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Sliding bone graft combined with double locking plate fixation for the treatment of femoral shaft nonunion

Wenzhao Xing, Zhenhua Pan, Lei Sun, Liang Sun, Chunpu Zhang, Zhiguo Zhang, Wenling Feng and Changcheng Liu

Abstract

Objectives: The aim of this study was to describe and evaluate a novel method of sliding bone graft combined with double locking plate fixation in treating femoral shaft nonunion.

Methods: Clinical data from patients with femoral shaft nonunion that was treated with sliding bone grafts combined with double locking plate fixation were retrospectively collected. Data included duration of surgery, blood loss, union rate, time to union and possible complications.

Results: Twenty-five patients included in the study were followed for a mean duration of 16.6 ± 2.6 months (range, 12–22 months). All of the fractures (100%) achieved bony union. Mean time to union was 6.0 ± 1.0 months (range, 4–8 months). No infections or medullary cavity occlusions were observed.

Conclusions: Sliding bone graft combined with double locking plate fixation was shown to be a safe, effective, and convenient surgical option for the treatment of nonunion, due to its high union rates with no complications. Further studies with larger sample sizes and longer-term follow-up are warranted.

Keywords

Nonunion, sliding bone graft, locking plate fixation, fracture healing

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Introduction

Complex femoral shaft fractures caused by high-energy trauma are a common injury treated by the orthopaedic surgeon, and may be associated with significant

Department of Orthopaedics, The Third Hospital of Hebei Medical University, Shijiazhuang, Hebei province, China

Corresponding author:
Changcheng Liu, Department of Orthopaedics, The Third Hospital of Hebei Medical University, 139 Ziqiang Road, Shijiazhuang, Hebei province 050051, China.
Email: liuchangcheng88@yeah.net

disability.[1,2] To date, clinical treatment has widely involved internal fixation techniques, due to good curative effects,[3,4] however, nonunion may be more common than realised, with rates ranging from approximately 5–10%.[5,6] The main causes of nonunion are inadequate fracture stability, insufficient blood supply, bone loss or presence of an infection.[7] Nonunion treatment is more difficult than treating fresh fractures due to poor prognosis, and multiple operations may be needed. As well as being a treatment dilemma for the surgeon, femoral nonunion is a functional and economic challenge for the patient, since the causes of the nonunion are complex and multiple factors are involved.[8] Consequently, the question of how to effectively manage the nonunion of femoral shaft fractures has become a hot topic.

Surgery is currently the mainstay of femoral shaft non-union treatment, and there are several different treatment modalities available to the surgeon. These include nail dynamization, plate osteosynthesis, external fixation, intramedullary nail replacement and adjuvant alternatives, such as electrical or ultrasound stimulation, bone grafting with autogenous or allogenic bone grafts and use of bone morphogenetic proteins.[7,9] However, due to variability in the types of union and specific fractured ends of the femur, there is no uniformly accepted therapeutic method for femoral shaft nonunion. The principle of surgical treatment is to recover the limb alignment and length, clean out the scar tissue and sclerotic bone in the fractured ends of the femur, repair the defects, reduce periosteum stripping, protect local blood supply and provide stable internal fixation.[10,11]

The purpose of the present study was to describe and evaluate a novel method of sliding bone graft combined with double locking plate fixation in the treatment of femoral shaft nonunion.

Patients and methods

Study population

This retrospective study included patients with femoral shaft nonunion who were treated using sliding bone grafts combined with double locking plate fixation at the Third Hospital of Hebei Medical University, Shijiazhuang, China between June 2009 and August 2014. Patients were sequentially enrolled according to the following inclusion criteria: aged 18–65 years and diagnosed with nonunion based on clinical and radiographical examinations performed by the attending surgeon (WX and ZP). Nonunion was defined as no fracture healing within 8 months following the last surgery with no radiological progression (including clear fracture line, sclerosis of the medullary canal, and no continuous callus formation) for three consecutive months.[12]

Exclusion criteria comprised the following: patients who were unable to tolerate secondary surgery due to severe concomitant diseases, such as heart disease, hypertension, metabolic disease, or cardiovascular disease, and thus, did not undergo sliding bone grafts combined with double locking plate fixation; patients with latent osteomyelitis at the fractured ends of the femur; and patients without follow-up data. Clinical data were retrospectively collected for all included patients.

The study was approved by the ethics committee of The Third Hospital of Hebei Medical University and conducted in accordance with the Declaration of Helsinki. Written informed consent was obtained from each participant.

Surgical technique

Preoperative planning—position and skin incision. The patient was positioned supine on a radiolucent table under combined spinal and epidural analgesia using 3.5 ml ropivacaine 0.5% (AstraZeneca AB, Sodertalje, Sweden) injected into the subarachnoid space. The nonunion site was exposed through a lateral skin incision. For patients who had previously undergone open reduction with bone plate or intramedullary nail internal fixation, a skin incision was made along the original incision. For patients who had previously undergone closed reduction with intramedullary nail fixation, a 25–30 cm incision was made on the anterolateral or lateral side of the thigh, depending on the non-union location (middle femur or upper/lower femur, respectively). The previous internal fixation instruments were then removed.

