ORIGINAL ARTICLE

Acta Orthop Traumatol Turc 2015;49(6):668–675
doi: 10.3944/AOTT.2015.14.0404

Exchanging reamed nailing versus augmentative compression plating with autogenous bone grafting for aseptic femoral shaft nonunion: a retrospective cohort study

Jiang-Ying RU[1*], Yun-Fei NIU[2*], Yu CONG[1], Wen-Bo KANG[1], Hai-Bin CANG[3], Jian-Ning ZHAO[1]

[1]*Nanjing University Faculty of Medicine, Jinling Hospital, Department of Orthopaedics, Nanjing, China*
[2]*Changhai Hospital Affiliated to Second Military Medical University, Department of Orthopedics, Shanghai, China;*
[3]*Jiangsu Provincial Corps Hospital of the Chinese People's Armed Police Force, Department of Orthopaedics, Yangzhou, China*

Objective: The purpose of this study was to compare the outcomes of exchanging reamed nailing (ERN) and augmentative compression plating (ACP) with autogenous bone grafting (BG) for the treatment of aseptic femoral shaft nonunion secondary to the treatment of intramedullary nailing (IMN).

Methods: A multicenter retrospective study was performed for 178 patients (180 cases) of aseptic femoral shaft nonunion secondary to first treatment of IMN. All cases were fixed with either ERN (n=87) or ACP (n=93). In the ERN group, 42 cases (48.3%) were nonisthmal nonunions and 45 (51.7%) were isthmal nonunions. In the ACP group, 46 cases (49.5%) were nonisthmal nonunions, and 47 (50.5%) were isthmal nonunions. Operation time, blood loss, time to union, union rate, volume of drainage, time to renonunion, and complication rate were compared between the 2 groups.

Results: All patients were followed up, with a mean period of 4.1 years (range: 1–7.1 years). Bone union occurred in 93/93 cases (100%) in the ACP group versus 75/87 cases (86.2%) in the ERN group (odds ratio [OR]=3.28, 95% confidence interval [CI] 0.8–14). Of the 12 cases involved with renonunion in the ERN group, 10 were nonisthmal nonunions, and 2 were isthmal nonunions with cortical bone defect >3 cm. The union time, blood loss, and complication rate of the ERN group were significantly higher than those of the ACP group (p=0.028, p=0.035, and p=0.021, respectively). No significant difference was found in the average operation time of the 2 groups (p=0.151). However, for the non-isthmal nonunions, a significant difference was found between the ERN and ACP groups (p=0.018).

Conclusion: ACP with autogenous BG can obtain a higher bone union rate and shorter time to union than ERN in the treatment of aseptic femoral shaft nonunion after failed IMN. Especially for non-isthmal femoral shaft nonunions or isthmal nonunions with larger bone defects, ACP with autogenous BG can be more advantageous than ERN for patients. A future prospective observational study should be conducted.

Keywords: Femoral fracture; intramedullary nailing; nonunion; exchanging reamed nailing; augmentative compression plating; autogenous bone grafting.

Level of Evidence: Level III Therapeutic Study

**The first two authors contributed equally to this work.*

Correspondence: Jian-Ning Zhao, MD. Nanjing University Faculty of Medicine, Jinling Hospital, Department of Orthopaedics, Nanjing, People's Republic of China.

Tel: +86 – 25 – 80860191 e-mail: wangyanfen315@163.com

Submitted: July 11, 2014 **Accepted:** February 15, 2015

Available online at
www.aott.org.tr
doi: 10.3944/AOTT.2015.14.0404
QR (Quick Response) Code

