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Analysis of the influence of circumference and displacement of the third fracture fragment on the healing of femoral shaft fractures treated with intramedullary nailing

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The effect of circumference and displacement of the third fracture fragment on fracture healing after intramedullary nailing of femoral shaft fractures with a third fracture fragment was investigated. A retrospective cohort study was conducted to analyze the data of 142 patients who suffered femoral shaft fractures with a third fracture fragment and were admitted to the First People's Hospital of Lianyungang from February 2016 to December 2021. According to the circumference of the third fracture fragments, these were divided into three types of type 1: 71 cases; type 2: 52 cases; and type 3: 19 cases. On the basis of the diaphyseal diameter, the degree of displacement of the third fracture fragment was classified into three degrees of degree I: 95 cases; degree II: 31 cases; and degree III: 16 cases. Postoperative follow-up was performed to compare the fracture healing rate, healing time, and the modified Radiographic Union Scale for Tibia (mRUST) at 9th month after surgery in each group. All 142 patients were followed up after operation, with an average of (14.7 ± 4.1) months, and the overall healing rate was 73.4%. When the third fracture fragments were displaced in degree II and III, the mRUST score at 9th month in the type 1 group was higher than that in the type 2 and 3 groups ($P = 0.017$). Logistic regression analysis showed that greater displacement of third fracture fragments and greater circumference were associated with lower fracture healing rates ($P < 0.05$). After intramedullary nailing of femoral fractures, the degree of third fragment displacement and circumference affect fracture healing, and the former has a greater impact. When the third fracture fragment is displaced to degree II or III and its circumference is type 2 or type 3, it significantly affects the fracture healing. Intraoperative intervention to reduce the distance of third displacement of the fragment is required to reduce the incidence of non-union.

With the advancement of social modernization in recent years, the incidence of femoral shaft fractures caused by high-energy injuries such as traffic accidents, crushing injuries, and falls injuries from heights has gradually increased. Intramedullary nails have advantages of closed reduction, higher healing rates, and lower complication rates and have now become the standard treatment for femoral shaft fractures[1,2]. According to the relevant literature, 10–34% of femoral shaft fractures have a large single third fracture fragment[3], which may increase the technical difficulty of anatomical reduction when accompanied by large fragments. Therefore, there is usually a continuous gap between the main axis of the femoral shaft and the third fracture fragment after closed reduction[4,5], resulting in an increased risk of delayed union or nonunion of the fracture. In the study by Layon et al.[3], it was found that femoral shaft fractures had a union rate of approximately 92% without open reduction

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of the third fragment, but nonunion still occurred in 8% of patients. Open reduction allows for easier anatomic reduction while maintaining better rotational stability. However, open reduction and fixation of the fragment may further disrupt its blood supply and affect fracture end healing. Therefore, the indication for open reduction of the third fragment after intramedullary nailing[3] remains a strongly debated issue. According to the literature, the incidence of nonunion after intramedullary nailing of femoral shaft fractures with a third fracture fragment is higher than that of femoral shaft fractures without such a fragment[6]. Without intervening third fracture fragments, domestic and foreign researchers believe that the degree of displacement of third fracture fragments is related with nonunion[1,7,8]. This article mainly investigates the effect of the third fracture size and displacement degree on fracture healing. Fragment size is presented as circumference. The circumference and diameter of femoral fracture in different patients are not the same, and there are also differences in the magnification ratio of femoral shaft fracture between the "C" arm machine used for intraoperative observation and the imaging instrument used for postoperative reexamination. Therefore, this study used the tripartite method to study femoral shaft fracture to eliminate the measurement error and increase the clinical practicability. According to the circumference of the third fracture fragments, the fracture fragments were divided into three types: type 1, the circumference of the third fracture fragment was less than 1/3 of the diaphyseal circumference at the fracture site; type 2, the circumference of the third fracture fragment was greater than 1/3 of the diaphyseal circumference at the fracture site and less than 2/3 of the diaphyseal circumference; type 3, the circumference of the third fracture fragment was greater than 2/3 of the diaphyseal circumference at the fracture site. On the basis of the diaphyseal diameter, the degree of displacement of the third fracture fragment was classified into three degrees: degree I, third fracture fragment displacement was less than 1/3 of the diaphyseal diameter at the fracture site; degree II, third fracture fragment displacement was greater than 1/3 of the diaphyseal diameter at the fracture site while less than 2/3 of the diaphyseal diameter at the fracture site; degree III, third fracture fragment displacement was greater than 2/3 of the diaphyseal diameter at the fracture site. According to previous studies[9], when third fracture fragments are of degree I displacement, non-intervention of third fracture fragments can also achieve a good therapeutic effect. However, when fractures are of degree II or III displacement, they need to be additionally reduced as much as possible and approach the defect of femoral shafts to avoid postoperative nonunion. To our knowledge, whether the size of the fracture fragment evaluated in terms of circumference has an effect on fracture healing remains unknown. Consequently, several points require clarification: when the circumference of the fracture fragment is large, does degree I displaced fragment require intervention? When the circumference of the fracture fragment is small, do degree II and III displaced fragments not require intervention? Under what precise conditions, is limited open reduction of the fracture fragment required, such as bone grafting, prying, and wire cerclage, to reduce the incidence of nonunion of fracture fragments? Further discussion remains needed. Which influencing factor of fracture size and displacement degree plays a more important role in fracture healing? The authors designed a retrospective cohort study to analyze the clinical data of 142 patients suffered from femoral shaft fracture with a third fracture fragment and were admitted to the First People's Hospital of Lianyungang from February 2016 to December 2021. According to the circumference group and the degree of displacement group, we analyzed the related conditions of fracture healing and concluded in order to provide treatment strategies and the experimental basis for clinical treatment.

