ORIGINAL RESEARCH

Augmentative Plating in the Treatment of Femoral Nonunion after Intramedullary Nail Fixation

Hanxiao Zhu, MD; Hang Li, MD; Xiangfeng Zhang, MD; Deting Xue, MD

ABSTRACT

Objective • Failure of bone healing after intramedullary nailing (IMN) of a femoral diaphyseal fracture is an uncommon condition, which can cause obvious pain symptoms and seriously affect the daily life of patients. Ununion of femoral fracture requires treatment to promote successful bone union. Augmentative plating (AP) has yielded good results in treating femoral nonunion after IMN. However, there are few large cohort studies and no technical standard for this treatment. To determine (1) the proportion of individuals with femoral nonunion after IMN who achieved radiographic signs of osseous union following the additional treatment of AP and autogenous bone grafting and (2) the factors associated with the failure of this treatment.

Methods • Nonunion after IMN fixation is defined as an unhealed fracture with no radiographic signs of osseous union at least six months after IMN treatment. Osseous union as bridging bone on three of four cortices with the absence of a radiolucent line. Between January 2011 and January 2022, 83 individuals diagnosed with femoral nonunion after IMN fixation underwent AP and an autogenous bone graft.

Results • Seventy-six of the 83 nonunion individuals attained osseous union by 12 months. Six of 36 (16.7%) subjects with mono-cortical plates had non-union. Conversely, one of 47 subjects (2%) with bi-cortical plates had non-union. There were 18 individuals whose AP had ≤6 cortices. Five of these 18 (38.5%) individuals had non-union. Two of 65 with an AP of >6 cortices had non-union. AP with ≤ 6 cortices was a major risk factor for the likelihood of unsuccessful procedures compared to AP with > 6 cortices. Three individuals experienced incision infection at the bone graft harvest site and were treated with local wound care.

Conclusions • A high proportion of individuals with femoral nonunion after IMN fixation were salvaged by AP and an autogenous bone graft. Bi-cortical plate and screw intersection of more than six cortices may increase the treatment effectiveness.

Limitations • There were limitations of this study. First, it was a retrospective study over a 10-year period, and the patients were treated by different orthopedic surgeons. Second, lack of functional evaluation is another limitation of the present work.

Generalizability • The technique of bi-cortical plate and screw intersection of more than six cortices is not difficult for experienced orthopedic surgeons, and no special surgical tools is required.

Closing Statement • Many literature has confirmed the good effect of APP technology in treating femoral nonunion after intramedullary nail fixation, but there are still cases of failure. Our study may enable this technology to achieve better therapeutic effects. (*Altern Ther Health Med.* 2023;29(8):750-753).

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INTRODUCTION

The femur is the strongest long bone in the human body. Locked intramedullary nailing (IMN) is a standard treatment for adult femoral fracture. Aseptic bony nonunion is an uncommon but serious complication which can cause obvious pain symptoms and seriously affect the daily life of patients. The frequency of femoral nonunion after IMN is about 1.1% to 14%.[1,2] With a common denominator, the maintenance of the initially implanted intramedullary nail, proposed techniques include the use of electrostimulation or pulsed low-intensity ultrasound, dynamization of the nail, use of external fixation over the existing nail, infusion of biological stimulus in the non-union site, and augmentation plating.[3] Among these treatments, exchanging reamed nailing (ERN) and augmentative plating (AP) are commonly employed approaches with excellent outcomes.[1,4-6] A meta-analysis including 5 RCT demonstrates that both AP and EN methods have achieved good results in the treatment of nonunion of femoral shaft fractures after IMN.[4]

IMN fixation is the gold the gold standard for treating femoral fresh shaft fractures. However, IMN may develop rotational instability.[7] In contrast, Augmentative antirotational plating provided a significantly higher union rate than exchanging reamed nailing in treatment for femoral shaft aseptic atrophic nonunion, which indicated AP is more rotationally stable.[1] Also, autogenous bone grafting can be used with AP to improve bone healing. AP has a higher union rate than ERN.[1,4,8] Nonetheless, large patient series of AP with IMN for femoral nonunion are uncommon and standard protocols are wanting.

Base on previous literature, We hypothesize that AP and autogenous bone grafting will lead to good outcomes in femoral nonunion cases with in situ IMN, but there are still cases of failure. Therefore, this study was undertaken to assess (1) outcomes in individuals who underwent AP and autogenous bone grafting for femoral nonunion with *in situ* IMN and to determine (2) possible factors associated with non-union.