Recently, a number of surgical strategies have been suggested for aseptic femoral shaft nonunion after failed intramedullary nailing (IMN), which include exchanging reamed nailing (ERN), augmentative compression plating (ACP), internal fixation after hardware removal, bone grafting (BG), and dynamization of static interlocking nails.[1–5] ERN tends to yield better outcome in the treatment of these nonunions, with a union rate of 72–100%.[1–7] Nevertheless, several studies have revealed that ERN could not achieve satisfactory clinical outcomes in the treatment of femoral nonunion after failed IMN for comminuted femoral shaft fractures, with or without obvious bone defects, and nonisthmal femoral fractures.[8–10] In contrast, ACP has increasingly shown more advantages, including less injury, shorter operation time, and no requirement of IMN removal. More importantly, a postoperative bone union rate of up to 100% can be achieved after ACP surgery.[11] Yet, it remains unclear whether ACP can bring more advantages than ERN to patients with femoral shaft nonunion after failed IMN, regardless of anatomical sites. The current study aimed to analyze and compare the clinical outcomes between ERN and ACP in treatment of femoral shaft nonunion subsequent to failed IMN.

Patients and methods

Between 2001 and 2012, 178 patients (180 cases) with femoral shaft nonunion after IMN received therapy with either ERN (n=87) or ACP with autogenous BG (n=93). Patients were identified through a computerized record database. Nonunion was defined as when there was a radiolucent line between the fracture ends that did not show signs of callus formation at least 6 months after treatment of IMN. It was characterized as persistent pain at the fracture site, which could be exacerbated by mobilization or weight-loading. X-ray films of all patients displayed sclerotic margins without continuous callus spanning the fracture site or no callus in at least 3 cortices.[12] According to the anatomic features of the isthmus and extraversion of the metaphysis, the femoral shaft was divided into isthmal and nonisthmal (supraisthmal and infraisthmal) sections.[10,11] ERN was selected for 42 cases of nonisthmal nonunion and 45 cases of isthmal nonunion, while ACP with autogenous BG was selected for 46 cases of nonisthmal nonunion and 47 cases of isthmal nonunion. The choice of ERN or ACP with autogenous BG depended on the patients' financial means and the difficulty of IMN removal. When patients' financial means were poor or IMN was hard to extract, ACP with autogenous BG was chosen. In the present study, patients aged between 19–60 years with aseptic nonunion were included. Patients with pathologic fracture, suspected latent infection, leg length discrepancy >1.5 cm, severe cardiovascular disease, or recent administration of corticosteroids and immunosuppressive drugs were excluded. This was a retrospective multicenter study, the sample size of which was calculated and approved by the institutional review boards at all included centers.

For ERN surgery, the IMN was removed from the original incision site by C-arm X-ray positioning and monitoring of nonunion areas. The sclerotic margins and fibrous tissue fillings in the fracture gap were removed. The diameter of the reamed medullary cavity was increased by 1–2 mm for the newly inserted IMN. Excessive proximal reaming was avoided for prevention of mechanical instability. The diameter of the replaced nails was 1–2 mm larger than the original ones in 87 cases (86 patients). Of these, 72 cases were replaced with antegrade femoral IMN (Synthes, West Chester, PA, USA) and 15 cases with retrograde ones (Synthes, West Chester, PA, USA). For patients with atrophic nonunions or cortical bone defect >1 cm (length in cm around the nail), autologous iliac grafting with cortical and cancellous bone was performed to fill in the fracture gap. The average weight of bone grafting in this group was 4.52±0.25 g (range: 0–11 g).

For the ACP group, subperiosteal dissection was performed to expose the lateral or one-third to one-half of the anterolateral fracture ends along the original incision. Periosteum or muscle dissection was minimized to avoid blood supply damage. In 93 cases (92 patients) of this group, 42 received 7–11-hole locking compression plates (Synthes, West Chester, PA, USA), and the other 51 received 6–10-hole dynamic compression plates (Synthes, West Chester, PA, USA). To prevent drill breakage, 3–3.5-mm Kirschner wires were used to enable the screws to pass through the cortical bones completely. A certain range of angle adjustment (5-15°) was allowed for the screws to avoid IMN baffle. Three to four locking screws or ordinary cortical screws were fixed on the distal and proximal ends of the plate. Autologous iliac grafting with an average of 8.66±0.35 g (range: 7–12 g) was applied to all patients in this group.

