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Effect of Interlocking Mode on the Outcomes of Exchange Nailing for the Treatment of Aseptic Femoral Shaft Nonunion

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Background: Exchange nailing is a standard treatment for femoral shaft nonunion after intramedullary nailing. However, substantial uncertainty and controversy remain regarding the mode of interlocking fixation. This study aimed to compare the success rate and time to union of exchange nailing based on interlocking modes.

Methods: We retrospectively analyzed all consecutive patients who underwent exchange nailing for aseptic femoral shaft nonunion between February 2000 and February 2021. Patients who underwent exchange nailing using the dynamically locked mode and statically locked mode constituted the dynamic group and static group, respectively. We compared the success rates of the index surgery and the time to union between the groups and measured the extent of interlocking screw migration on the dynamic oblong hole in the dynamic group.

Results: The dynamic group and static group comprised 17 patients and 18 patients, respectively. All patients in the dynamic group achieved bone union, whereas 5 patients in the static group did not and underwent additional intervention. The success rate of the index surgery was significantly higher in the dynamic group than in the static group (100% vs. 72.2%, $p = 0.045$). Four of the 5 failed unions in the static group achieved bone union after dynamization. The median time to union was significantly shorter in the dynamic group than in the static group (6.0 months [range, 4.0–6.0] vs. 12.0 months [range, 3.7–21.7], $p = 0.035$). In the dynamic group, 3 of 17 patients exhibited interlocking screw migration ranging from 1.1 to 4.1 mm.

Conclusions: Exchange nailing with dynamic mode yields a higher success rate and shorter time to union in aseptic femoral shaft nonunion than that with static mode, without the risk of excessive shortening.

Keywords: *Femur, Fracture, Ununited, Nonunion, Exchange nailing, Interlocking mode*

Exchange nailing is a standard treatment for femoral shaft nonunion after intramedullary nailing. Exchange nailing has the advantage of providing more stable fixation through the insertion of a larger-diameter nail after reaming and biological reactivation through the reaming process.[1-7] The reported success rates of exchange nailing range from 53% to 100%.[1-11] This wide variation in the success rates across studies is affected by differences in the nonunion status and operation methods, such as the increment in the diameter of the new nail and the mode of interlocking fixation. Among them, substantial uncertainty and controversy remain regarding the mode of interlocking fixation in exchange nailing.

Oh et al.,[12] reported that exchange nailing with a dynamically locked mode achieved union in 11 of 12 aseptic femoral nonunions without requiring a secondary procedure. The authors[12] noted that the gap at the nonunion

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site was decreased in some cases on follow-up radiographs and surmised that the compression under the dynamic mode was a major contributing factor for bone union. Weresh et al.[10] reported that 3 of 10 nonunions (30%) treated via the dynamically locked mode and 6 of 9 (67%) treated using the statically locked mode failed to unite after exchange nailing and required additional procedures to achieve union. Although the findings seem to favor the dynamically locked mode, they found no statistical difference in the healing rates between the modes owing to the small sample sizes. A recent systematic review showed that the average union time and overall union rate did not differ between statically and dynamically locked modes of exchange nailing for delayed or nonunion femoral fractures.[13]

Theoretically and clinically, load-bearing at the fracture callus promotes fracture healing.[14-17] However, the dynamic mode of intramedullary nailing for acute femoral shaft fractures may cause acute shortening and instability owing to the displacement of an undetected fracture extension, which later results in the collapse of the structure.[18,19] When exchange nailing is performed for nonunions, one major fracture line usually proceeds nonunion. A mixture of fibrous tissue with or without a healing callus occupies the fracture gap at the nonunion site. In this condition, gradual axial compression at the healing callus would be possible with minimal risk of rotational instability and excessive shortening when the exchange nailing was performed with the dynamically locked mode.

In our institution, exchange nailing was performed in length stable femoral shaft nonunions, which had sufficient bone substance for bony contact at the nonunion site. In the cases with length unstable nonunions, augmentative plating or conversion to plate was indicated. The purpose of this study was to compare the success rate and time to union of exchange nailing based on the interlocking modes. We scrutinized the effects of dynamic mode in exchange nailing for aseptic femoral shaft nonunion.