Materials and methods

A total of 636 patients diagnosed with femoral shaft fractures were included from February 2016 to December 2021 in the First People's Hospital of Lianyungang City. Femoral shaft fractures were defined as fractures starting 5 cm distal to the lesser trochanter and 5 cm proximal to the adductor tubercle[10]. A total of 142 patients with 142 fractures met the inclusion criteria, including 88 males and 54 females, with an average age of (42.2 ± 16.3) years; 81 cases on the right side and 61 cases on the left side; 78 isthmic fractures and 64 non-isthmic fractures; Injury mechanisms were: 98 cases of car accident injury, 13 cases of falling from height, 18 cases of a riding fall, 13 cases of a crushing injury, etc. According to the AO/OTA (Arbeitsgemeinschaft für Osteosynthesefragen/Orthopedic Trauma Association) classification, they were included in 32-B classification. According to the Winquist-Hansen classification, Type 0: no third fragment between the two ends of the fracture; Type I; the third fragment is small and has no effect on fracture stability in 21 cases; Type II: the third fragment is large, but more than 50% cortical contact remains between the two ends of the fracture in 94 cases; Type III: the third fragment is large, but less than 50% cortical contact between the two ends of the fracture in 27 cases; Type IV: comminuted fracture of the femoral fracture end, without cortical contact. The retrospective study was approved by the Medical Ethics Committee (No. JS-20151223003) of the First People's Hospital of Lianyungang, Jiangsu Province, China, and conducted according to the ethical norms of the Declaration of Helsinki. Informed consent was obtained from all individual participants included in the study.

Inclusion criteria

(1) Imaging examination confirmed femoral shaft fracture combined with third fragment with displacement, with clear surgical indications; (2) the age of the patients ranged from 17 to 70 years at the time of surgery; (3) treated with an intramedullary nail; (4) no cardiopulmonary dysfunction or other obvious surgical contraindications (Fig. 1).

Exclusion criteria

(1) Open femoral shaft fractures; (2) combined with underlying diseases affecting fracture healing; (3) combined with ipsilateral proximal or distal femoral fractures; (4) previous history of ipsilateral femoral fractures; (5) patients with incomplete follow-up data or who did not cooperate with the treatment (Fig. 1).

