



The impact of the third fragment features on the healing of femoral shaft fractures managed with intramedullary nailing: a radiological study

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Abstract

Introduction Femoral shaft fractures with third fragments have a high non-union rate, which may reach 14%. This study aims to assess the impact of the radiological features of the third fragment, evaluated on post-operative X-rays, on the outcome of femoral shaft fractures type 32-B managed with intramedullary nailing, in order to obtain an algorithm which could predict the fracture healing time.

Materials and methods We have retrospectively evaluated a series of 52 patients. On post-operative X-rays, four radiological parameters were evaluated: the third fragment angle, the fracture gap, the third fragment size, and the mean third fragment displacement. All the patients underwent a radiologic follow-up at one, two, three, six, nine and 12 months post-operatively, to assess the bone healing. The patients were then divided into three groups, according to the fracture healing time: within six months (group A), between six and 12 months (group B), or fracture non-union after 12 months (group C).

Results In 28 patients, out of 52 (53.85%), the fracture healing was observed at 6-month follow-up; in 18 patients, out of 52 (34.62%), the fracture healed within 12 months after trauma; and in six patients, out of 52 (11.54%), no fracture healing was observed at 12-month follow-up. The mean third fragment size was significantly different in each group ($p < 0.05$), while the mean third fragment displacement was significantly higher in group C, compared with group A ($p = 0.0006$) and group B ($p = 0.0027$). In group B, a positive correlation was found between the fracture healing time and the mean third fragment size ($R = 0.594$, $p = 0.036$); in group C, the fracture union time was positively related to the third fragment size ($R = 0.689$, $p = 0.013$) and the mean third fragment displacement ($R = 0.7107$, $p = 0.006$). Regression analysis showed that the third fragment size and the mean third fragment displacement are the most important features which affect the fracture healing time.

Conclusions The third fragment size (cutoff 40 mm) is the leading parameter to influence the fracture healing within or in more than six months. The mean third fragment displacement (cutoff 12 mm); on the other hand, impacts on the fracture delayed rather than absent healing.

Keywords Femoral shaft fractures · Third fragment · Butterfly fragment · Intramedullary nailing · Delayed union · Non-union

Introduction

Femoral shaft fractures are a quite common injury, with a reported incidence of 37.1 per 100,000 person-years in the USA [1]. This kind of injury commonly results from high-energy trauma—i.e., motor vehicle accidents, pedestrian accidents, sports injuries, and falls from a height—but they can also be caused by low-energy trauma, especially in older adults with osteoporotic bone [2].

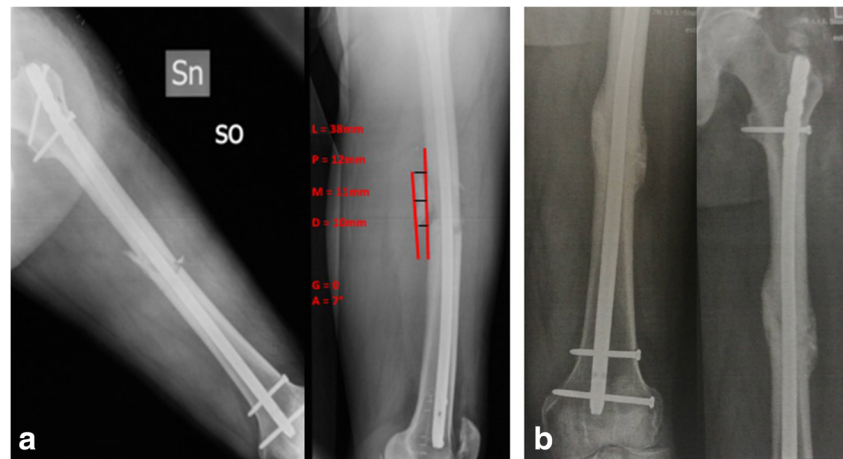
Closed reduction with intramedullary nailing is currently the most used technique in the management of femoral shaft fractures, since it is associated to low non-union, delayed union, and infection rates and to a better functional outcome [2, 3].