METHODS

This study was approved by Institutional Review Board of Gangnam Severance Hospital (No. 3-2021-0217) and was conducted in accordance with the tenets of the Declaration of Helsinki. The requirement for informed consent was waived owing to the retrospective nature of the study.

Study Population

For this retrospective study, we identified 53 consecutive patients who underwent exchange nailing for nonunion of femoral shaft fractures after intramedullary nailing in a single institution between February 2000 and February 2021. We defined nonunion as an unhealed fracture at 9 months after surgery or fracture without progression of callus formation on three sequential monthly radiographs, along with persistent pain at the fracture site. Metal failure due to nail breakage that was not associated with high-energy trauma was also regarded as nonunion. We excluded 5 patients who were lost to follow-up before bone healing. To minimize potential confounding factor, 13 patients treated with simultaneous auto-iliac bone graft for partial bone defects were excluded. There was no infected nonunion based on the clinical presentation and result of the intraoperative culture.

Exchange Nailing

Exchange nailing was conducted under fluoroscopic guidance, with patients in the lateral position on a regular radiolucent table. After removal of the previous nail, the medullary canal was over-reamed to ensure a tight canal fit with cortical reaming confirmed by the reaming debris in the reamer flutes. The nail diameter increased by 1 to 3 mm in relation to the previous nail diameter. After introducing a new nail, we fixed the interlocking screw sequentially; first, interlocking fixation with 1 or more screws, including the static hole, was performed on the shorter fragment of the shaft, with little or no isthmic portion. Then, any distraction gap at the nonunion site was compressed by a forward or backward striking technique. Next, interlocking fixation was performed on the longer fragment of the shaft. In the dynamic group, the dynamically locked mode was the standard method for interlocking fixation and, therefore, only 1 interlocking screw on the dynamic hole was fixed to the longer fragment. Considering the possibility of later dynamization as a dynamically locked mode, 2 or more interlocking screws were inserted including a dynamic oblong hole in the static group. Additional Poller screw insertion was performed at the surgeon's discretion. All surgeries were performed by a single experienced surgeon (KHY). Weight-bearing as tolerated with the use of two crutches was permitted immediately after surgery.

Clinical and Radiological Assessments

Electronic medical record charts and radiographs were reviewed to obtain the following patient data: age, sex, smoking history, initial open fracture, nonunion of atypical femoral fracture, previous operation for delayed union and nonunion before current exchange nailing, partial bone defect of nonunion due to butterfly fragment, time from

initial injury to exchange nailing, position of nonunion, type of nonunion, and callus-to-diaphysis ratio (CDR). Based on the isthmus, the position of nonunion was classified as supra-isthmus, isthmus, or infra-isthmus.[11] Nonunions were classified as hypertrophic or atrophic. CDR was measured on anteroposterior and lateral plain radiographs of the femur performed before exchange nailing and reported as the average of two measurements.[20-22] Since CDR < 1.19 was reported as a predictor for failure of dynamization, this value was included as a means of categorizing patients.[22]

Patients were evaluated 1, 2, 3, 4, 6, 9, and 12 months after surgery and annually thereafter. If there was no evidence of union on radiographs, patients were followed up every 3 months at 1 year after surgery. We defined union as bridging callus formation in at least 3 cortices, as observed radiographically, as well as painless full weight-bearing ambulation. When a patient had persistent pain at the nonunion site and no evidence of progression of callus formation on radiographs, we considered performing a secondary intervention, such as dynamization (first-line treatment in the static group) or augmentative plating. To evaluate shortening in the dynamic group, the extent of migration of the interlocking screw on the dynamic oblong hole was measured on an anteroposterior radiograph acquired after union. In addition, we evaluated malalignment on the final anteroposterior and lateral femur radiographs, defined as > 10° angulation. A single orthopedic surgeon who did not participate in the treatment (CHL) performed all radiological measurements; distance measurements were calculated using the known screw and nail diameters.

Statistical Analyses

Data are reported as the median with the 25% and 75% quartiles or frequencies and percentages. The Mann-Whitney *U*-test was performed for continuous variables after checking normality, whereas the chi-square or Fisher's exact test was performed for categorical variables. Fisher's exact test was also performed to compare the success rates of the index surgery based on the interlocking mode. We defined success of the index surgery as the achievement of union without secondary intervention. In addition, the time to union after exchange nailing according to the interlocking mode was compared using the Mann-Whitney *U*-test. The *p*-values of < 0.05 were considered statistically significant. All statistical analyses were performed using IBM SPSS ver. 25 (IBM Corp., Armonk, NY, USA).