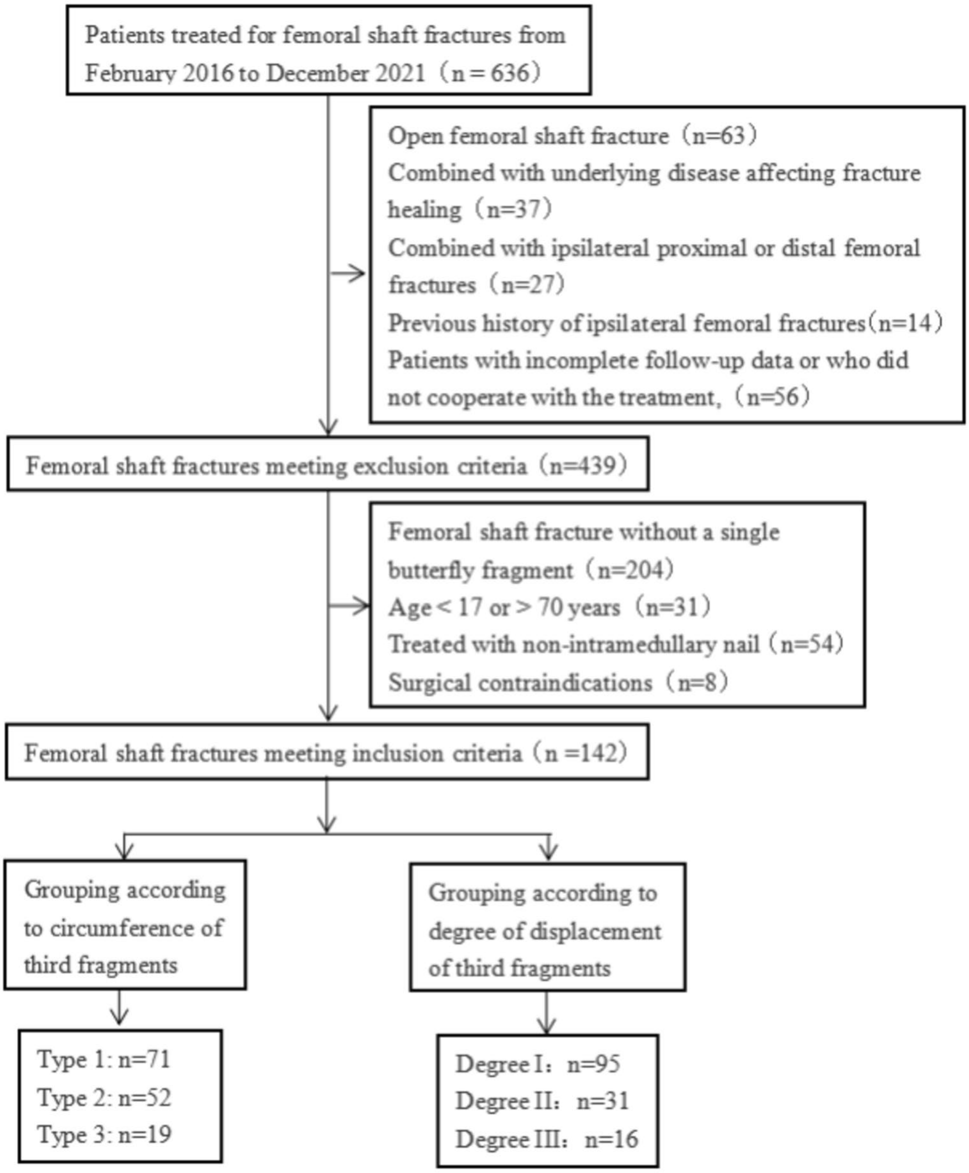

Figure 1. Flow chart for screening patients with femoral shaft fractures following inclusion and exclusion criteria.

Surgical technique

The average time was (4.3 ± 3.3) days from injury to surgery. Interlocking reamed intramedullary nail surgery was performed by experienced orthopedic surgeons in the same department using a standard closed reduction technique without intervening regarding the displaced third fracture fragments during the operation. Appropriate functional exercise in the early postoperative period can effectively avoid the complications of joint stiffness[11]. Depending on the age of the patients, quadriceps isometric contraction training and flexion and extension exercise of the hip, knee, and ankle joints were started on the first to second day after the surgery. On the third day after operation, the patients were allowed to moderately take the sitting position and even to mobilize with the help of crutch after pain relief, but the affected limb must not bear weight. After the operation, the affected limb was reexamined regularly in the outpatient department, and anteroposterior (AP) and lateral radiographs of the fracture end were taken to observe the callus growth and fracture healing around the fracture end and third fracture fragment until the fracture healed.

Observation index

The size of the third fracture fragments was defined as the circumference, which was the maximum value of the third fracture fragments in preoperative cross-sectional CT scans. Femoral shaft fractures were fixed with intramedullary nails and radiographs were taken on the first postoperative day to measure the displaced length of the third fracture fragment and the diameter of the femoral shaft at the fracture site. The displacement length of the third fracture fragment was half of the sum of the maximum vertical distance from the upper and lower apices of the cortical bone of the third fracture fragment to the cortical bone of the femur measured from AP and lateral radiographs. The diameter of femoral shaft was half of the sum of the distance of cortical bone on both sides of the proximal femoral defect and the distance of cortical bone on both sides of the distal femoral defect when measuring the displacement length of third fracture fragment.

The modified Radiographic Union Scale for Tibia (mRUST) uses four cortical scores to quantify callus to better assess fracture healing[12] and has a slightly higher diagnostic value than the RUST score[12–15].The application of this scoring system in the treatment of femoral shaft fractures with intramedullary nails has been confirmed to be effective and reliable[14], and its scoring criteria are: 1 point, the fracture line between the fracture ends is clearly visible; 2 points, there is callus formation between the fracture ends, but the fracture line is also visible; 3 points, there is bridging callus formation between the fracture ends, blurred fracture line; 4 points, there is bone bridge formation between the fracture ends, and there is no fracture line. A total of 16 points in the four cortices in the AP and lateral views suggested complete fracture healing. In order to ensure the accuracy of data, the data collection of this study was jointly completed by three medical staff in our hospital using the hospital Picture Archiving and Communication Systems, and the mean value of the measured results was taken as the data of this study. Fracture union was defined as bridging callus in at least three cortices on four cortical surfaces in the AP and lateral views. Failure of fracture healing follows the Food and Drug Administration criteria for nonunion: nonunion remains unhealed within 9 months of fracture surgery and has been without any tendency to heal for 3 consecutive months[16], or requires reoperation. In this study, nonunion refers to nonunion of the fracture itself rather than nonunion of third fracture fragments.

