CLINICAL ARTICLE

The Butterfly Fragment in Wedge-Shaped Femoral Shaft Fracture: Comparison of Two Different Surgical Methods

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Objective: Our study compared the results of wedge-shaped femoral shaft fracture following intramedullary (IM) nailing with or without fixation of the third fragment.

Methods: We retrospectively reviewed patients presenting with femoral shaft fracture with AO/OTA type 32-B from 2011 to 2016. Patients were divided into two groups: closed reduction without touching the third fragment and open reduction with fixation of the third fragment. The fragment ratio, fragment length, nail size, dynamization or not, mRUST scores, union rate, and union time were compared between the two groups. Risk factors of non-union were also investigated, including sex, age, fracture pattern, fracture location, dynamization, nail size, fragment ratio, fragment size, and postoperative fragment displacement.

Results: A total of 80 patients met inclusion criteria, 20 patients with wedge-shaped shaft femoral fracture were managed with IM nailing and open reduction with fixation of the third fragment. Sixty patients were treated with IM nail without touching the third fragment. The union rate for the fixation and non-fixation groups were 60.0% and 81.7%, respectively. The mean union time for the fixation group was 19 months *vs* 14 months for the non-fixation group. Multi-regression analysis showed larger nail size (odds ratio: 2.26) and fixation of the third fragment (odds ratio: 0.18) influenced fracture healing.

Conclusions: Fixation of the third fragment in wedge-shaped shaft femoral fracture results in a longer union time and lower union rate. In the management of femoral fracture with a third fragment, a larger nail size is recommended and fixation should be performed in a closed manner. Fixation of the fragment may achieve better fracture reduction. However, disruption of the vasculature and surrounding structures may further result in nonunion of the fracture site.

Key words: femoral shaft fracture; intramedullary nailing; third fragment; union rate; union ratio

Introduction

Femoral shaft fracture is one of the most common injuries seen by orthopaedic trauma surgeons. It accounts for 5%–10% of all fractures[1]. In young patients, femoral shaft fracture typically involves a high-energy mechanism, while in the elderly, such injuries tend to be caused by low-energy trauma. Different surgical methods, including open and closed techniques, have been described and each may be preferred by some surgeons according to availability of operating setting equipment (e.g. C-arm and fracture table), patient factors (e.g. morbid obesity), and fracture pattern and associated injuries (i.e. floating knee injury, concomitant acetabular fracture, and spinal injury).

The most common surgical method of treating femoral shaft fractures is using an intramedullary nail. Modern nailing traces its origins to Küntscher in 1939, but descriptions of intramedullary devices have been found from well before the 20th century[2]. To date, intramedullary nailing

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with closed reduction of the fracture site is the gold standard treatment for this kind of fracture[3] because of its high union rate and low infection and malunion rates.

For wedge femoral shaft fracture (Arbeitsgemeinschaft für Osteosynthesefragen/Orthopedic Trauma Association, AO/OTA 32-B), there is no consensus for the management of the third fragment. Open reduction in the acute fracture should be avoided if possible. Perhaps an exception is the use of a clamp or cable to reduce a subtrochanteric fracture, as any malreduction here (especially varus) will lead to an increased risk of implant fatigue failure. Colinear reduction clamps have a smaller footprint and require smaller incisions; nonetheless, their use still leads to a disturbance of the fracture biology[4].

Aprato *et al.* reported a postless distraction technique to facilitate distraction to allow reduction and internal fixation of the femoral fracture with a standard femoral nail[5]. Some surgeons strictly adhere to the principle of closed reduction with intramedullary nailing leaving the third fragment untouched (Figure 1). Layon *et al.* found wedge fragments may successfully be treated without open reduction of the third fragment[6]. They believe that minimizing surgical damage and using indirect reduction techniques contribute to faster bone healing because the vascularity of bone is preserved allowing earlier recovery[7]. Rokkanen *et al.* compared the functional results of closed and open intramedullary nailing of femoral shaft fracture by measuring the time interval between accident and walking without a stick or return to work and reported that closed nailing was slightly better than open nailing. They also listed the advantages of closed nailing as less traumatic and more tolerable for the patient, as well as being an easier surgical procedure than open reduction, except in the cases with shortening or interposed tissue[8].

Another surgical approach involves opening the fracture site and applying cerclage wiring to fix the butterfly fragment (Figure 2). Wiring provided stable reduction of the fracture in anatomical position, which might result in less rotational malunion and less shortening[9–12]. Burç *et al.* even listed their reasons for preferring open nailing as follows: no requirement for fracture table, less requirement of fluoroscopy, anatomic reduction can be accomplished more easily, ability to maintain rotational stability, and comminuted or segmental fracture can be managed more easily[13]. Therefore, according to the literature, whether or not to fix the third fragment of the femoral shaft fracture remains a controversial issue[6,7,9,10].