The drainage tube was left in place for 1–2 days postoperatively, according to the drainage volume. Hip and knee mobilization, with continuous passive motion (CPM) exercises, began 24 h postoperatively to avoid knee joint adhesion. Patients were encouraged to begin isometric and isotonic functional quadriceps training. Weight-bearing mobilization on crutches began 8 weeks postoperatively. Full weight-bearing began once continuous callus appeared in X-ray films.

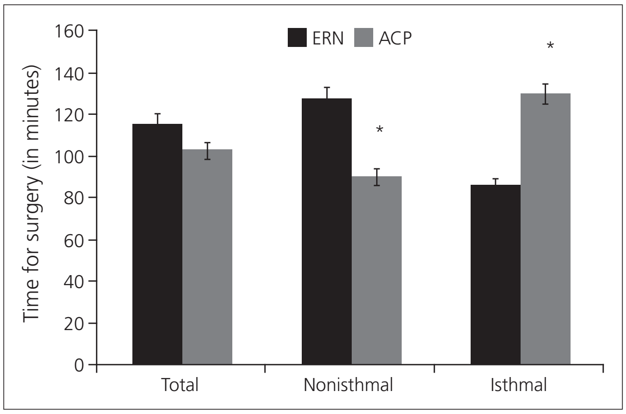

Fig. 1. There was no significant difference in time for surgery between the ERN and ACP groups. For nonisthmal nonunions, the mean surgical time of the ERN group was significantly longer than that of the ACP group. However, for isthmal nonunions, the mean surgical time of the ERN group was significantly shorter than that of the ACP group (*p<0.05).

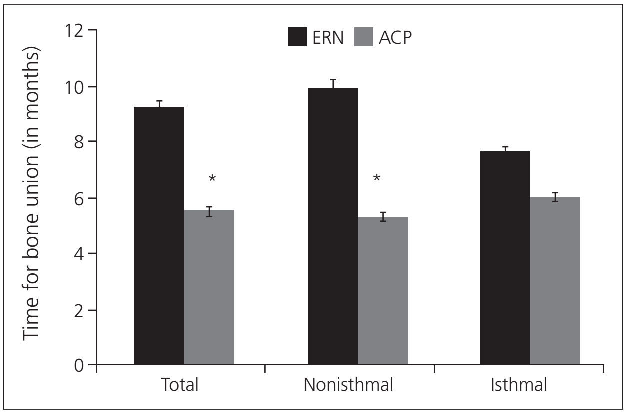

Fig. 2. The results showed that time to bone union in the ERN group was significantly longer than that of the ACP group. For nonisthmal nonunions, the mean time to bone union in the ERN group was significantly longer than that of the ACP group. However, for isthmal nonunions, there was no significant difference in the mean time to bone union between the ERN and ACP groups. (*p<0.05).

Collected data included demographics (age, gender, smoking, side, comminution grade, exposure and reaming of the first IMN surgery, interlocking mode of nail, previous number of operations, nonunion type, cortical bone defect, interval from injury), operation time, intraoperative blood loss, time to union, union rate, postoperative draining volume, time to renonunion, and related complications. Outpatient follow-ups were carried out at 1, 2, 3, 4, 6, and 12 months postoperatively and then once a year thereafter. Radiological examinations included femoral plain radiographs in 2 views (anteroposterior view and lateral) to monitor callus growth. Monthly follow-ups were performed for those without obvious progression of healing 4 months postoperatively. In data collection, the operation time referred to the duration from skin opening to wound closure. Intraoperative blood loss was calculated by hematocrit changes (theoretical value) with extra transfusion volume. The calculation was made according to the following formulae: total volume of blood loss=preoperative blood volume × (preoperative hematocrit – postoperative hematocrit); PBV=kl × height (cm) + k2 × weight (kg) + k3 (male kl=0.3669, k2=0.032l9, k3=0.6041; female kl=0.3561, k2=0.03308, k3=0.1833).[13] Postoperative drainage volume referred to the actual volume in the postoperative wound drainage bag combined with net weight increase of gauze pad. The data were extracted through review of patient charts and computerized records.