Statistical analysis
Excel data table is established and all statistical analyses were performed using SPSS 26.0 software. Measurement data are expressed as mean ± SD. If normal distribution is observed, independent sample t-test will be used for analysis. If normal distribution is not observed, non-parametric test will be used. Enumeration data are expressed as percentages, and the chi-square test is used for comparison between groups. Binary logistic regression analysis was used to investigate the effect of fracture circumference and degree of displacement on bone healing. Significance level was set at $P < 0.05$.

Results
Fracture healing quality
A total of 142 fractures in 142 patients were included in this study. The mean followed-up time was (14.7 ± 4.1) months, and the overall healing rate was 73.4% (105/142). Delayed union or nonunion rate was 26.4% (37/142). The minimum follow-up period was 12 months, and if there was poor healing 9 months after surgery and there was no progression of healing after delayed retreatment (3 months), reoperation was performed for revision. Reoperation revision was performed by cortical stripping of the fracture end, autologous cancellous bone grafting, replacement of intramedullary nails in the isthmus, and additional plates in the non-isthmus.

The effect of the degree of third fracture fragment displacement on fracture healing quality
According to the degree of third fragment displacement, fractures were divided into three degrees: degree I including 95 patients, with an average displacement distance of (5.5 ± 2.3) mm; degree II including 31 patient, with an average displacement distance of (13.8 ± 2.1) mm; degree III including 16 patients, with an average displacement distance of (26.4 ± 3.3) mm, as shown in Table 1. There was no significant difference in age ($P = 0.775$), sex ($P = 0.066$), left or right side ($P = 0.520$), and fracture location ($P = 0.289$) among the three groups of degree I, II, and III. Overall, there were statistically significant differences in the healing rate, healing time, and mRUST score at 9th month among these three groups, in which the healing rate in the degree I group was higher than that in the degree II and III groups ($P < 0.05$); the healing time in the degree I group was shorter than that in the degree III group ($P < 0.05$); and the mRUST score at 9th month in the degree I group was higher than that in the degree II and III groups ($P < 0.05$). When the displacement distance of the third fracture fragment was in degree II and degree III, the corresponding quality of fracture healing was considered to be affected.

Group	Degree I	Degree II	Degree III	*P*-value
Cases	95	31	16	
Age (year)	42.8 ± 16.1	41.3 ± 15.8	40.4 ± 19.2	0.775
Male (%)	67.4	58.1	18.8	0.066
Left (%)	41.1	41.9	56.3	0.520
Isthmic (%)	50.5	61.3	68.8	0.289
Degree of displacement (mm)	5.5 ± 2.3	13.8 ± 2.1	26.4 ± 3.3	
Healing rate (%)	93.7	41.9	18.8	0.000*
Fracture healing time (month)	8.9 ± 0.8	9.3 ± 1.4	11.7 ± 2.9	0.012*
mRUST Score at 9th month	13.0 ± 1.7	10.4 ± 2.7	9.2 ± 2.3	0.000*

Table 1. Fracture healing of the third fracture displacement grouping. $^*P < 0.05$.

The effect of the circumference of the third fracture fragment on fracture healing quality

According to the circumference of the third fracture fragment, fractures were divided into three types: type 1 including 71 patients; type 2 including 52 patients; and type 3 including 19 patients. There was no significant difference in age ($P=0.614$), sex ($P=0.214$), left or right sides ($P=0.672$), fracture location ($P=0.565$), and degree of displacement ($P=0.565$) among the three groups of type 1, type 2, and type 3, as shown in Table 2. Overall, there were statistically significant differences in the healing rate, healing time, and mRUST score at 9 months among these three groups, with the healing rate in the type 1 group being higher than that in the type 2 and 3 groups ($P<0.05$); the healing time in the type 1 group was shorter than that in the type 3 group ($P<0.05$); and the mRUST score at 9th month in the type 1 group was higher than that in the type 2 and 3 groups ($P<0.05$). When the circumference of the third fracture fragment was classified as type 2 and type 3, it affected fracture healing quality.

The effect of degree I third fracture fragment size on fracture healing

According to the circumference of the third fracture fragment, the degree I fractures were divided into three types: type 1 including 54 patients; type 2 including 31 patient; type 3 including 10 patients. There was no significant difference in age ($P=0.309$), sex ($P=0.223$), left or right sides ($P=0.677$), fracture location ($P=0.698$), and degree of displacement ($P=0.788$) among the three groups of type 1, type 2, and type 3, as shown in Table 3. For degree I displaced third fracture fragments, there was no significant difference in the degree of displacement, healing rate, healing time and mRUST score at 9th month the three types classified by circumference of third fracture fragments ($P>0.05$). In summary, for patients with grade I displaced fragments, circumference size, as an influencing factor, had little effect on fracture healing.