However, no studies to date have compared the outcomes of these two different methods of fracture management. Whether fixation of the third fragment influences the result of fracture healing is unclear. For the present study, we conducted a retrospective analysis of 80 patients presenting femoral shaft fracture with wedge fragment (AO/OTA 32B2). The aims of this study are: (1) to compare the clinical outcomes of two techniques managing wedge fragment of femoral shaft fracture with or without fixation of the third fragment by comparing the union time and union rate; (2) to perform subgroup analysis to identify the risk factors of non-union for patients for both techniques.

Materials and Methods

Patients

This study was a retrospective study conducted at a regional level I trauma center, Taichung Veterans General Hospital from January 2011 to December 2016 using the institutional orthopaedics trauma database.

After Institutional Review Board approval (approval no. CE17332A) was obtained, the medical records and radiographs of patients with closed wedge-shaped femoral shaft fracture treated during the study period were reviewed. Inclusion criteria were: (1) 18–80 years old; (2) a consecutive series of adult patients with acute closed wedge-shaped femoral shaft fracture (AO/OTA type 32-B) treated with the same surgical procedure of antegrade intramedullary nail with the canal reamed; (3) patients received antegrade intramedullary nail with the canal reamed. All patients should complete out-patient clinic follow-up until fracture union or until second surgery because of non-union; and (4) the radiographic union of femur, the union time and rate, character of the fracture pattern, and wedge fragment of the patients should be recorded. Exclusion criteria were: (1) patients with multiple fractures, pathologic fracture, open fracture, or brain injury including simultaneous brain concussion, traumatic brain injury and hemorrhage; (2) subtrochanter fracture (5 cm lower than trochanter); and (3) distal femur fracture (distal to metaphyseal-diaphyseal junction).

Patients were divided into two groups according to whether or not butterfly fragment was fixated. The open reduction group underwent sufficient exposure of the fracture site for direct reduction of the fracture before insertion of the intramedullary nail, with reduction of the butterfly fragment preliminarily maintained by clamps or Kirschner wire followed by fixation by cerclage wiring. The closed reduction group underwent manual reduction of the fragment during insertion of the intramedullary nail. A total of 80 patients were included in the final analysis. Twenty patients received intramedullary nailing with open reduction, and 60 patients underwent intramedullary nailing in a closed manner.

Surgery Process

The surgery process was performed as the following steps. (1) All patients received spinal or general anesthesia and were put in a supine position on a fracture table. (2) The piriformis entry point is used for straight nails, while trochanteric entry for proximally curved nails. Antegrade reamed intramedullary nailing was employed. (3) The canal prepared by reaming to 1.5 mm greater in diameter than the anticipated nail diameter. In closed reduction group, fracture reduction was made by traditional closed means. In open reduction group, surgeon performed sufficient exposure of the fracture site for direct reduction of the fracture before insertion of the intramedullary nail, with reduction of the butterfly fragment preliminarily maintained by clamps or Kirschner wire followed by fixation by cerclage wiring. (4) Two proximal and two distal screws were set to maintain length and rotational stability.

Measurements

The primary outcomes were union time and union rate in the two groups. "Union" was defined as a modified Radiographic Union Scale for Tibia (mRUST) score > =13 within 24 months postoperatively[14,15]. Union time was defined as the period between surgery completion and the last outpatient clinic visit in which radiographic union was noted. Union rate was defined as the percentage of patients in a group achieving union of fracture during follow-up.

Union of fracture was defined as achieving bone continuity in more than or equal to three of four cortexes in the anterior–posterior and lateral views of plain radiographic images. In contrast, "non-union" was defined as an mRUST score < 13, or the need for any revision procedure, including nail exchange, plate augmentation, or bone grafting within 24 months postoperatively[14,15] or no evidence of radiographic union at the last follow-up.

mRUST score, derived from Radiographic Union Scale for Tibia (RUST) score, is to quantify healing and to define a value for radiographic union in a large series of metadiaphyseal fractures treated with plates or intramedullary nails. mRUST scored each cortex on the AP and lateral radiograph as 1 = no callus, 2 = callus present, 3 = bridging callus, and 4 = remodeled, fracture not visible. The modified RUST score is the sum of these and therefore has a value from 4 to 16.