PATIENTS AND METHODS

Study Design and Setting

Between January 2011 and January 2022, 83 individuals with femoral nonunion after IMN were managed with Ap and bone graft. All subjects met the criteria of nonunion, which were (1) persistent pain at the fracture site at least 6 months after the last surgery; (2) a fracture without complete healing at 6 months on radiographic examination; or (3) a lack of progressive healing for three consecutive months.[9] Nonunion was confirmed by plain radiographs, computed tomography (CT), or by a combination of both.[10] Individuals having nonunion with infection and malalignment, or if the initial fracture was open, were excluded. The individuals with nonunion due to infection, malalignment, or open fractures were exculded.

ZXF was a statistician in this study who did not participate in the treatment. Medical records and radiographic studies were reviewed, and the following data were abstracted: age, sex, soft tissues at the time of original injury (closed versus open), dates of injury and initial IMN fixation, other prior nonunion treatment, date of presentation for nonunion treatment, nonunion type (atrophic, hypertrophic, infected), dates and descriptions of all surgeries, type of plate (mono-cortical or bi-cortical), number of cortices inserted by the screws, postoperative complications, and final outcome of fracture healing. Time to union could not be calculated precisely because of inconsistent follow-up intervals.

All study participants were at least 18 years old. There were 59 men and 24 women. The characteristics of cases were showed in Table 1.The mean age of the cohort was 45 years (range 18–72 years, standard deviation [SD] 16). Furthermore, 71% (59 of 83) of subjects were men, 29% (24 of 83) were female, 16% (13 of 83) were smokers, and 5% (4 of 83) had type 2 diabetes. All individuals reported pain and less mobility at the time of presentation. AP and bone grafting were performed an average of 18 (SD, 19 months, range 6–120) months after the primary fixation. The mean follow-up time was 21 (SD, 11 months, range 12–48) months.

Description of Treatment of Surgical Technique

At surgery, the nonunion site was exposed through a lateral approach. Rotational instability of the nonunion site was verified by a direct view of rotational movement between the two fracture ends. The location of the plate fixation was chosen according to the previous implant and anatomic factors. A locking compression plate (LCP) was selected for nailed femurs that did not require excessive bone or soft tissue devascularization. Bone grafts were obtained from the iliac crest. A plate was used to bridge the nonunion site. Nonlocked or locking screws were placed mono- or bi-cortically, depending on the indwelling nail or plate position. For the purpose of this analysis, if all screws were mono-cortical, the plate was defined as a mono-cortical plate. The plate was defined as a bi-cortical plate if there was at least one bi-cortical screw. The number of bone cortices inserted by screws was calculated as the cortex number of the AP. One mono-cortical screw represents 1 cortex, and one bi-cortical screw represents 2 cortices.

Postoperative Protocol

All individuals received antibiotics postoperatively for 24 hours. After surgery, individuals were instructed to perform lower extremity functional exercises and use crutches to avoid bearing weight on the affected leg. Full weight bearing ambulation was encouraged based on clinical and radiographic evidence of healing. Clinical and radiographic assessments were conducted at 1, 2, 3, 6, 9, and 12 months. Evidence of bony callus on radiographs and painless walking reported, bone union was considered complete. Hypertrophic nonunion referred to a fracture line persisting beyond the expected time for union, with callus in variable amounts about the fracture site on radiographic examination. On the contrary, atrophic nonunion referred to a fracture line persisting beyond the expected time for union, with no demonstrable callus on radiographic examination.[1]

The primary study endpoint was the osseous union rate. Osseous union was defined as continuous trabecular and complete cortical bridging in the fusion interface. Nonunion was defined as fusion not achieved within 12 months. Complications and reoperations were quantified through record review by an individual not involved in the care of the study subjects. The secondary study endpoints were factors associated with failure of the treatment.

Ethical Approval

This study was reviewed and approved by the Institutional Review Board of Zhejiang University (IRB protocol 2023-0099).

Statistical Analysis

The Statistical Package for the Social Sciences version 23.0 (SPSS version 23.0, IBM Corp, Armonk, NY, USA) was used for statistical analyses. Univariate analysis is used to assess differences in individual and surgical characteristics between failure and non-failure events. The multivariate Cox regression model was applied to identify independent

predictors of failure. Continuous variables are presented as the mean ± SD or as the median and range. $P < .05$ was taken as statistically significant.