The effect of degree II and III third fracture fragment size on fracture healing

According to the circumference of the third fracture fragment, the degree II and III fractures were divided into three types: type 1 including 17 patients; type 2 including 21 patients; and type 3 including 9 patients. There was no significant difference in age ($P=0.307$), sex ($P=0.480$), left or right sides ($P=0.412$), fracture location ($P=0.396$), and degree of displacement ($P=0.897$) among the three groups, as shown in Table 4. For degree II and III displaced third fracture fragments, the healing rate ($P=0.053$) and healing time ($P=0.097$) were not statistically significant among the three groups, and the mRUST score at 9th month in the type 1 group was higher than those in the type 2 and type 3 groups ($P<0.05$). For patients with a degree II or III displaced fragment, higher mRUST scores could also be obtained without intervening regarding the third fracture fragments, when the circumference was considered to be type 1.

Group	Type 1	Type 2	Type 3	*P*-value
Cases	71	52	19	
Age (year)	40.8 ± 15.0	44.1 ± 18.1	41.8 ± 16.2	0.614
Male (%)	69.0	53.8	57.9	0.214
Left (%)	46.5	38.5	42.1	0.672
Isthmic (%)	59.2	51.9	47.4	0.565
Degree of displacement (mm)	8.6 ± 7.0	10.5 ± 7.8	11.2 ± 7.0	0.586
Healing rate (%)	87.3	63.5	52.6	0.001*
Fracture healing time (month)	8.8 ± 0.8	9.2 ± 1.3	9.7 ± 1.2	0.016*
mRUST Score at 9th month	12.8 ± 2.0	11.4 ± 2.7	10.7 ± 2.4	0.002*

Table 2. Fracture healing of the third fracture circumferential grouping. *$P<0.05$.

Group	Type 1	Type 2	Type 3	*P*-value
Cases	54	31	10	
Age (year)	41.7 ± 15.3	46.0 ± 17.6	38.4 ± 15.5	0.309
Male (%)	74.1	61.3	50.0	0.223
Left (%)	42.6	35.5	50.0	0.677
Isthmic (%)	53.7	48.4	40.0	0.698
Degree of displacement (mm)	5.4 ± 2.1	5.6 ± 2.1	5.8 ± 3.6	0.788
Healing rate (%)	98.1	90.3	90.0	0.375
Fracture healing time (month)	8.7 ± 0.8	9.0 ± 0.7	9.4 ± 0.9	0.054
mRUST Score at 9th month	13.1 ± 1.5	12.9 ± 1.9	12.5 ± 1.5	0.552

Table 3. Fracture healing of degree I third fracture fragment size subgrouping. *$P<0.05$.

Group	Type 1	Type 2	Type 3	*P*-value
Cases	17	21	9	
Age (year)	38.0 ± 14.0	41.4 ± 19.0	45.7 ± 17.1	0.307
Male (%)	52.9	42.9	33.3	0.480
Left (%)	58.8	42.9	33.3	0.412
Isthmic (%)	76.5	57.1	55.6	0.396
Degree of displacement (mm)	18.8 ± 7.3	18.0 ± 6.9	17.2 ± 4.2	0.897
Healing rate (%)	52.9	23.8	11.1	0.053
Fracture healing time (month)	8.9 ± 1.1	10.8 ± 2.5	12.0 ± 0.0	0.097
mRUST Score at 9th month	11.6 ± 2.9	9.3 ± 2.1	8.8 ± 1.6	0.017*

Table 4. Fracture healing of degree II and III third fracture fragment size subgroupings. *$P < 0.05$.

Logistic regression analysis of the effect of the fragment degree of displacement and circumference on fracture union

Logistic regression analysis was performed to determine the odds ratio for fracture healing for selected variables. The greater displacement and circumference of the third fracture fragments were associated with lower fracture healing rate ($P < 0.05$). The factor that had a greater impact on fracture healing was the degree of displacement of the fracture fragments, as shown in Table 5.

*Typical case (*Figs. 2, 3, 4*)*

Discussion

Femoral shaft fractures are common injuries in patients suffered from high-energy trauma. With the benefited of the central fixation, a lower incidence of fatigue fracture and a higher incidence of fracture healing, intramedullary nail fixation technique has become the gold standard in the surgical treatment of femoral shaft fractures[1,2], which is suitable for comminuted fracture or associated fragments or even open fractures[17]. However, it remains greatly debated whether intraoperative intervention is needed for femoral shaft fractures with a displaced third fracture fragment.