Data were analyzed with SPSS Version 18.0 statistical software (SPSS Inc., Chicago, IL, USA). Descriptive frequencies and percentages were tabulated. Pearson's chi-squared test or Fisher's exact chi-squared test was used, as appropriate, to detect differences in nonparametric variables. Unadjusted odds ratios (ORs) with 95% confidence intervals (CIs) are presented. Continuous variables were compared using t-test or the Mann–Whitney U test, as appropriate. All tests were two-tailed and $p \leq 0.05$ was considered statistically significant (80% power).

Results

In the ERN group, 42 cases (48.3%) were nonisthmal nonunions, and 45 cases (51.7%) were isthmal nonunions. In the ACP group, 46 cases (49.5%) were nonisthmal nonunions, and 47 cases (50.5%) were isthmal nonunions. No significant difference in demographics of patients was observed between the ERN and ACP groups (p>0.05) (Table 1).

After a mean follow-up of 4.1 years (range: 1–7.1 years), the bone union occurred in 93 cases of the ACP group versus 75 cases of the ERN group (OR=3.28, 95% CI 0.8–14) (Figure 1). Twelve cases with renonunion in the ERN group included 10 cases of nonisthmal nonunions and 2 of isthmal nonunion. Of the 12 cases, 2 nonisthmal nonunion patients declined subsequent procedures due to financial reasons and achieved final healing 3 and 5 months postoperatively with only cast immobilization. The other 10 cases achieved bone union after secondary autologous BG (Figure 2). The time to union, time to renonunion, and blood loss of the ERN group were significantly greater than that of the ACP group (p=0.028, p=0.023, and p=0.035, respectively). No significant difference was found in the average operation time and postoperative drainage volume between the 2 groups (p=0.151 and p=0.109, respectively) (Table 2).

Table 1. Demographic characteristics of cases.

	Nonisthmal (n=88)		Isthmal (n=92)	
	ERN (n1=42)	**ACP (n2=46)**	**ERN (n1=45)**	**ACP (n2=47)**
Age (years), mean±SD	46.5±11.2	48.2±8.4	48.9±8.2	47.9±10.2
Gender (% male)	52.4 (22/42)	58.7 (27/45)	57.8 (26/44)	53.2 (25/47)
Smoking, n (%)				
Yes	16 (38.1%)	20 (43.5%)	19 (42.2%)	19 (40.4%)
No	26 (61.9%)	26 (56.5%)	26 (57.8%)	28 (59.6%)
Side, n (%)				
Left	23 (54.8%)	26 (57.8%)	27 (61.4%)	24 (51.1%)
Right	19 (45.2%)	18 (40%)	16 (36.4%)	22 (46.8%)
Bilateral	0 (0)	1 (2.2%)	1 (2.2%)	0 (0)
Comminution grade, n (%)[a]				
0–I	15 (35.7%)	17 (37%)	18 (40%)	16 (34%)
II–III	19 (45.2%)	22 (47.8%)	21 (46.7%)	21 (44.7%)
IV	8 (19.1%)	7 (15.2%)	6 (13.3%)	10 (21.3%)
Exposure of the first IMN surgery, n (%)				
Open	25 (59.5%)	27 (58.7%)	28 (62.2%)	29 (61.7%)
Closed	17 (40.5%)	19 (41.3%)	17 (37.8%)	18 (38.3%)
Reaming of the first IMN surgery, n (%)				
Reamed	18 (42.9%)	20 (43.5%)	18 (40%)	19 (40.4%)
Non-reamed	24 (57.1%)	26 (56.5%)	27 (60%)	28 (59.6%)
Cortical bone defect, median (cm, range)	1 (0–2.5)	1.5 (0–4)	1.5 (0–4.5)	1 (0–3)
Interlocking mode of nail, n (%)				
Static	25 (59.5%)	29 (63%)	28 (62.2%)	27 (57.4%)
Dynamic	17 (40.5%)	17 (37%)	17 (37.8%)	20 (42.6%)
Previous number of operations, median (range)	2 (0–4)	1.5 (0–2)	1.5 (0–2)	2 (0–3)
Nonunion type, n (%)[b]				
Hypertrophic	19 (45.2%)	24 (52.2%)	24 (53.3%)	21 (44.7%)
Atrophic	23 (54.8%)	22 (47.8%)	21 (46.7%)	26 (55.3%)
Interval from injury, median (years, range)	1.5 (0–3.5)	1 (0–2)	1 (0–2)	1.5 (0–3)