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Fig. 1 A group A clinical case: **a** post-operative X-ray and **b** 6-month follow-up X-ray



Femoral shaft fractures with third fragments, classified as 32-B fracture type according to the Arbeitsgemeinschaft für Osteosynthesefragen/Orthopaedic Trauma Association



Fig. 2 Third fragment angle (A): defined as the angle between a line parallel to the femoral diaphyseal cortex and a line parallel to the third fragment cortex

classification system (AO/OTA 32-B), account for 10–34% of all femoral shaft fractures [2, 4]. This injury pattern shows a high non-union rate which may reach 14% [5], since the presence of a third fragment makes the anatomical reduction of the fracture challenging, thus interfering with the bone healing [4, 6]. Non-union is defined, according to the Food and Drugs Administration (FDA), as a fractured bone that has not completely healed within 9 months of injury and that has not shown progression towards healing over three consecutive months on serial radiographs [7].

Lee et al. [3], in a retrospective cohort study on 64 femoral shaft fractures with third fragments managed with intramedullary nailing, have recently observed that non-union occurs more frequently in fractures with great third fragment size and high displacement degree. These authors depicted that the displacement degree has more influence on the union rate than the third fragment size.

The role of the displacement degree on the healing time of femoral shaft fractures with third fragments was also observed by An et al. [8]; thus, care should be taken to avoid an excessive displacement of the third fragment during the intramedullary nail implantation.

None of the previous studies, to the authors' knowledge, however, has quantified how the third fragment features could increase the fracture healing time.

This retrospective study aims to evaluate the impact of the radiological features of the third fragment, evaluated on post-operative X-rays, on the outcome of AO/OTA type 32-B fractures managed with intramedullary nailing, to obtain an algorithm which could predict the fracture healing time.

Materials and methods

Selection of study population: inclusion/exclusion criteria

We retrospectively reviewed a series of 127 patients with femoral shaft fractures referred to our department between

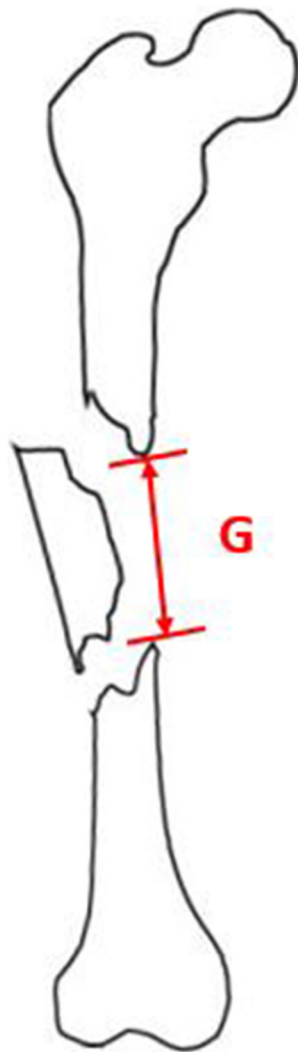


Fig. 3 Fracture gap (G): defined as the distance between the proximal diaphyseal fragment and the distal one

January 2009 and January 2016. Clinical and radiological data were obtained from our trauma database.

Inclusion criteria were type 32-B fracture according to AO/OTA classification system, minimum clinical and radiological 12-month follow-up, and surgical management with intramedullary nailing. Exclusion criteria were type 32-A or 32-C fractures according to AO/OTA classification system; surgical management with open reduction and internal fixation; concomitant ipsilateral femoral neck fracture; periprosthetic fractures; exposed fractures; history of infections or malignant neoplasms; osteoporosis, defined as lumbar or hip T score < 2.5; diabetes mellitus; and BMI > 35 kg/m².

By applying the inclusion and exclusion criteria, 52 patients (33 male and 19 female, mean age 34.6 years old, range 21–58) were recruited for the current study. All the patients had undergone a clinical and radiographic follow-up at one, two, three, six, nine and 12 months post-operatively.