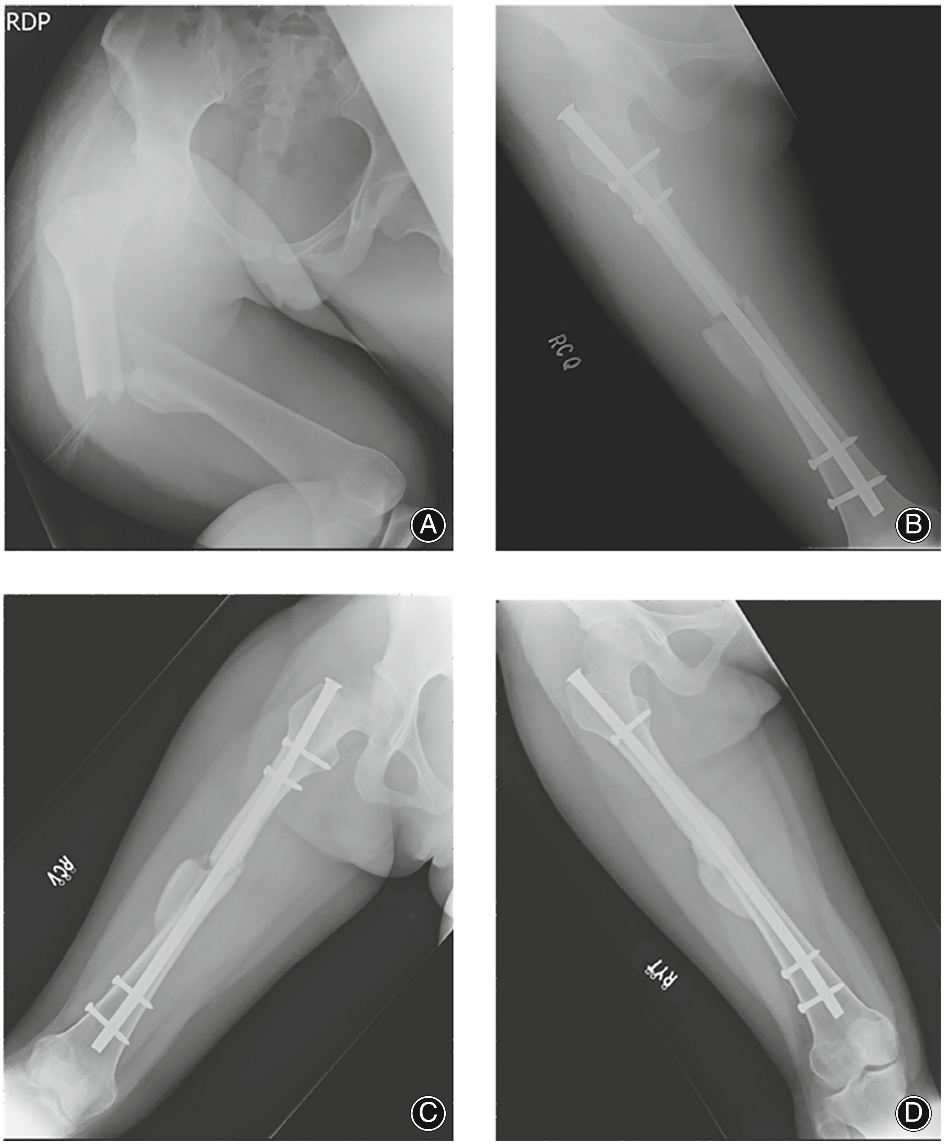

Fig. 1 Radiography of a 21-year-old girl who suffered from a right wedge-shaped femoral shaft fracture (AO/OTA 32-B2) and underwent closed intramedullary nailing with third fragment untouched. (A) Preoperative anteroposterior view. (B) Immediate postoperative anteroposterior view. The third fragment was displaced 18 mm. (C) 6 months postoperative anteroposterior view. Partial union between wedge fragment was noted. However, delayed union over proximal fracture site existed. Surgeon removed one proximal screw (dynamization). (D) 12 months postoperative anteroposterior view. Complete union of fracture was noted