RESULTS

AP treatment was successful in 76 (91.6%) of the 83 subjects. At the most recent follow-up, 76 individuals had radiographic signs of osseous union and tolerated partial or full body weight on the extremity. Treatment failure occurred in 7 (8.4%) cases. Three of the individuals achieved bony union with additional interventions, two declined further surgery, and two were lost to follow-up.

The operation time averaged 97 min (SD 9 min, range 80–120 min), the mean blood loss was 146 ml (SD 89 ml, range 30–400 ml), and there were no complications during the procedures. The mean follow-up period was 21 months (SD 11 months, range 12–48 months). There were no deep infections or implant failures. Three patients experienced infection at the bone graft harvest skin incision and were treated with local dressing changes. Plate loosening was noted in one subject one month after treatment (Figure 1). The individual was advised to avoid bearing weight on the limb. By postoperative month four, continuous callus along with painless ambulation were noted.

Seven of 59 (11.9%) males had non-union. All 24 female subjects achieved bony union. Six non-union individuals reported no tobacco use, while one none-union reported tobacco use. There were four individuals with diabetes in the cohort and all achieved bony union. Seven of 79 (8.9%) non-diabetic individuals had non-union. One of 18 (5.6%) individuals who had dynamization of IMN had non-union. Six of 65 (9.2%) non-dynamized individuals suffered non-union. Six of 61 (9.83%) individuals with isthmus nonunion at presentation did not achieve union. One of 16 (6.25%) individuals with non-isthmus nonunion at presentation did not achieve union. Six of 36 (16.7%) subjects with mono-cortical plates had non-union. Conversely, one of 47 subjects (2%) with bi-cortical plates had non-union. Four of 57 (7%) individuals with hypertrophic non-union did not achieve. Three of 26 (11.5%) individuals with atrophic non-union did not achieve union. There were 18 individuals whose AP had ≤6 cortices. Five of these 18 (38.5%) individuals had non-union. Two of 65 (3%) with an AP of >6 cortices had non-union.

Univariate analysis suggested that mono-cortex plates with ≤ 6 cortices were associated with failure outcomes ($P = .018$ and $P = .001$) (Table 1). However, logistic regression analysis (Table 2) eliminated the mono-cortex plate as an independent predictor for outcome. The univariate and logistic regression analyses identified ≤6 cortices as the only independent predictor of failure. The remaining factors did not predict success or failure (Table 1).

DISCUSSION

Herein, we found that AP with autogenous bone grafting was useful in achieving healing in individuals with nonunion of the femoral shaft fracture after IMN. AP with bone grafting was employed as anti-rotational fixation at the femoral nonunion site was encountered. The results of this study are consistent with previous reports.[1,3,5,11-14]

Femoral non-union after IMN has been addressed using AP with or without autogenous bone graft. All subjects (17) achieved union after treatment with augmentative internal fixation[6]. AP obtained bony union in five individuals with femoral non-union in the face of a broken in situ interlocking nail.[14] Comparison of AP to ERN, rated AP better in terms of the nonunion healing, operating time, and time to routine activity.[5,11,15] A meta-analysis found that AP provides a shorter operative time and less blood loss during the surgery, and a higher union rate, a shorter union time, and a lower complication rate during the postoperative period.[1]

In the present cohort, a 91.6% rate of bony union was obtained. Adding AP to IMN *in situ* provided a reliable means to obtain bony union. Still, seven individuals failed to achieve bony union. Analysis of variance (Table 1) revealed that individuals with an AP of ≤ 6 cortices had a greater risk of non-union than individuals with an AP of > 6 cortices

Figure 1. (A, B) Lateral lower extremity radiographs from a 65-year-old male with femoral nonunion. (C) One month after AP and bone graft the subject was found to have plate loosening. (D, E) Four months after AP treatment boney union was noted.