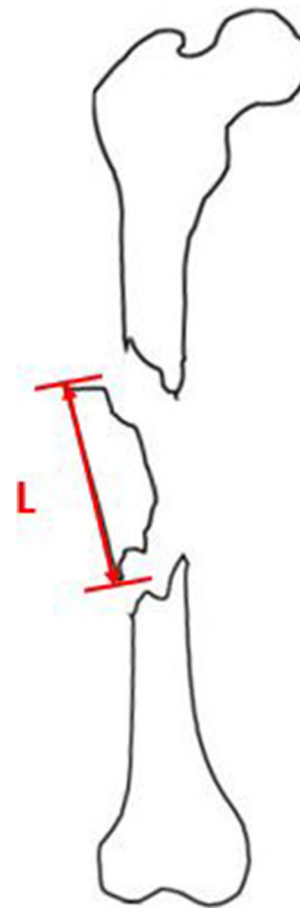


Fig. 4 Third fragment size (L): defined as the length of the major axis of the fragment

The patients were then divided into three groups according to the fracture healing time:

- Group A: fracture healing occurred within six months (Fig. 1)
- Group B: fracture healing occurred between six and 12 months
- Group C: fracture non-union after 12 months

Surgical management and post-operative care

The average time from trauma to surgery was about 42 hours (range 21–72 h). All the patients were treated by the same surgical team. The intramedullary nailing was always performed after the fracture reduction was obtained on a traction table; antegrade intramedullary reamed nails were used in all surgery. The distal screws were implanted in both static and dynamic holes. The mean length of post-operative hospital stay was eight days (range 6–14 days). Passive mobilization, i.e., static quadriceps exercises and passive mobilization of the knee with an electric motion device, started on post-operative

day one. The patients observed a non-weight-bearing until the callus formation, but they were encouraged, under the supervision of a physiotherapist, to mobilize the hip and the knee progressively actively.

After the callus formation, partial weight bearing was authorized with a ten weight increase a week for six weeks.

Radiographic study

Post-operative anteroposterior (AP) and lateral (LL) femur X-rays were analyzed by two orthopaedic surgeons with more than five years of experience in lower limb surgery. On each X-ray, the following parameters (Figs. 2, 3, 4, and 5) were measured in AP view:

- Third fragment angle (A): defined as the angle between a line parallel to the femoral diaphysis cortex and a line parallel to the third fragment cortex
- Fracture gap (G): defined as the distance between the proximal diaphysis fragment and the distal one
- Third fragment size (L): defined as the length of the major axis of the fragment

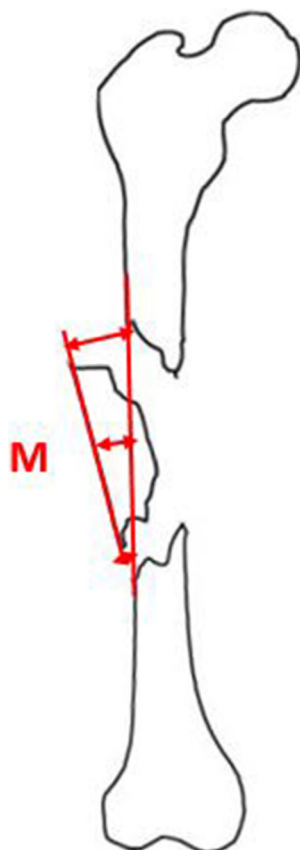


Fig. 5 Mean third fragment displacement (M): defined as the perpendicular distance between the midpoint of the fragment and the nearest femoral shaft cortex

Table 1 General data of the study

	Group A	Group B	Group C
Number of patients	28	18	6
Age			
Mean \pm SD	35.5 \pm 16.9	29.75 \pm 7.63	36.16 \pm 10.2
Range	25–58	23–42	21–47
Gender			
Male, <i>n</i> (%)	16 (30.77%)	11 (21.15%)	4 (7.7%)
Female, <i>n</i> (%)	12 (23.07%)	7 (13.46%)	2 (3.85%)
BMI (kg/m ²)			
Mean \pm SD	27.2 \pm 5.1	28.4 \pm 5.8	26.3 \pm 4.9
Side			
Left, <i>n</i> (%)	16 (30.77%)	7 (13.46%)	2 (3.85%)
Right, <i>n</i> (%)	12 (23.07%)	11 (21.15%)	4 (7.7%)
Smoking status			
No. of smokers, <i>n</i> (%)	9 (17.3%)	5 (9.6%)	2 (3.8%)
AO classification			
32-B1, <i>n</i> (%)	11 (21.15%)	6 (11.5%)	2 (3.85%)
32-B2, <i>n</i> (%)	9 (17.3%)	7 (13.5%)	3 (5.77%)
32-B3, <i>n</i> (%)	8 (15.4%)	5 (9.6%)	1 (1.92%)
Injury mechanism			
Fall from a height, <i>n</i> (%)	4 (7.7%)	3 (5.77%)	2 (3.85%)
Motor vehicle accident, <i>n</i> (%)	18 (34.62%)	9 (17.3%)	4 (7.7%)
Pedestrian accident, <i>n</i> (%)	6 (11.5%)	4 (7.7%)	–
Sports injury, <i>n</i> (%)	–	2 (3.85%)	–
Union time (months)			
Mean \pm SD	5.12 \pm 0.8	10.23 \pm 1.15	N/D
Range	4–6	7–12	> 12