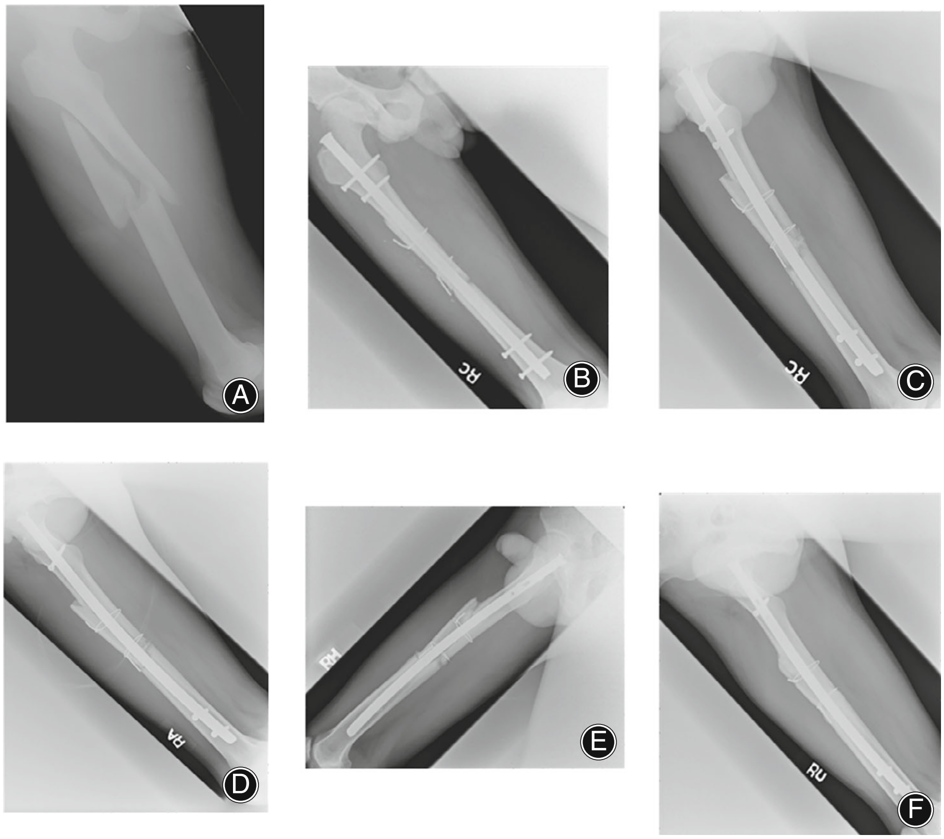

Fig. 2 Images of a 26-year-old man who suffered from a right wedge-shaped femoral shaft fracture (AO/OTA 32-B2) and underwent closed intramedullary nailing with third fragment fixed. (A) Preoperative view. (B, C) Immediate postoperative anteroposterior and lateral view. The third fragment was fixed with two sets of cerclage wires. (D) 3 months postoperative anteroposterior view. Delayed union over fracture site existed. Surgeon removed one proximal screw (dynamization). (E) 12 months postoperative anteroposterior view. Cortex continuity does still not show. (F) 21 months after initial operation. Complete union of fracture was noted

The minimum follow-up time in our hospital was at least 12 months. If 9 months of time elapsed with no healing progress for 3 months, we would perform dynamization first. If no callus was noted 3 months after dynamization, surgeons would do reoperation. We also compared the fracture patterns (32-B1, -B2, -B3), the fracture locations (proximal, middle, and distal of femoral shaft), and the third fragment size and ratio between the two groups.

The fragment size was determined by measuring the length of its long axis using the larger measurement shown on anteroposterior or lateral view of plain radiographic images. The fragment ratio was defined as the ratio of the width of the fragment to the diameter of the femoral shaft at the point nearest to the fracture surface.

Postoperative fragment displacement was determined by the formula: ½(Dpro+Ddis-2Ds) (Figure 3). Dpro refers to the distance from the proximal end of the fragment to intact cortex; Ddis represents the distance of the distal end of the fragment to intact cortex; and Ds indicates the diameter of the femoral shaft at the point nearest the fracture site[16].

Risk factors of non-union were also investigated, including sex, age, fracture pattern, fracture location, dynamization, nail size, fragment ratio, fragment size, and postoperative fragment displacement.

Statistical Analysis

Statistical analysis was performed using IBM SPSS 22.0. Baseline demographics and outcomes were compared using the Mann–Whitney U test for continuous variables (age, fragment size/ratio, nail size, and union time) along with the chi-squared test with Yate's correction or Fisher's exact test for categorical variables (sex, fracture side, and fracture pattern/site). A p value of <0.05 was considered significant. Survival analysis using the Kaplan–Meier method was performed to analyze the union rate of the two groups.

Results

Demographics and Fracture Characteristics

A total of 42 men and 38 women were enrolled (Table 1). There were 15 men and five women in the open reduction group, and 27 men and 33 women in the closed reduction group. The average age was 24.5 years with a range of 20–45 years. The average age in the open reduction group was 29.0 years, and in the closed reduction group the average age was 23.0 years. There were no significant differences in age, lesion side, fracture pattern, and fracture location between the two groups.

Fragment Characteristics and Union

Twenty patients with wedge-shaped shaft femoral fracture were managed with interlocking nail and fixation of the third

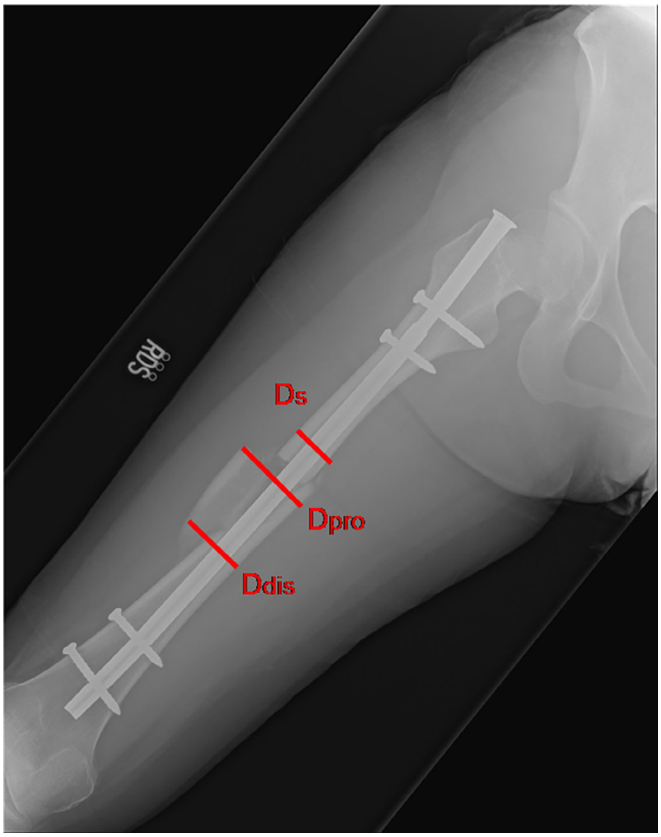

Fig. 3 Postoperative fragment displacement = ½(Dpro+Ddis-2Ds). Dpro refers to the distance from the proximal end of the fragment to intact cortex; Ddis represents the distance of the distal end of the fragment to intact cortex; and Ds indicates the diameter of the femoral shaft at the point nearest the fracture site

fragment (open reduction group). Sixty patients were treated with interlocking nail without fixation of the third fragment (closed reduction group) (Table 2).