ERN: Exchange reamed nailing; ACP: Augmentation compression plating; IMN: Intramedullary nailing; [a]Winquist-Hansen classification; [b]Weber-Cech classification.

For nonisthmal nonunion, there was no significant difference in drainage volume between the ERN and ACP groups (p=0.508). However, the mean operation time, blood loss, and time to union of the ERN group were significantly higher than those of the ACP group (p=0.018, p=0.028, and p=0.031, respectively). Bone union occurred in 46 cases (100%) in the ACP group versus 32 cases (76.2%) in the ERN group (OR=3.75, 95% CI 0.7–15) (Table 3).

In the isthmal nonunions, there were no significant differences in postoperative drainage volume, blood loss, time to union, and union rate between the ERN and ACP groups (p=0.250, p=0.130, p=0.775, and p=0.198, respectively). However, the mean operation time of the ERN group (85.6±10.6 min) was less than that of the ACP group (129.8±28 min) (p=0.023) (Table 4).

Two patients in the ACP group experienced delayed wound infection, which healed successfully after hardware removal. The complication rate of the ERN group was significantly higher than that of the ACP group (p=0.021). Likewise, in the nonisthmal nonunions, a significant difference was found in the complication rate between the 2 groups (p=0.019) (Tables 2, 3). No patients experienced failure of internal fixation, neurovascular injury, angular or rotational malunion, or other complications.

Discussion

ERN tends to yield better outcomes in the treatment of nonunion, with a union rate of 72–100%.[1–7] Court-Brown et al.[14] suggested that reaming could increase periosteal blood circulation to stimulate new bone generation. Bhandari et al.[15] found that IGF I/IGF II antibodies and indomethacin could reduce bone formation after reaming. Activated growth factors could play a critical role in reamed bone formation, due to weakened

Table 2. Comparison of outcomes between the ERN and ACP groups.

	ERN group (n=87)			ACP group (n=93)			p
	n	%	Mean±SD	n	%	Mean±SD	
Mean operation time, min[a]			115.3±22.1			102.4±14.2	0.151
Mean intraoperative blood loss, ml[a]			598.7±101.4			349.3±89.7	0.035*
Mean postoperative draining volume, ml[a]			180.3±53			171.8±48	0.109
Mean time to union, months[a]			9.2±2.1			5.5±0.8	0.028*
Union rate[b]	75	86.2		93	100		0.037*
Mean time to renonunion, months[a]			7.2±1.8			0	0.023*
Complication rate postoperatively[c]							
Infection	0	0		2	2.2		0.021*
Renonunion	12	13.8		0	0		

ERN: Exchanging reamed nailing; ACP: Augmentative compression plating; [a]Mann-Whitney U-test; [b]Pearson's chi-square test; [c]Fisher's exact chi-square test; *p<0.05.

Table 3. Comparison of outcomes between the ERN and ACP groups for nonisthmal nonunion.