Table 1. Patient Demographics

Variable	Dynamic group (n = 17)	Static group (n = 18)	*p*-value
Age (yr)	42.0 (30.5–67.0)	38.5 (27.5–56.0)	0.405
Sex (male)	11 (64.7)	15 (83.3)	0.264
Affected side (right)	12 (70.6)	13 (72.2)	> 0.999
Current smoking (yes)	4 (23.5)	4 (22.2)	> 0.999
Initial open fracture (yes)	1 (5.9)	3 (16.7)	0.603
Non-union of atypical femoral fracture (yes)	4 (23.5)	0	0.045
Previous operation for delayed union and non-union (yes)	9 (52.9)	6 (33.3)	0.241
Partial bone defect of non-union (yes)	3 (17.6)	4 (22.2)	> 0.999
Time from initial injury to exchange nailing (mo)	24.0 (8.0–30.5)	9.0 (7.0–19.5)	0.047
Position of non-union			0.545
Supra-isthmus	5 (29.4)	3 (16.7)	
Isthmus	9 (52.9)	13 (72.2)	
Infra-isthmus	3 (17.6)	2 (11.1)	
Type of non-union (hypertrophic)	7 (41.2)	9 (50.0)	0.600
Callus-to-diaphysis ratio (< 1.19)	8 (47.1)	7 (38.9)	0.625

Values are presented as median (interquartile range) or number (%).

RESULTS

Overall, 35 patients (17 in the dynamic group and 18 in the static group) were included in this study. The median follow-up periods were 21.0 (range, 8.0–32.0) and 25.5 (range, 16.7–54.0) months in the dynamic and static groups, respectively. Patients' demographic data showed that the dynamic group had more nonunion of atypical femoral fracture (p = 0.045) and longer time from initial injury to exchange nailing (p = 0.047), compared with the static group. Other demographic factors were not significantly different between the groups (p > 0.05) (Table 1). During exchange nailing, Poller screws were used in 2 cases in each group.

In the dynamic group, all patients achieved bone union without secondary intervention (Fig. 1). However, in the static group, 5 of 18 patients failed to achieve bone union after exchange nailing and underwent later dynamization within 1 year after surgery. The success rate of the index surgery in exchange nailing was significantly higher in the dynamic group (17 / 17, 100.0%) than in the static group (13 / 18, 72.2%) (p = 0.045). Among the 5 patients who failed to achieve bone union, all except one achieved

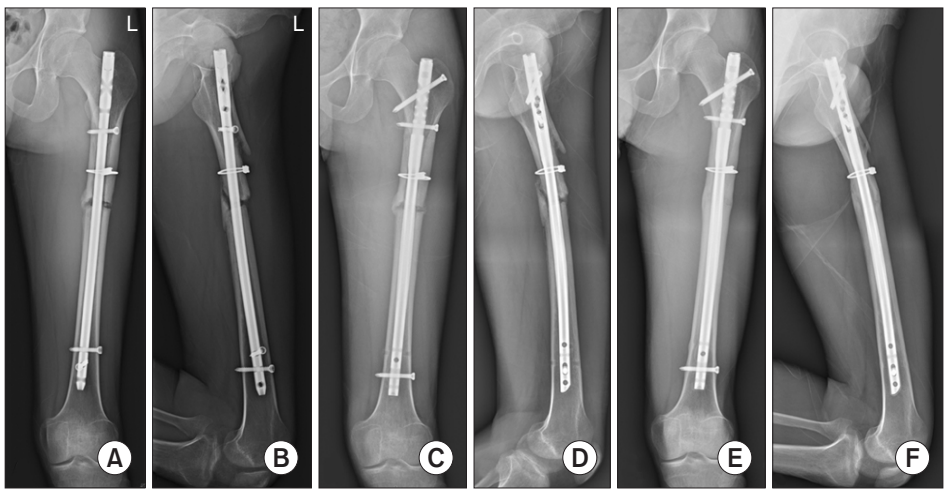

Fig. 1. Femoral shaft nonunion in a 22-year-old male patient treated with exchange nailing via the dynamic mode. (A, B) Anteroposterior and lateral plain radiographs 8 months after the initial surgery revealed nonunion with a fracture gap and callus-to-diaphysis ratio of < 1.19. (C, D) Postoperative radiographs after exchange nailing with the dynamic mode on the distal fragment. (E, F) Plain radiographs at 7 months after exchange nailing showing complete bone healing without apparent shortening.