- Mean third fragment displacement (M): defined as the perpendicular distance between the midpoint of the fragment and the nearest humeral shaft cortex

Other two orthopaedists evaluated the follow-up X-rays, performed at one, two, three, six, nine and 12 months post-

Table 2 Normality investigation

	Shapiro-Wilk	
	<i>W</i>	<i>P</i>
Third fragment size	0.82	0.234
Mean third fragment displacement	0.915	0.286
Third fragment angle	0.835	0.155
Fracture gap	0.926	0.187

Table 3 Radiological study: comparison between the three groups (one-way ANOVA)

	Group A	Group B	Group C	<i>p</i> value
Third fragment size (mm)	43.37 ± 23.6	80.6 ± 21.78	99.25 ± 23.3	0.03375*
Mean third fragment displacement (mm)	5.5 ± 3.34	7.67 ± 4.73	13.8 ± 3.42	0.00136*
Third fragment angle (°)	9.11 ± 6.11	12.8 ± 8.6	7.4 ± 2.70	0.3658
Fracture gap (mm)	10.7 ± 8.65	13.5 ± 8.87	15.66 ± 11.5	0.3494

*Significant *p* value

operatively, in order to assess the correct intramedullary nail placement and the bone healing. The fracture was considered healed when a bone callus could be depicted in at least three bone cortices out of four in AP and LL views [9].

Statistical analysis

Statistical analysis was performed using STATA/MP 14 for Windows (Stata Corp LP, College Station, USA). The Shapiro-Wilk test was conducted to verify the normal distribution of the data.

One-way ANOVA (analysis of variance) was used to assess the differences between the three groups. Bonferroni multiple-comparison test was then executed to evaluate the differences between each group.

Pearson correlation test was performed to assess the association between the union time and the fracture gap, third fragment size, angle, and mean displacement. Logistic regression analysis was conducted to investigate the effects of the fracture gap and the third fragment size, angle, and mean displacement on the fracture union. The tests were two-tailed with a confidence level of 5%.

Results

Fifty-two patients (33 male and 19 female, mean age 34.6 years old, range 21–58) were recruited for the current

Table 4 Bonferroni multiple-comparison test

	<i>p</i> value
Third fragment size (mm)	
Comparison between groups A and B	0.0048*
Comparison between groups A and C	0.0015*
Comparison between groups B and C	0.0158
Mean third fragment displacement (mm)	
Comparison between groups A and B	0.118
Comparison between groups A and C	0.0006*
Comparison between groups B and C	0.0027*

*Significant *p* value

study. In 28 patients out of 52 (53.85%), the fracture healing was observed at 6-month follow-up (group A); in 18 patients out of 52 (34.62%), the fracture healed within 12-months after trauma (group B); and in 6 patients out of 52 (11.54%), no fracture healing was observed at 12-month follow-up (group C). The main data of the study are summarized in Table 1.

Shapiro-Wilk test results are reported in Table 2: the radiological features of the third fragment showed a normal distribution.

Table 3 shows the one-way ANOVA results and Table 4 summarizes the Bonferroni multiple-comparison test results: the mean third fragment size was significantly different in group A compared with group B ($p = 0.0048$) and group C ($p = 0.0015$); the mean third fragment displacement was significantly higher in group C, compared with group A ($p = 0.0006$), and group B ($p = 0.0027$) (Table 4).