	Nonisthmal (n=88)						
	ERN group (n1=42)			ACP group (n2=46)			p
	n	%	Mean±SD	n	%	Mean±SD	
Mean operation time, min[a]			127.3±21.7			89.9±14.1	0.018*
Mean intraoperative blood loss, ml[a]			796.7±101.4			359.3±85.6	0.028*
Mean postoperative draining volume, ml			160.3±53			171.8±48	0.508
Mean time to union, months[a]			9.9±2.4			5.3±0.7	0.031*
Union rate[b]	32	76.2		46	100		0.030*
Mean time to renonunion, months[a]			7.5±2.1			0	0.019*
Complication ratec							
Infection	0	0		1	2.2		0.019*
Re-nonunion	10	23.8		0	0		

ERN: Exchanging reamed nailing; ACP: Augmentative compression plating; [a]Mann-Whitney U-test; [b]Pearson's chi-square test; [c]Fisher's exact chi-square test; *p<0.05.

Table 4. Comparison of outcomes between the ERN and ACP groups for isthmal nonunion.

	Isthmal (n=92)						
	ERN group (n1=45)			ACP group (n2=47)			p
	n	%	Mean±SD	n	%	Mean±SD	
Mean operation time, min[a]			85.6±10.6			129.8±28	0.023*
Mean intraoperative blood loss, ml[a]			472.3±92.1			316.1±49.7	0.130
Mean postoperative draining volume, ml[a]			159.3±36.4			165.2±38	0.250
Mean time to union, months[a]			7.6±1.4			6.0±0.8	0.775
Union rate[b]	43	95.6		47	100		0.198
Mean time to renonunion, months[a]			6.8±1.6			0	0.028*
Complication ratec							
Infection	0	0		1	2.1		0.277
Re-nonunion	2	4.4		0	0		

ERN: Exchanging reamed nailing; ACP: Augmentative compression plating; [a]Mann-Whitney U-test; [b]Pearson's chi-square test; [c]Fisher's exact chi-square test; *p<0.05.

inflammation and immune system response, which can decrease the production of indomethacin and IGF I/IGF II antibodies. The mechanical advantage of ERN lies in the use of thicker and longer IM (intramedullary) nails after reaming, which may increase the contact area between the nails and cortex. Consequently, the mechanical stability–particularly the anti-rotation stability (ARS) of the fracture ends–could increase, which is consistent with bone healing mechanisms. Nevertheless, some investigators remain unconvinced of the effectiveness and indications of ERN.[8–10] In a study by Banaszkiewicz et al.,[9] a union rate of only 58% was achieved in ERN-treated femoral shaft nonunion after failed IMN. Similarly, Park et al.[11] reported that 5 out of 7 patients with femoral shaft nonunion after failed IMN did not achieve bone healing after ERN resurgery, with a nonunion rate of 72%. It was concluded that patients with nonisthmal nonunion were unable to increase the effective contact area and thus had poor ARS after ERN surgery. However, there is an absence of biomechanical studies addressing this aspect of ERN in the literature. In contrast, ACP has increasingly demonstrated more advantages, including fewer injuries, shorter operation time, and no requirement of IMN removal. Significantly, a postoperative bone union rate of up to 100% can be achieved by ACP surgery for femoral shaft nonunion after failed IMN.[12] However, it remains unclear whether ACP can bring more advantages than ERN to patients with femoral shaft nonunion after failed IMN, regardless of anatomical site. As a result, the debate between advocates of ACP and ERN is likely to continue until a long-term follow-up study reveals the clinical outcomes and indications of ERN and ACP surgery.