Accurate judgement of fracture healing is essential for patient care and measuring the success of various fracture interventions. Evaluating whether a fracture heals, the measurement of both the continuity of the cortical bone at the fracture end and the number of cortical bone with bridging calluses have been shown to be a reliable and scientific scoring system for assessing the fracture healing[18,19]. In this study, we mainly used the quantitative measurement method of mRUST to quantify callus using four cortical scores for four cortices in AP and lateral radiographs, so as to better assess fracture healing[12], and its application to intramedullary nailing of femoral shaft fractures has proved to be effective and reliable[14]. After intramedullary nail treatment, the fracture healing scores were calculated using AP and lateral views at the fracture end, which was superior in identifying the degree of fracture healing, because the fracture ends were not obscured by a locking compression plate, etc.

Lin et al. was a pioneer in studying factors affecting femoral shaft fracture healing with a third fragment and found that a displacement distance of more than 10 mm after intramedullary nailing negatively affected fracture healing by reviewing the data of 48 relevant patients[7]. A migration distance of more than 10 mm is an important reference for us to consider whether intraoperative intervention is required. It was considered that the diameter of femoral shaft was different in different patients, and did the diameter of fracture site. Moreover, there was also a difference in the magnification ratio of the fracture site between the "C" arm machine used for intraoperative observation and the imaging instrument for postoperative reexamination. Considering that the diameter of femoral shaft is approximately 30 mm and the displacement distance is more than 10 mm, it should be paid attention to. Therefore, the tripartite method is used to study the femoral shaft fracture to eliminate the measurement error and increase the clinical practicability.

Approximately 10–34% of femoral shaft fractures have a large single third fracture fragment[3–5]. We discovered that if the displacement distance was degree II or degree III (Table 2), or the circumference of the third fracture fragments was type 2 or type 3 (Table 3), non-intervention regarding the third fracture fragment during surgery leads to a higher rate of nonunion. Poor cortical bone contact, poor axial loading capacity[20,21], and gaps between

	B	S.E	Wals	*P*-value	Odd ratio	95% odd ratio
Degree of displacement	− 2.707	0.460	6.580	< 0.001*	0.467	0.027, 0.965
Circumference	− 1.118	0.397	7.947	0.005*	0.327	0.150, 0.711
Constant term	7.453	1.233	36.554	0.000	1724.260	

Table 5. Logistic regression analysis of the effect of the fragment degree of displacement and circumference on fracture union. *$P < 0.05$.

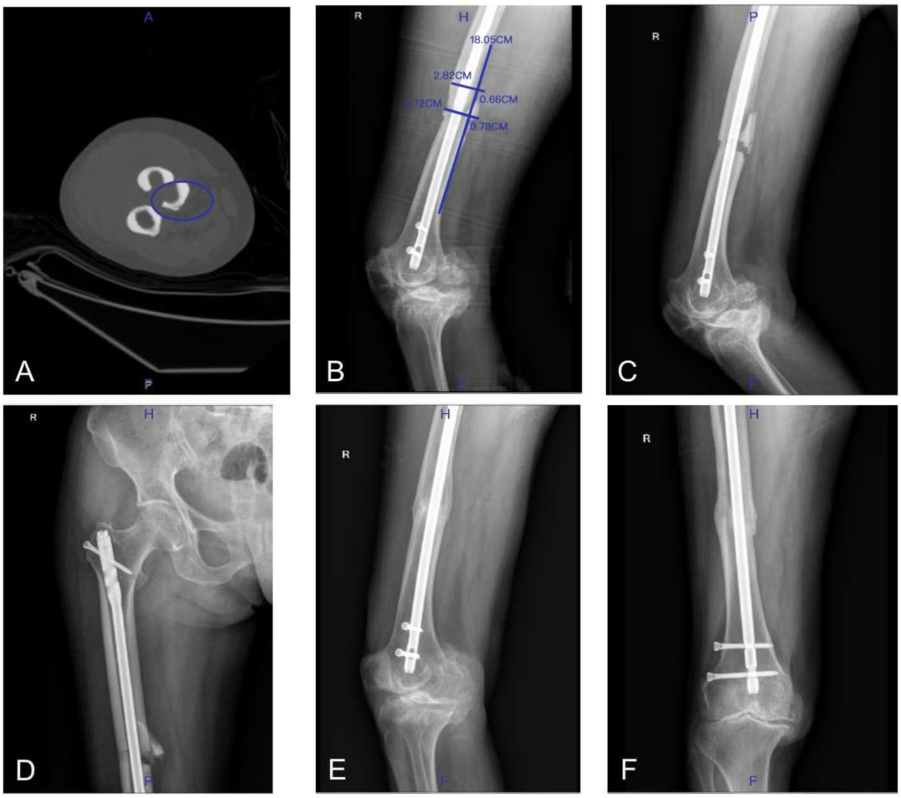

Figure 2. A 69-year-old female patient presented with a right femoral shaft fracture caused by a car accident, classified as degree I displaced with type 2 circumference, which was treated with intramedullary nails 4 days after injury (A) Preoperative CT tomography showed type 2 circumferential fracture of femoral shaft; (B) postoperative X-ray showed degree I displaced fracture of femoral shaft; (C, D) anteroposterior and lateral X-ray at 1 months after operation showed clear fracture line between the fracture ends; (E, F) anteroposterior and lateral X-ray at 13 months after operation showed blurred fracture line at the fracture ends, with bridging callus production.