Pearson correlation test is shown in Table 5: in group B, a positive correlation was found between the fracture healing time and the mean third fragment size ($R = 0.594$; $p = 0.036$); in group C, the fracture union time was positively related to the third fragment size ($R = 0.689$; $p = 0.013$) and the mean third fragment displacement ($R = 0.7107$; $p = 0.006$) (Table 5).

The linear regression analysis results are summarized in Table 6: the impact of the third fragment size (X) on the fracture healing (Y) is summarized by the following equation:

$$Y = 2.290 + 0.0955 X \quad (1)$$

It could be noted that a femoral shaft fracture, treated with an intramedullary nail, needs about 69 days to heal; when a third fragment is present, the fracture healing time increases of about three days, every millimeter of the third fragment size enlargement.

The following equation describes the influence of the mean third fragment displacement (Z) on bone healing (Y):

$$Y = 3.739 + 0.6745 Z \quad (2)$$

It could be argued that a femoral shaft fracture with a third fragment which is not displaced, after closed reduction with an intramedullary nail, needs about 112 days to heal; every millimeter of the third fragment displacement increases the fracture healing time of about 20 days.

Table 5 Pearson correlation test

	Union time					
	Group A		Group B		Group C	
	<i>R</i>	<i>p</i>	<i>R</i>	<i>p</i>	<i>R</i>	<i>p</i>
Third fragment size (mm)	0.3144	0.3763	0.594	0.036*	0.689	0.013*
Mean third fragment displacement (mm)	0.038	0.919	0.19	0.717	0.7107	0.006*
Third fragment angle (°)	0.043	0.906	0.47	0.346	0.309	0.5509
Fracture gap (mm)	0.23	0.522	0.325	0.219	0.275	0.443

*Significant *p* value

Multiple regression analysis was finally conducted to evaluate the concomitant effect of the mean third fragment size (*X*) and the mean third fragment displacement (*Z*) on the healing of femoral shaft fractures with third fragments; thus, the following equation was obtained:

$$Y = 0.13 + 0.074 X + 0.501 Z \tag{3}$$

From these data, we have proposed a prognostic algorithm which is shown in Fig. 6.

Discussion

Femoral shaft fractures with third fragments are a quite common injury, accounting for about one third of all femoral fractures [2, 4]. Closed reduction and internal fixation with an intramedullary nail is widely considered as an appropriate management for femoral shaft fractures [3, 4, 10, 11]. Intramedullary nailing, indeed, could be performed through

minimal accesses, respecting the soft tissue and the fracture hematoma, and the periosteal blood perfusion [3].

Despite all these advantages, delayed-union or non-union could develop even in femoral shaft fractures treated with intramedullary nailing, especially in comminuted fractures or in fractures with third fragments. Several studies have investigated the risk factors which could affect the healing time of this kind of injuries and the role of the dynamization of the nail [12–14]. Some authors affirm that chipping and lengthening over nailing technique for femoral shaft non-union may be the first choice of treatment in case of shortening more than 10 mm [15].

Lee et al. [3], in a retrospective study on 64 femoral shaft fractures with third fragments, have recently observed that the healing of femoral shaft fractures with third fragments is mainly affected by the third fragment degree of displacement and the third fragment size. Consequently, according to these authors, fractures with fragments 8 cm or longer or when the third fragment proximal displacement is 20 mm or greater or the distal displacement is 10 mm or greater, non-union is more frequent. An et al. also reported similar data [8], who

Table 6 Linear regression analysis

Union time	Third fragment size	Mean third fragment displacement
<i>R</i> ²	0.6857	0.662
<i>p</i>	0.0003*	0.008*
Intercept		
Coefficient	2.290	3.739
Std. error	1.28	1.2397
95% CI	– 1.15–5.87	1.45–6.85
<i>p</i>	0.01*	0.001*
Slope		
Coefficient	0.095	0.06475
Std. error	0.022	0.0054
95% CI	0.05–0.14	– 0.125–0.10
<i>p</i>	0.003*	0.0054*