The union rates in the open reduction group and closed reduction group were 60.0% (12/20) and 81.7% (49/60), respectively. There was no significant difference between the two groups ($p = 0.069$), but a relatively higher union rate was observed in the closed reduction group. The mean union time in the open reduction group was 19.0 months, compared with 14.0 months in the closed reduction group. There was a significantly longer union time in the open reduction group ($p = 0.024$), as well as larger fragment length and fragment ratio.

The fragment lengths in the open reduction group and closed reduction group were 8.5 cm and 5.2 cm, respectively ($p < 0.001$). The fragment ratios in the open reduction group and closed reduction group were 70% and 50%, respectively ($p = 0.001$). There were no significant differences in nail size and dynamization rate between the two groups (Table 2).

The union rate of the closed reduction group was higher than that of open reduction group at all of the time points. Union rates were 5.3% and 60.5% at the 12th and 24th month in the open reduction group, compared with 19.0% and 74.3% in the closed reduction group, respectively (Figure 4). There were significantly higher union rates in the closed reduction group at all time points ($p = 0.001$). All of the patients in the closed reduction group achieved union before 35 months, whereas only 84.5% of patients had achieved union after 60 months in the open reduction group.

Risk Factors of Non-Union

The features of all 80 patients and the results of the regression analysis regarding the effects of the risk factors for non-union are listed in Table 3. This univariate analysis revealed no significant association between non-union and any of the

TABLE 1 Demographics and fracture characteristics

	Open reduction group (n = 20)		Closed reduction group (n = 60)		*p* value	X^2 or *Z*
Sex					0.039	4.277
Female	5	(25.0%)	33	(55.0%)		
Male	15	(75.0%)	27	(45.0%)		
Age[c]	29.0[a]	(20.0–45.8)[b]	23.0[a]	(20.0–40.5)[b]	0.531	0.881
Lesion side					1.000	0.000
Left	9	(45.0%)	26	(43.3%)		
Right	11	(55.0%)	34	(56.7%)		
Fracture pattern					0.185	3.372
B1	4	(20.0%)	7	(11.7%)		
B2	12	(60.0%)	48	(80.0%)		
B3	4	(20.0%)	5	(8.3%)		
Fracture Location					0.640	0.892
Proximal	6	(30.0%)	13	(21.7%)		
Middle	11	(55.0%)	40	(66.7%)		
Distal	3	(15.0%)	7	(11.7%)		

Note: Chi-square test.; [a] Median.; [b] Interquartile range.; [c] Mann–Whitney U test.

TABLE 2 Fragment characteristics and union

	Open reduction group (n = 20)		Closed reduction group (n = 60)		p value	X^2 or Z
Fragment ratio[e]	0.7[a]	(0.6–0.9)[b]	0.5[a]	(0.3–0.6)[b]	0.001	3.474
Fragment length[e] (cm)	8.5[a]	(6.0–10.9)[b]	5.2[a]	(3.8–7.0)[b]	<0.001	3.918
Nail size[e]	12.0[a]	(10.3–13.0)[b]	11.0[a]	(10.0–12.0)[b]	0.067	1.832
Dynamization					0.795	0.067
Yes	10[c]	(50.0%)[d]	34[c]	(56.7%)[d]		
No	10[c]	(50.0%)[d]	26[c]	(43.3%)[d]		
Union rate[f]					0.069	—
No	8[c]	(40.0%)[d]	11[c]	(18.3%)[d]		
Yes	12[c]	(60.0%)[d]	49[c]	(81.7%)[d]		
Union time[e]	19.0[a]	(14.3–25.5)[b]	14.0[a]	(12.0–18.5)[b]	0.024	−2.312

Note: Chi-square test.; [a] Mean.; [b] 95% confidence interval (CI).; [c] Number of cases.; [d] Percentage.; [e] Mann–Whitney U test.; [f] Fisher's exact test.

other risk factors (sex, age, fracture pattern, fracture location, dynamization, and fracture ratio). The univariate analysis results showed that the open reduction technique ($p = 0.054$) and nail size ($p = 0.024$) might be the potential risk factors relating to fracture non-union.

To confirm the relationship of the two risk factors and fracture non-union, we analyzed using a multivariate regression model, which showed that the open reduction technique (OR 0.18, 95% confidence interval [CI] 0.05 to 0.68, $p = 0.011$) and nail size (OR 2.26, 95% CI 1.25 to 4.06, $p = 0.007$) were the independent risk factors for fracture non-union. It means open reduction technique had a negative effect for fracture healing, and the larger the nail size was, the better the fracture union was.

