6th month	Secondary bone grafting	20

Table 4
Complication and reoperation rates in the open and closed groups

	Open (26)	**Closed (17)**	***p*-value**
Complication (*n*, %)	5 (19.23)	4 (23.52)	0.964
Nonunion (*n*)	5	3	
Infection (*n*)	0	0	
Malrotation (*n*)	0	1	
Reoperation (*n*, %)	5 (19.23)	4 (23.52)	0.964

Figures

Fig. 1

Figure 1

A 23-year-old female (case 8) sustained left complex femoral shaft spiral fractures (AO type 32-C1). (a) Anteroposterior and (b) lateral view. Closed reduction following intramedullary nail fixation was performed. A reversed butterfly fragment and residual large gap were observed after the first operation (c). A secondary surgery was performed at the fifth postoperative month: revision reduction and fixation with wiring, and secondary bone grafting (d). This patient achieved union in the twelfth postoperative month (e)