Fig. 2. Femoral shaft nonunion in a 44-year-old male patient treated with exchange nailing via the statically locked mode (patient 3 in Table 2). (A, B) Anteroposterior and lateral plain radiographs 7 months after the initial surgery revealed nonunion with a fracture gap and callus-to-diaphysis ratio of 1.21. (C) Postoperative radiograph after exchange nailing with the statically locked mode shows that the fracture gap is diminished by the back-striking technique during exchange nailing. (D) Plain radiograph at 6 months after exchange nailing showing an increase in the callus size but no bridging of callus. The patient complained of persistent pain at the nonunion site; therefore, subsequent dynamization was performed by removal of the proximal 2 static interlocking screws. (E, F) Plain radiographs at 1 year after dynamization revealed complete bone healing without apparent shortening.

Table 2. Characteristics of the 5 Patients Who Failed

Patient	Age (yr)	Sex	Initial open fracture	AFF	Position of non-union	CDR* before exchange nailing	CDR* before dynamization	Time to dynamization after exchange nailing (mo)	Union after dynamization
1	43	M	-	-	Isthmus	1.24	1.23	4	Healed
2	17	M	-	-	Isthmus	1.00	1.32	6	Healed
3	44	M	-	-	Isthmus	1.21	1.32	6	Healed
4	59	M	-	-	Isthmus	1.54	1.55	11	Healed
5	32	M	-	-	Isthmus	1.00	1.00	6	Failed

AFF: atypical femoral fracture, CDR: callus-to-diaphysis ratio.
*CDR to achieve bone union after exchange nailing in the static group.

bone union after dynamization (Fig. 2, Table 2). However, additional time was required to achieve union after dynamization (range, 14–31 months). One patient failed to achieve bone union even after dynamization at 6 months after exchange nailing and eventually obtained bone union after augmentative plating and auto-iliac bone grafting 3 years after exchange nailing. The median time to union after exchange nailing was significantly shorter in the dynamic group than in the static group (6.0 [range, 4.0–6.0] months vs. 12.0 [range, 3.7–21.7] months; $p = 0.035$). Migration of the interlocking screws within the dynamic hole was seen in 3 of the 17 patients (17.6%) in the dynamic group; the position of nonunion was the supra-isthmus in 2 patients and the isthmus in 1 patient. The extent of shortening was < 5 mm (range, 1.1–4.1 mm) in these patients. There were no patients with malalignment after union in either group.

DISCUSSION

In this study, we found that exchange nailing with dynamic mode yielded a higher success rate and shorter time to union in femoral shaft nonunion than that with static mode, without the risk of excessive shortening. Our results suggest that the gradual axial stimulation of the nonunion site under the dynamic mode could improve the outcomes of exchange nailing. In addition, most failed cases after exchange nailing with static mode achieved bone union after later dynamization. Swanson et al.[6] reported that exchange nailing with the statically locked mode resulted in a 100% healing rate among 50 aseptic femoral nonunions. However, more than a quarter of the patients (28%, 14 / 50) required later dynamization to achieve bone union. This is similar to our result: 28% (5 / 18) needed additional intervention and 22% (4 / 18) healed after dynamization in the static group. If 1 patient who failed to achieve bone union even after dynamization had been regarded as a failure of exchange nailing in our study, the success rate of the static group would have been 94% (17 / 18) and comparable to that of the dynamic group. Nevertheless, exchange nailing with the dynamic mode is still beneficial to clinical outcomes in the aspect of the time to union. Early recovery is also an important goal in the treatment of patients with nonunion who suffered pain and discomfort for a long duration after the initial injury.