Because we found that open reduction manner would be harmful for bony union, we only analyzed the risk factors of non-union in the closed reduction group. The characteristics of the 60 patients in the closed reduction group and the results of the univariate analysis regarding the effects of the risk factors for non-union are listed in Table 4. This univariate analysis revealed no significant associations between non-union and any of the other risk factors (sex, age, fracture pattern, fracture location, dynamization, fracture ratio, and fragment displacement). Nail size (OR 2.53, $p = 0.032$) and fragment size (OR 0.73, $p = 0.017$) were the potential risk factors ($p < 0.05$) capable of predicting fracture non-union individually. These potential risk factors were also analyzed using a multivariate regression model, which showed that both nail size (OR 2.15, 95% CI 1.22 to 3.78, $p = 0.008$) and fragment size (OR 0.80, 95% CI 0.67 to 0.97, $p = 0.020$) were the independent risk factors for fracture non-union.

	Union rate (%)				p value
	9m	12m	18m	24m	
Open	0.0%	5.3%	28.9%	60.5%	0.001
Closed	15.4%	19.0%	69.4%	74.3%	

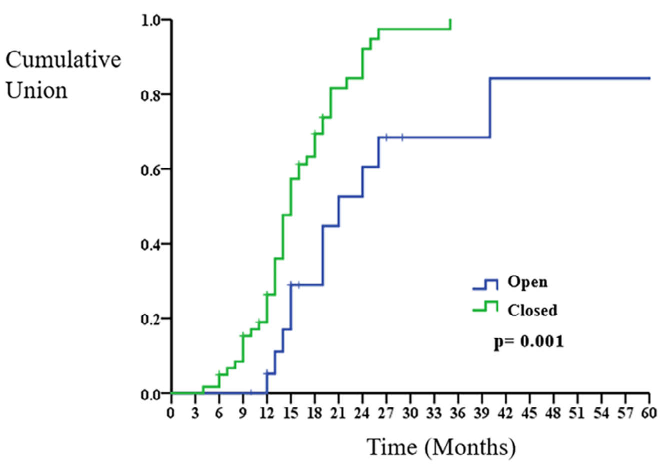

Fig. 4 Cumulative union rate. Kaplan–Meier survival analysis for the union rate of the two groups. The union rate of the closed reduction group was higher than that of open reduction group at all of the time points ($p = 0.001$). Union rates were 5.3% and 60.5% at the 12th and 24th months in the open reduction group, compared with 19.0% and 74.3% in the closed reduction group, respectively

Fragment Size and Union

Because larger fragment size appeared to be a factor affecting fracture union in the closed reduction group, we used receiver operating characteristic curve (ROC curve) analysis to determine the cutoff for fragment size as 5.4 cm (Table 5 and Figure 5). In the closed reduction group, the non-union rate was 5.6% (2/36) in patients with a fragment size ≤5.4 cm, compared with 37.5% (9/24) in patients with a fragment size >5.4 cm. The non-union rate was significantly higher in patients with a fragment size >5.4 cm ($p = 0.004$).

Complication

Complications were collected using information documented in the medical records. In this study, there was no direct intraoperative or postoperative complication, including femoral nerve injury, pudendal nerve injury, iatrogenic fracture, rotational malalignment, and infection.

TABLE 3 Risk factors of non-union (n = 80)

	Univariate			Multivariable		
	Odds ratio	95% CI	*p* value	Odds ratio	95% CI	*p* value
Sex						
Female	Reference	Reference				
Male	2.31	(0.80–6.67)	0.123			
Age	0.98	(0.95–1.01)	0.185			
Fracture pattern						
B1	Reference	Reference				
B2	0.30	(0.04–2.54)	0.270			
B3	0.20	(0.02–2.39)	0.203			
Fracture Location						
Proximal	Reference	Reference				
Middle	0.78	(0.22–2.78)	0.701			
Distal	1.07	(0.16–7.15)	0.947			
Dynamization						
No	Reference	Reference				
Yes	0.67	(0.24–1.88)	0.445			
Group						
Non-Open	Reference	Reference				
Open	0.34	(0.11–1.02)	0.054	0.18	(0.05–0.68)	0.011
Nail size	1.85	(1.08–3.15)	0.024	2.26	(1.25–4.06)	0.007
Fragment ratio	0.27	(0.02–3.12)	0.296			
Fragment size	0.87	(0.74–1.02)	0.080			

Note: 95% CI, 95% confidence interval.