In situ locking plate fixation. The lateral femoral locking plate placement area was revealed without excessive dissection of the periosteum and soft tissue at the fractured end, to protect the fractured end and surrounding blood supply. Using preoperative X-ray radiographs, in situ locking plate fixation was performed if there was good alignment of the fractured ends of the femur. If alignment of the fractured ends was poor, locking plate fixation (10–12 holes) was performed after correcting the alignment and length of the affected limb.

Bone slab design. Following plate fixation, periosteum from the anterior surface of the femur was stripped to expose the anterior portion of the femur at the nonunion site. Two bone slabs were designed for both sides of the fracture ends: a long bone slab and a short bone slab of the same width (approximately 1/4 of the femur circumference), but of different lengths (long slab length: short slab length ratio of 2:1). A 2.5 mm diameter drill was used to make holes at approximately 1 cm intervals. A groove was cut using a sharp osteotome, then the bone slabs were obtained.

Treatment of nonunion fractured end. After lifting the bone slab, the directly visible fractured end and medullary cavity were cleared of fibrous scar tissue. The medullary cavity was then opened and 2 mm of sclerotic bone was removed from the fractured end. In all cases, the nonunion site was decorticated subperiosteally using an osteotome.

Bone grafting and bone slab placement. Autologous bone grafts were harvested from the iliac crest and cut into small matchstick-like pieces (approximately 30 mm × 5 mm × 5 mm) before use. Cancellous bone was procured from the ipsilateral iliac crest with a curette. Cancellous bone bulks were then impacted into the posterior, lateral and medial gap of the femur fractured ends. The matchstick-like strips of iliac crest bone were placed in the medullary cavity, along the long femoral shaft and extended beyond the fractured ends.

Once adequate bone grafting was achieved within the medullary cavity, the long and short bone slabs were embedded into the bone grooves after exchanging positions between the long and short slabs. The long bone slab extended beyond the fractured ends to help to create the bone bridge, and the short bone slabs were placed on the other side. Gaps surrounding the bone slabs were then implanted with sufficient cancellous bone bulks.

Front locking plate fixation, stability testing and closure. Following bone slab embedding, a further appropriately sized locking plate was placed at the anterior site of the femur covering the bony plate area, and stabilized with at least three screws on each side.

Stability testing was performed by flexion and extension on the surgical side to check that there was no micro-motion at the fractured end. The wound was thoroughly irrigated and the incision was repaired anatomically with a continuous suture (3-0 absorbable suture; Ethicon Inc/ Johnson & Johnson, USA), closing the wound in layers, as standard. One drainage tube was inserted into the wound. Finally, bone graft integrity at the fractured end was checked, and if a defect was found, the bone grafting procedure was repeated.

Postoperative treatment

As an infection preventive measure, antibiotics were administered intraoperatively (2 g cefazolin sodium, intravenously [i.v.]) and for 1 day postoperatively (4–8 g cefazolin sodium, i.v.). Lower limb muscle isometric contraction and knee-joint functional exercises were permitted, without weight-bearing activities, at 3–5 days following surgery. At 6 weeks following surgery, partial weight bearing was initiated based on X-ray results, as long as the patient was comfortable to walk with crutches. Full weight-bearing walking was initiated after complete bone union was achieved.

Outcome measures

Following discharge from hospital, patients were asked to visit the outpatient department at 1, 2, 3, 6 and 12 months and then at least once per year. During the follow-up period, anteroposterior and lateral X-ray examinations were performed to assess the status of union. Radiographic bone union was defined as disappearance of the fracture line (the marrow cavity and cortices were continuous from one fragment to the other) and continuous callus formation, as previously described.[12,13] The following recorded parameters were collected: duration of surgery, blood loss, incision length, duration of hospital stay, union rate, and time to union.

Statistical analyses

Categorical data are presented as number and percentage, and continuous quantitative data are presented as mean $\pm$ SD. Descriptive statistical analyses were performed using SPSS, version 16.0 (SPSS Inc., Chicago, IL, USA).

Results

Baseline demographic and clinical data

The study included a total of 25 patients with femoral shaft nonunion who were treated with sliding bone graft combined with double locking plate fixation, comprising 14 male and 11 female patients, with a mean age of 41.8 ± 9.6 years (range, 25–60 years) (Table 1). Fracture site was in the upper and middle parts of the femur in five cases, middle parts of the femur in seven cases, and middle and lower parts of the femur in 13 cases. Fracture types were comminuted (11 cases), transverse (nine cases), and oblique (five cases), with five cases of open fracture and 20 cases of closed fracture. Initial surgical treatments comprised interlocking intramedullary nail (18 cases) and plate fixation (seven cases). Among the 18 patients who were treated with interlocking intramedullary nail, five patients presented with dynamization, four patients presented with shortened nail, and two patients presented with transverse nail breakage. Seven patients who received plate fixation presented with loose screw or prolapse. Mean duration since first surgery was 11.4 ± 2.0 months (range, 9–15 months). Nonunion was classified as atrophic (eight cases) or hypertrophic (17 cases), according to previously published criteria.[14,15] Baseline data for each patient is summarized in Table 1.