There has been considerable debate regarding routine dynamization after interlocked femoral nailing. In the late 20th century, most nails were equipped with static round holes alone; therefore, removal of all interlocking screws from one main fragment was inevitable to achieve the dynamization effect. Advocates for routine dynamization believed that load-bearing on the fracture callus promoted fracture healing and rehabilitation of patients.[23] However, Brumback et al.[24] reported that most fractures healed when treated with the statically locked mode; thus, routine dynamization was not indicated.[25] They believed that the statically locked mode did not interrupt the micro-motion necessary for fracture healing. Moreover, the unlocked mode sometimes resulted in rotational instability and excessive shortening owing to the displacement of the undetected fracture line in 10% of patients.[18] Therefore, the statically locked mode became the standard method of interlocking fixation in femoral nailing for acute fractures.[19,24,25]

On the other hand, many surgeons still prefer the dynamic mode if the fracture is length stable, such as the non-comminuted transverse type. The preference is increased in exchange nailing. Exchange nailing is indicated when the minor fracture lines are healed but healing of the major fracture line remains compromised for several months after intramedullary nailing. In the case of osteosynthesis for nonunion using a plate and screws, the gap of

the nonunion site is compressed with a tension device before plate fixation and an autogenous bone graft is added to promote bone healing.[26] Similarly, compression at the nonunion site is an important factor in exchange nailing. Although intraoperative compression can be obtained moderately via forward or backward striking technique, it is difficult to achieve a solid compression force at the nonunion site during exchange nailing. In the dynamic mode, however, weight-bearing can lead to generating gradual axial compression, as well as closing a remaining gap. In this study, we observed that 3 patients in the dynamic group exhibited migration of interlocking screws along the dynamic oblong hole despite intraoperative compression, particularly in cases of supra-isthmal nonunion.

In the treatment of nonunion, stable fixation is a key factor for the achievement of bone healing regardless of nonunion type. Although exchange nailing by the insertion of a larger-diameter nail after reaming can achieve more stability, there might be concerns about the risk of inadequate stability in exchange nailing with the dynamic mode because only 1 dynamic hole is available for interlocking fixation in each proximal and distal parts of most contemporary nails. The fear of instability would be aggravated in the treatment of nonunion with less abundant callus formation. However, our results showed that exchange nailing with the dynamically locked mode was safe and effective for bone healing, even in the 8 patients with poor callus formation (CDR < 1.19). To minimize the risk of instability while performing the dynamically locked mode, it should be performed in the longer fragment of the shaft including the isthmic portion. In the case of nonunion at the middle isthmic area, the proximal portion is often more favorable than the distal one because the interlocking screw can be inserted precisely under the guidance of the targeting guide and the cortex of the proximal portion is thicker than that of the distal one. Additionally, augmentation of the interlocking fixation is possible by placing additional Poller screws beside the nail.[27]

This study has several limitations. First, owing to the retrospective nature of the study, selection bias might exist because the determination of the interlocking mode was not randomized. We tended to perform exchange nailing via dynamic mode in patients with nonunion of atypical femoral fractures or longer time from initial injury. However, these factors could have affected negatively bone union. In practice, it is not always possible to obtain proper screw purchase via a single dynamic hole owing to traces of previously failed intramedullary nailing or poor bone quality. Although some hypertrophic nonunion can be treated by exchange nailing with the dynamically unlocked mode, we believe that the dynamically locked mode is essential for preventing rotational instability and excessive shortening. In addition, we confirmed that all patients had sufficient bone substance for bony contact at the nonunion site on preoperative plain radiographs and computed tomography such that both interlocking modes were applicable in all cases. Second, owing to the high success rate of intramedullary nailing (including dynamization) in the treatment of acute femoral shaft fractures, the number of potential cases requiring exchange nailing was limited. In addition, many infra-isthmal femoral shaft nonunions were treated using other surgical methods, such as augmentative plating and bone grafting. Third, we did not evaluate the functional outcome in this study.

In conclusion, exchange nailing with dynamic mode yields a higher success rate and shorter time to union in aseptic femoral shaft nonunion than that with static mode. To improve the outcomes of exchange nailing for aseptic femoral shaft nonunion, the dynamic mode should be considered as the standard interlocking mode if the nonunion is length stable and has sufficient bone substance for bony contact at the nonunion site.

CONFLICT OF INTEREST

No potential conflict of interest relevant to this article was reported.

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