*Significant *p* value

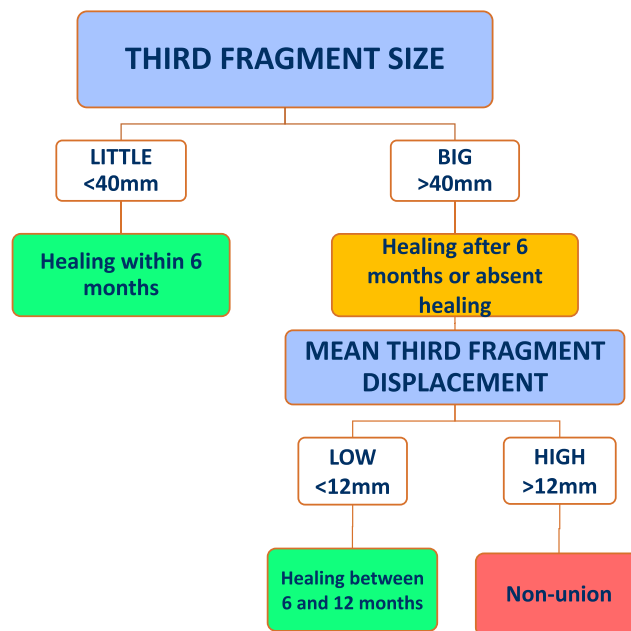


Fig. 6 The prognostic algorithm

confirmed that the degree of the third fragment displacement affects the fracture healing, so they suggest that during the intramedullary nail placement care should be taken to avoid an excessive third fragment displacement or angulation.

The current study aims to obtain an algorithm which could be useful in predicting the healing time of femoral shaft fractures on the basis of third fragment features, evaluated on a post-operative X-ray. For this purpose, we retrospectively reviewed a series of 52 patients with 32-B fracture type according to AO/OTA classification.

Our data show that the third fragment size and the mean third fragment displacement, evaluated on post-operative X-rays of femoral shaft fracture treated with intramedullary nailing, are the two key features, which could affect the fracture healing time. We found that a third fragment smaller than 40 mm is a predictive factor of fracture healing within six months, while in fractures with a third fragment bigger than 40 mm, the third fragment displacement is the primary factor which influences the fracture healing time. Indeed, a low third fragment displacement (< 12 mm) is a predictive factor of fracture healing within 12 months, while a third fragment displacement greater than 12 mm may predict a fracture non-union. Consequently, the aim of the closed reduction of 32-B fractures with an intramedullary nail is to minimize the third fragment dislocation, in order to shorten the fracture healing time.

The role of the third fragment displacement on the fracture healing time could be explained considering a high displacement may increase the movements between the fragments, also after the fracture fixation, thus slowing down the callus formation [3, 16, 17].

We remark that our data agree with the ones reported in other studies [3, 18]. As stated by Lee et al. [3], we also found that the third fragment displacement and its size are the two main factors that affect the fracture healing in patients with femoral shaft fractures.

Lin et al. [18], in a retrospective study in 50 patients with 32-B and 32-C fractures according to AO/OTA classification, observed that fractures non-union was more frequent when the third fragment displacement is greater than 10 mm; these authors also noticed that the third fragment shape could affect the fracture healing.

Our study, however, has the advantage of proposing a prognostic algorithm, which could help the physician in decision making, in the management of femoral shaft fractures.

This study has some limitations that could not be overcome. Even if all the data were collected in a blinded manner, the sample size is quite small. Thus, future studies with a more significant sample size are needed to confirm our data with higher statistical power. The retrospective nature of this study is another limitation; however, we are currently recruiting, at our Department, patients with femoral shaft fractures with third fragments in a prospective trial to finally validate the algorithm proposed.

Conclusions

Femoral shaft fractures with third fragments are an insidious fracture pattern. In this study, we have proposed a prognostic algorithm to predict the healing time of femoral shaft fractures treated with intramedullary nailing. Our data shows the third fragment size (cutoff 40 mm) is the leading parameter which influences the fracture healing within or in more than 6 months. The main third fragment displacement (cutoff 12 mm), on the other hand, impacts on the fracture delayed rather than absent healing.

Compliance with ethical standards

This study was conducted in accordance with the declaration of Helsinki. Informed consent was obtained from all participants.

Conflict of interest The authors declare that they have no conflict of interest.

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