fragments or between fragments and the main axis of the femoral shaft may lead to the larger gaps, thereby increasing movement between segments after fracture fixation and inhibiting callus formation, which in turn may lead to nonunion[22,23]. In terms of the fracture healing rate, most researchers believe that the degree of third fracture fragment displacement has a greater impact on femoral shaft fracture healing than the third fracture fragment size[1,7,24]. This is due to the fact that when third fracture fragments are displaced for a large distance, they tend to be accompanied by periosteal stripping at the fracture end, blood supply disruption, potential soft tissue injury or even combined with open wounds, while open fractures and greater fracture severity lead to a higher risk of nonunion[25]. In addition, the greater the distance between the third fracture fragment and the main axis of the femoral shaft, the lower the concentration of bone morphogenetic protein-2 (BMP-2), which is also one of the causes of nonunion[26].

We followed up 216 patients with femoral shaft fractures and found that when the third fracture fragment was displaced by degree I after intramedullary nailing, no additional intervention was required during the operation and a good fracture healing rate could be obtained. By contrast, when the third fracture fragment was displaced by degree II or III, intervention regarding the fracture fragment was required during the operation to reduce the displacement distance of the fracture fragment, which could significantly reduce the incidence of postoperative nonunion[9]. In this study, we found that in the presence of degree I displacement of the fracture fragment, the circumference size of it had little effect on fracture healing. With the fracture classified as degree II or degree III, a higher mRUST score could still be obtained without intervening regarding the third fracture fragments when the fracture was defined as type 1. The use of indirect reduction techniques and preservation of the vascular supply to the fracture ends allows earlier recovery of the fracture ends and minimizes surgical trauma. However, the fracture healing was significantly affected when the fracture was defined as type 2 or type 3. Therefore, when the circumference of the fracture fragment is type 2 or type 3, the distance between the main axis of the femoral shaft and fragments needs to be reduced via roof pressure or percutaneous prying of the fracture fragment, thus increasing the likelihood of achieving satisfactory fracture reduction. However, it may be difficult to reduce the fracture by prying in some cases, most of the reasons are traction by the soft tissue attached to the fracture fragment or soft tissue entrapment in the residual space between the third fragment and femoral shaft, and limited open reduction of the fracture fragment is adopted at the same time for fixation. For the fixation of third fracture

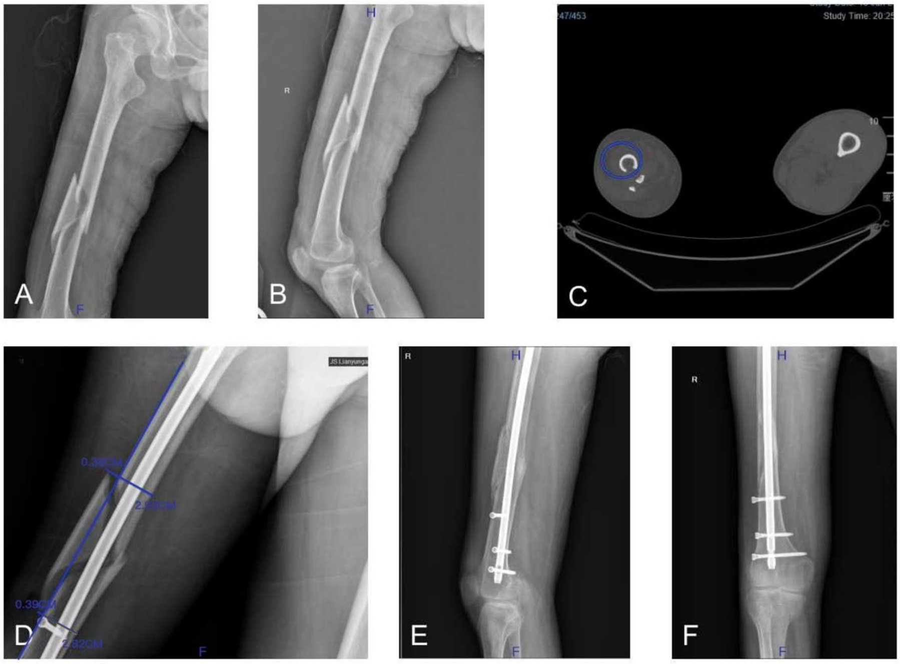

Figure 3. A 60-year-old male patient presented with a right femoral shaft fracture, classified as degree I displacement with type 3 circumference, caused by a fall on an electric car, which was treated with intramedullary nails 9 days after injury. (A, B) AP views in preoperative X-rays showed femoral shaft fracture with butterfly fracture fragments; (C) Preoperative CT tomography showed femoral shaft type 3 circumferential fracture; (D) Postoperative X-ray showed femoral shaft fracture with degree I displaced fragment; (E, F) AP views in postoperative radiographs 9 months after surgery showed fracture healing.