Discussion

This is the first study comparing the clinical outcomes of two techniques managing wedge fragment of femoral shaft fracture. Furthermore, subgroup analysis to identify the risk factors of non-union for patients encountering wedge-shaped femoral shaft fracture will help surgeons with delicate management. In our study, fixation of the third fragment in wedge-shaped femoral shaft fracture (AO/OTA type 32-B) resulted in a longer union time and lower union rate (Table 2). Closed reduction without opening the fracture site

TABLE 4 Risk factors of non-union in Group 2 (closed reduction, n = 60)

	Univariate			Multivariable		
	Odds ratio	95% CI	*p* value	Odds ratio	95% CI	*p* value
Sex						
Female	Reference	Reference				
Male	2.56	(0.61–10.81)	0.201			
Age	0.98	(0.94–1.02)	0.259			
Fracture pattern						
B1	Reference	Reference				
B2	0.83	(0.09–7.90)	0.874			
B3	0.25	(0.02–4.00)	0.327			
Fracture Location						
Proximal	Reference	Reference				
Middle	0.29	(0.03–2.52)	0.260			
Distal	0.50	(0.03–9.46)	0.644			
Dynamization						
No	Reference	Reference				
Yes	0.57	(0.15–2.14)	0.410			
Nail size	2.53	(1.08–5.89)	0.032	2.15	(1.22–3.78)	0.008
Fragment ratio	0.28	(0.01–7.40)	0.449			
Fragment size	0.73	(0.56–0.94)	0.017	0.80	(0.67–0.97)	0.020
Fragment displacement	0.71	(0.40–1.28)	0.257			

Note: 95% CI, 95% confidence interval.

TABLE 5 Fragment size and union evaluated only related to the patients treated with closed reduction

	≤5.4 cm (n = 36)		>5.4 cm (n = 24)		*p* value
	n	%	n	%	
Non-union	2	5.6	9	37.5	0.004
Union	34	94.4	15	62.5	

and using a larger nail facilitated fracture union. When dealing with a larger size or ratio of the third fragment, fixation tends to result in better fracture reduction.

However, minimizing disruption of vasculature and maintaining the structural integrity of surrounding biological tissue may further enhance the union of the fracture site. Closed nailing of the fracture with a third fragment >5.4 cm results in inferior union rates (Table 5). Therefore, our results indicate that the larger nail size, the better fracture union, and a larger fragment size was more harmful for fracture union.

Comparison of Two Techniques Managing Wedge Fragment of Femoral Shaft Fracture

Our main results were in line with previous studies. There are several theories that possibly explain the advantages of closed reduction without cerclage wiring. Perren reported managing or removing the fragments during open reduction results in a reduced likelihood of revascularization even under long-term protection[17]. Burç *et al.* reported that if the hematoma is broken in order to expose the fracture site, bone union time is prolonged, and the infection rate is elevated[13]. Apivatthakakul *et al.* reported that open reduction requires stripping of soft tissue and wiring fixation, both of which may cause blood supply strangulation and disruption of the vasculature at the fracture site[7].

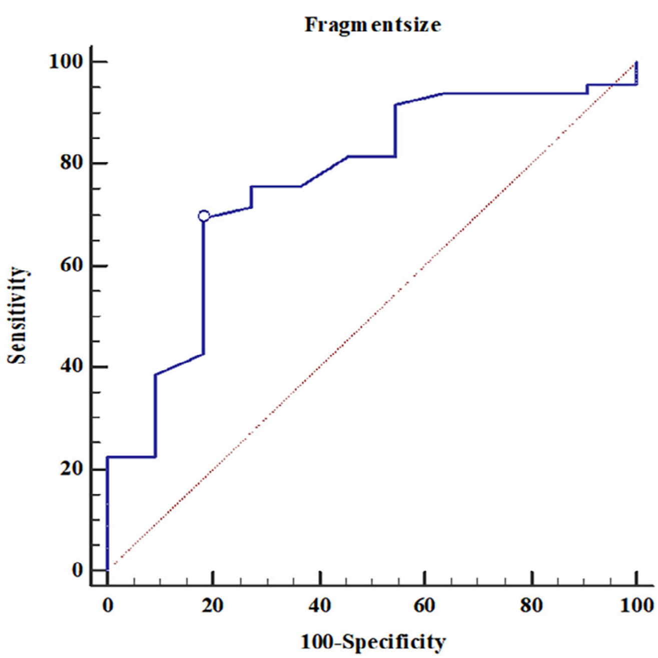

Fig. 5 The ROC curve analysis to determine the cutoff for fragment size. AUC = 0.763; sensitivity = 63.39%; specificity = 81.82%

However, there are conflicting opinions in the literature with some authors emphasizing the importance of anatomical reduction. Layon *et al.* found wedge fragments may successfully be treated without open reduction of the third fragment[6]. Leighton *et al.* reported similar satisfactory rates and complication rates between closed and open intramedullary nailing for femoral shaft fracture[18]. Harper *et al.* reported that while there were no significant differences in duration of hospitalization, union rate, union time, time to full weight-bearing, and postoperative complications between the closed and open methods, rotational malunion was found to occur more frequently in the closed nailing group[19]. However, these are very old studies, where the role of soft tissue in healing was not yet given more emphasis. The technical instruments and surgical techniques were different from today. Among the available studies on femoral shaft fracture, few investigations analyzed the data based on the AO fracture types. Because fracture types may range from simple fracture to multi-fragmentary fracture, comparisons between groups might not reveal any notable differences. In order to gain a thorough understanding of the effects of bone vascularity impairment or unreduced fragments on femoral shaft bone union and to reduce the sampling bias, we exclusively analyzed AO/OTA type 32-B fracture and determined the effects of fracture site, implant, and operation method. A comparison of the two groups (closed *vs* open method), which had similar demographic characteristics, fixation of the third fragment in wedge-shaped femoral shaft fracture was shown to result in a longer union time and lower union rate.

