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 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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**Tables**

| 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

| Case no. | Sex/age (years) | Etiology                     | Gap     | Timing of complications | Secondary intervention                                         | Time to union (months) |
|----------|-----------------|-------------------------------|---------|-------------------------|----------------------------------------------------------------|------------------------|
|          |                 | Nonunion/broken nail         | Small   | 12th month              | Exchange nail and bone grafting                                  | 20                     |
| 1        | Male/28         |                               |         |                         |                                                                  |                        |
| 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                     |

| Case no. | Sex/age (years) | Etiology                     | Gap     | Timing of complications | Secondary intervention                                         | Time to union (months) |
|----------|-----------------|-------------------------------|---------|-------------------------|----------------------------------------------------------------|------------------------|
|          |                 | Nonunion                     | Small   | 4th month               | Dynamization                                                    | 12                     |
| 6        | Male/21         |                               |         |                         |                                                                  |                        |
| 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

| Complication                  | 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
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).