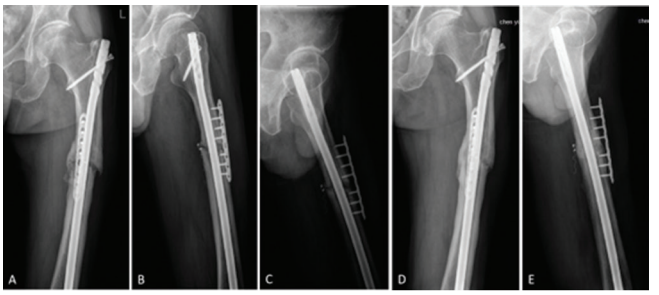


Table 1. Univariate analysis of subject and characteristics according to outcome

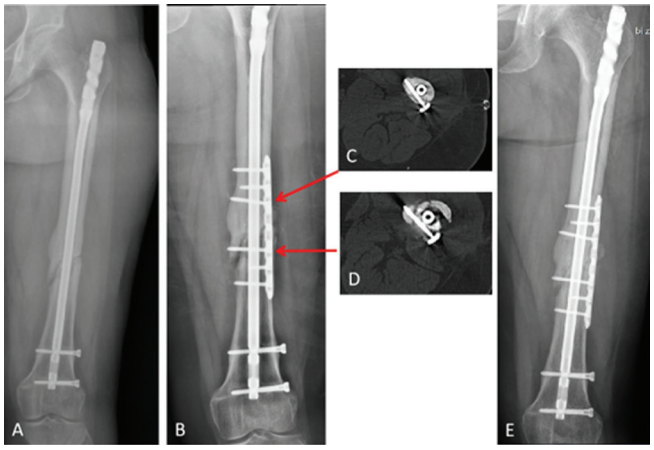
Variable		Failure 7 (8.6%)	Success 76 (91.6%)	χ^2	*P* value
Gender	Male	7	52		
	Female	0	24	3.110	.078
Smoking	Yes	1	12		
	No	6	64	0.011	.917
Diabetes	Yes	0	4		
	No	7	72	0.387	.534
Dynamization	Yes	1	17		
	No	6	59	0.247	.620
Isthmic	Yes	6	61		
	No	1	15	0.122	.726
Hypertrophic	Yes	4	53		
	No	3	23	0.473	.492
Mono-cortical	Yes	6	30		
	No	1	46	5.580	.018
Number of cortices ≤ 6	Yes	5	13		
	No	2	63	11.137	.001

Table 2. Results of logistic regression analyses

Variable	β	Wald	95% CI	*P* value
Mono-cortical	-1.314	1.135	0.024-3.014	.287
Number of cortices ≤ 6	-2.027	4.125	0.019-0.932	.042[a]

[a]Statistically significant

Figure 2. (A) Radiographs from a 53-year-old female with a femoral nonunion who underwent AP and bone graft. (B, C, and D) The AP had four bi-cortical screws. (E) Radiographs three months after AP treatment show solid bony union.



(univariate P = .001). This was confirmed by multivariate analysis (P = .042) (Table 2).

By univariate analysis, it also appeared that a mono-cortical plate was associated with failure (P = .018). Under torsional loads, a bi-cortical screw (locked or unlocked screw) will exhibit greater stiffness.[16] This may explain why mono-cortical plates were associated with a greater risk for non-union. However, in multivariate analysis, a mono-cortical plate did not show a major association with failure (P = .287). Mono-cortical plate loosening occurred in a single individual at the follow-up after one month (Figure 1). It is interesting to speculate if the use of bi-cortical screws would have led to bony union in this individual. Regarding isthmic nonunion, use of bi-cortical screws may not be possible. Under this condition, a longer plate and more mono-cortical screws may promote stiffness and bony union in such situations. Indeed, for mono-cortical screws, longer length was associated with improved working length,[17] which may explain why in multivariate analysis, a mono-cortical plate did not show a major association with failure. CT scan was helpful to determinein nail position and bony anatomy (Figure 2) and informed choice of screws. Other factors, including gender, smoking, anatomic site of the fracture, type of fixation, diabetes, and nonunion, did not appear to be associated with the outcome.

There are several limitations in this study. First, the study was retrospective and covered over a decade. Thus, selection bias might have existed. As well, several surgeons provided care thus possibly introducing variation in technique. And, 76 subject were given bone morphogenic protein (BMP) along with bone graft, which is not a standard part of AP treatment. However, there was no placebo control for BMP. Lack of functional evaluation is another limitation of the present work. Finally, systematic postoperative follow-up was not realized, which limited data acquisition. We look forward to future research and analysis considering the potential benefits of bi-cortical screw fixation and further exploring the presented approach.

In summary, in a large group of individuals with femoral nonunion and *in situ* IMN, AP with bone graft achieved bony union. Bi-cortical screw fixation and > six cortices appeared to increase the bony union rate, which may enable this technology to achieve better therapeutic effects. This approach prospectively warrants further analysis.

CONFLICT OF INTEREST

The authors have no potential conflicts of interest to report relevant to this article.

AUTHOR CONTRIBUTIONS

HZ and HL designed the study and performed the experiments, HZ and XZ collected the data, HL and XZ analyzed the data, HZ and HL prepared the manuscript. All authors read and approved the final manuscript. HZ and HL contributed equally to this work

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