Subgroup Analysis to Identify the Risk Factors of Non-Union

Whether or not nail size affects union remains controversial. In a large retrospective analysis, Ma *et al.* reported that non-union was related to the use of an unreamed nail instead of a reamed nail[20]. However, in a more recent study, Serrano *et al.* obtained similar union rates regardless of nail diameter or the difference between femoral canal diameter and nail diameter after reaming[21]. In our study, smaller nail size was a risk factor for non-union in all patients and in the closed reduction group. We reasoned that larger nail size would offer more stability during healing of femoral shaft fracture.

Non-union develops significantly more frequently in femoral shaft fractures with a large third fragment and greater displacement during the closed intramedullary nailing procedure. Lee *et al.* reported higher rates of non-union in fragments larger or equal to 8 cm in length. Fragmentary displacement of the proximal end by 20 mm or more or of the distal end by 10 mm or more was also correlated with non-union[22]. In AO/OTA 32-B and C femoral shaft fracture with a fragmentary displacement of the fragment middle point of 10 mm or less, the union rate was 75.9%, which was significantly larger than the 21.1% displacement of more than 10 mm[16]. We also compared the union rates according to the fragment sizes in the closed reduction group. The non-union rate of fragments >5.4 cm was significantly higher than that of fragments ≤5.4 cm (Table 5). We proposed two hypotheses to explain the relationship between fragment size and nonunion—blood supply impairment and fragment instability. Deep femoral artery supplies the femoral diaphysis with its multiple perforating branches encircling the femur. A larger bony fragment may come with a higher risk of damaging the blood supply at the moment when the fracture occurs. Second, a fracture with a larger fragment is prone to instability and inadequate bony contact following closed reduction and intramedullary nailing, resulting in nonunion. Other studies suggested open reduction strengthen stability for severely comminuted fractures[13,19]. Larger fragment represents larger fracture gap which will hinder the bony union ability[23]. Luts *et al.* emphasized reduction of the bone fragments to achieve small fracture gaps to ensure proper fracture healing[24].

We all know the importance of closed reduction method in managing wedge fracture of femoral shaft. However, during routine practice, surgeons tend to open the fracture site and fixate the third fragment, especially a large one. According to our study, the outcome of closed reduction and intramedullary nailing was confirmed to be better than that of open reduction when the wedge fragment size is smaller than 5.4 cm. A displaced fragment with its size larger than 5.4 cm may hinder the bony union. In our experience, when facing a larger fragment, we will open the fracture site gently and manage to perform anatomic reduction of the third fragment, as well as applying iliac bone marrow aspirate with or without allograft to the fracture site in order to enhance the capability of fracture healing.

Limitations

This is a level III retrospective cohort study. However, this study had several limitations. First, apart from its retrospective nature and the relatively small case number for the open reduction group, the main limitation of this study was that the fragment size and gap in the open reduction group were greater than those in the closed reduction group. However, this phenomenon was commonly seen in previous investigations with a similar study design. Second, we strictly controlled our demographic characteristics by AO/OTA type and operation methods. We were not able to comprehensively establish an appropriate method for femoral shaft fracture with a third fragment size larger than 5.4 cm. Further well-designed prospective studies are needed. Third, according to our charts, not all patients received regular follow-up in outpatient clinic till bony unions were noted. We did not record all patients' follow-up time, because some patients with fracture unions still received outpatient clinic management due to other musculoskeletal problems. Forth, clinical improvement and functional evaluation were also not available because of incomplete charts records.

Conclusions

Open reduction and internal fixation for the butterfly fragment in wedge-shaped femoral shaft fracture (AO/OTA type 32-B) were revealed to result in a longer union time and lower union rate. For femoral shaft fracture with butterfly fragment, we suggest managing it with intramedullary nailing with closed reduction, as well as larger nail size. A displaced fragment with its size larger than 5.4 cm may hinder the bony union.

Authorship Contribution

YHT and CHC designed the study. All authors collected and analyzed the clinical data. YHT drafted the manuscript. CHC edited the manuscript. All authors read and approved the final manuscript.

Conflicts of Interest

The authors declare that they have no conflict of interest.

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None.

Authorship Declaration

All authors listed meet the authorship criteria according to the latest guidelines of the International Committee of Medical Journal Editors, and all authors are in agreement with the manuscript.

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Ethical Standard Statement

This study has been approved by the Institutional Review Board of Taichung Veterans General Hospital, and the informed consent requirement was waived.

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