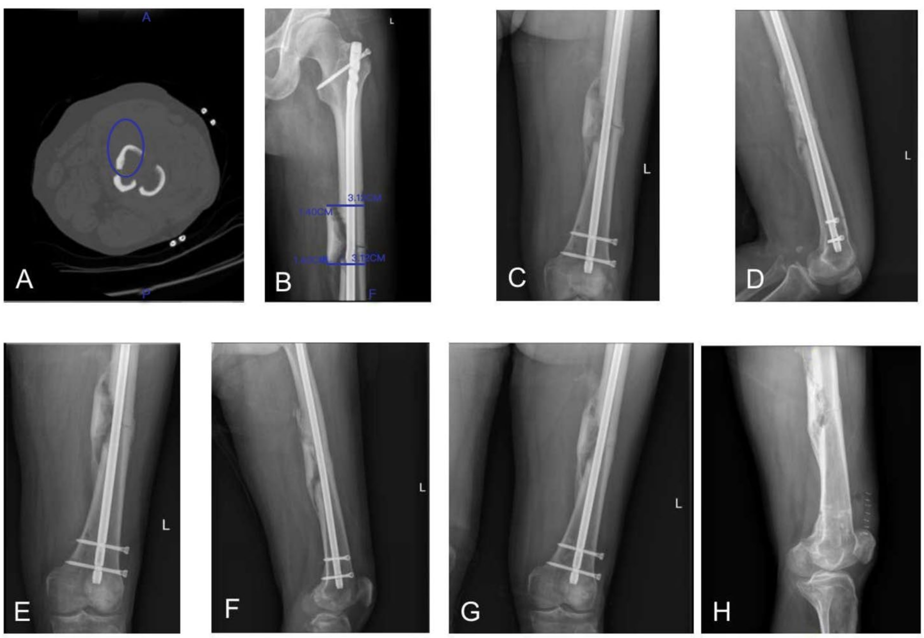

Figure 4. A 52-year-old male patient presented with a right femoral shaft fracture caused by a car accident, classified as degree II displaced with type 2 circumference, which was treated with intramedullary nails 12 days after injury. (A) Preoperative CT tomography showed type 2 circumferential fracture of femoral shaft; (B) postoperative X-ray showed degree II displaced fracture of femoral shaft; (C, D) AP and lateral views of X-ray at 3 months after operation showed clear fracture line between the fracture ends; (E, F) AP and lateral views of X-rays at 6 months after operation showed clear fracture line between the fracture ends; (G) AP view of X-ray at 18 months after operation showed clear fracture line between the fracture ends, which did not reach the standard of healing; (H) AP view of X-ray at 43 months after operation showed blurred fracture line at the fracture ends, with bridging callus production, which had reached the healing criteria.

fragments, wire cerclage is recommended, with the advantages of less dissection, less impact on the blood supply, reduced stress load, and increased stability of the fracture fragments[27]. While passing cerclage wires may lead to vascular strangulation[28,29], this may affect fracture healing. Therefore, we recommend that the wire be placed outside the periosteum as far as possible and no more than two wire cerclages be used as far as possible.

Nevertheless, there were some limitations in this study. First, this study was a retrospective study, lack of repeated study. Second, the clinical case data were all from the same hospital with a long time-span, and therefore had inherent bias. A multicenter prospective randomized controlled study with a larger sample size is needed in the future to further verify the effect of the circumference and displacement of third fracture fragments on the efficacy of intramedullary nails in the treatment of femoral shaft fractures.

Conclusions

After intramedullary nailing of femoral fractures, the degree of third fragment displacement and circumference affect fracture healing, and the former has a greater impact. When the third fracture fragment is displaced to degree II or III and its circumference is type 2 or type 3, it significantly affects the fracture healing. Intraoperative intervention to reduce the third distance of displacement of the fragment is required to reduce the incidence of nonunion.

Data availability

No datasets were generated or analysed during the current study.

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Author contributions

Author contributions All authors contributed to the study conception and design. Material preparation, data collection, and analysis were performed by Y.Z., Y.S. and Jian Yu. Data analysis were performed by F.T., C.S., and H.Y. The first draft of the manuscript was written by Jian Yin and Z.Y. All authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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Competing interests

The authors declare no competing interests.

Additional information

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