In the current study, it was observed that the bone union rate in the ACP group was significantly higher than that of the ERN group (p=0.037). However, for isthmal nonunions, there was no significant difference in union rate between the ERN and ACP groups (p=0.198). This result indicated that ACP could obtain a higher bone union rate than ERN in the treatment of femoral shaft nonunion after failed IMN and be more advantageous for patients with nonisthmal femoral shaft nonunions or isthmal nonunions with larger bone defects in particular. Regardless of nonunion type, autogenous BG may be beneficial for bone healing when treated by ACP. Poor ARS may be responsible for low union rate after ERN surgery, yet larger studies and further biomechanical studies are needed to fully validate these results. Interestingly, this study showed a relatively higher bone healing rate for ERN surgery compared to that reported by Park et al. A possible explanation for this finding is that autologous iliac grafting was performed in this study for patients with atrophic nonunion or cortical bone defect >1 cm, whereas only closed surgery without autologous BG was performed for patients in the ERN group by Park et al.[11]

In a study by Ueng et al.,[16,17] ACP surgery in combination with autologous bone grafting was first reported to lead to 100% bone healing rate for femoral nonunion after failed IMN, the main cause of which was believed to be poor ARS. The mechanical advantages of ACP surgery include its axial stability and bending resistance due to retaining the original IMN as a prerequisite, reinforcement of ARS at the broken ends of the fracture via augmentative plating, and correction of rotational deviation. As a result, indispensable mechanical supports are provided for the formation of local callus bridging. In addition, for nonisthmal nonunions, dual cortical screw fixation for ACP surgery could provide mechanical stability, functioning as blocking screws. In a cadaveric fracture model study by Park et al.,[18] the augmentative plate group had a 3.3-fold increase in torsional stiffness and 2.6-fold increase in bending stiffness, compared with the interlocking IMN group. Moreover, the involved biological mechanism in ACP surgery is the stimulation of bone remodeling at the fracture ends through successful bone autografts with osteogenesis, osteoconduction, and osteoinduction.[16,17] Studies have shown that ACP surgery has many advantages over ERN in the treatment of long bone nonunion after failed IMN, such as minimal invasion, short operation time, high bone healing rate, and outcome satisfaction.[16,17,19–28] However, a major disadvantage of ACP lies in its required additionally invasive augmentative incision. Furthermore, for isthmal femoral nonunion after failed IMN, ACP surgery is associated with greater difficulties in screw fixation. The effectiveness of the 2 surgical methods (ACP and ERN) for femoral shaft nonunion subsequent to failed IMN at different anatomical sites is in need of further clinical comparison. The present study found no significant difference in the average operation time between the 2 groups (p=0.151). However, in the treatment of isthmal nonunion, mean operation time in the ACP group was longer than that of the ERN group (p=0.023), the cause of which may be related to difficult insertion and fixation of screws due to the blocking of IMN in ACP surgery. Although 2 ACP-treated patients suffered from delayed wound infection, successful wound healing was achieved after hardware removal. It was thought that the delayed wound infection in these patients may have resulted from such affective factors as skin scar, stiff joints, and poor systemic immune function. Moreover, the results of the present study indicate that the intraoperative blood loss in the ERN group was significantly more than that of the ACP group (p=0.035). The increased blood loss following ERN may be attributed to the reaming-related destruction of the intramedullary blood supply and the difficult removal of hardware, as the appropriate instruments were absent in the cases of some patients whose initial surgeries were performed at other hospitals. In the present study, 12 cases in the ERN group obtained renonunion, including 10 cases of nonisthmal nonunion and 2 cases of isthmal nonunion with cortical bone defect >3 cm. The renonunion rate of the ERN group was significantly more than that of the ACP group, especially for nonisthmal nonunions. Thus, this finding suggests that nonisthmal nonunions or isthmal nonunions with larger cortical bone defects should be identified as contraindications for ERN surgery.

In conclusion, the strength of this study lies in that it was a multicenter cohort study of larger sample size. The outcomes between ERN and ACP with autogenous BG according to different anatomical sites were compared in the treatment of femoral shaft nonunion after IMN, with the results indicating that ACP could obtain a higher bone union rate and shorter time to union than ERN. Especially for nonisthmal femoral shaft nonunions or isthmal nonunions with larger bone defects, ACP could be more advantageous than ERN. However, the limitation of the present study is its retrospective nature; therefore, the authors recommend that a future prospective observational study be conducted.

Conflics of Interest: No conflicts declared.

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