Surgery-related outcomes

Sliding bone graft combined with double locking plate fixation was successful (defined as radiographic bone union of the femoral shaft) in all 25 (100%) of the

Table 1. Baseline clinicodemographic data in patients with femoral shaft nonunion treated with sliding bone graft combined with double locking plate fixation.

Patient No.	Sex	Age, years	Fracture type	Nonunion type	First surgery	Time since surgery, months	Surgery duration, h	Incision length, cm	BL, ml	Follow-up duration, months	UT, months	Complication
1	Male	31	Comminuted	Hypertrophic	Intramedullary nail	12	2.7	28	650	15	5	No
2	Female	25	Oblique	Atrophic	Intramedullary nail	9	3.2	27	780	20	6	No
3	Female	39	Comminuted	Hypertrophic	Plate	9	3.7	29	850	16	5	No
4	Male	29	Comminuted	Hypertrophic	Intramedullary nail	10	2.8	30	700	15	6	No
5	Male	47	Transverse	Atrophic	Plate	9	4.0	30	1200	17	7	No
6	Female	46	Oblique	Hypertrophic	Intramedullary nail	14	3.6	31	1050	16	7	No
7	Male	35	Comminuted	Hypertrophic	Intramedullary nail	12	3.5	30	1100	21	8	No
8	Male	36	Transverse	Hypertrophic	Plate	10	2.6	26	800	20	8	No
9	Male	57	Comminuted	Hypertrophic	Intramedullary nail	9	3.0	25	800	15	6	No
10	Female	34	Comminuted	Atrophic	Intramedullary nail	11	4.9	32	1400	18	6	No
11	Female	44	Transverse	Hypertrophic	Intramedullary nail	14	3.3	31	1050	22	–	No
12	Male	48	Comminuted	Hypertrophic	Plate	12	3.4	27	1000	14	4	No
13	Female	60	Transverse	Hypertrophic	Intramedullary nail	10	4.5	33	1300	13	5	No
14	Male	54	Oblique	Atrophic	Intramedullary nail	11	3.6	28	1100	17	6	No
15	Female	37	Comminuted	Hypertrophic	Intramedullary nail	14	4.1	29	1150	18	5	No
16	Female	36	Transverse	Hypertrophic	Plate	13	3.6	27	950	15	5	No
17	Male	29	Transverse	Hypertrophic	Intramedullary nail	10	4.4	32	1200	17	6	No
18	Female	50	Comminuted	Atrophic	Intramedullary nail	15	3.2	30	1100	13	5	–
19	Male	41	Oblique	Atrophic	Plate	10	3.7	28	1100	12	5	No
20	Female	46	Transverse	Hypertrophic	Intramedullary nail	11	4.2	30	1250	16	6	No
21	Male	33	Oblique	Atrophic	Intramedullary nail	13	4.5	32	1350	18	7	No
22	Female	37	Transverse	Hypertrophic	Intramedullary nail	12	2.9	29	750	14	6	No
23	Male	45	Comminuted	Atrophic	Plate	10	3.0	27	950	16	6	No
24	Male	48	Transverse	Hypertrophic	Intramedullary nail	15	2.7	28	900	20	7	No
25	Male	58	Comminuted	Hypertrophic	Intramedullary nail	9	4.1	30	1150	18	7	No

BL, blood loss; UT, time to bone union.

patients. The lengths of the long and short bone slabs ranged from 6–8 cm, and 2–3 cm, respectively, in the current patient group. A summary of surgery-related data is shown in Table 2. Briefly, the duration of surgery ranged from 2.6 to 4.5 h and blood loss during surgery ranged between 650 ml and 1300 ml. Incision lengths ranged between 25 and 33cm. The mean duration of hospital stay was 11.2 ± 3.6 days (range, 8–15 days).

Postoperative results

All patients completed post-hospital follow-up, with a mean follow-up duration of 16.6 ± 2.6 months (range, 13–22 months). All patients achieved bone healing. Mean time to bone union was 6.0 ± 1.0 months (range, 4–8 months), and all fractures (100%) achieved bony union. No infections or medullary cavity occlusions were observed during the follow-up period. Pre-, intra- and postoperative clinical and radiographic images of representative cases are shown in Figures 1 and 2.

Discussion

Femoral shaft fractures are commonly observed in the clinic,[16,17] and the patient is at risk of deformity and dysfunction of the lower limb if they do not receive appropriate treatment.[18,19] Nonunion is a common complication of femoral shaft fracture, which may severely impact patient femoral function.[7] Surgery remains the most common method to treat bone nonunion, however, the conventional method of dealing with the fractured ends is associated with drawbacks, such as decreased blood supply, angulation or translocation.[20] Thus, the present study retrospectively investigated results from the use of a novel method for treating femoral shaft nonunion.

Table 2. Summary of surgery-related outcomes in 25 patients with femoral shaft nonunion treated with sliding bone graft combined with double locking plate fixation.

Parameter	Summary result
Surgery duration, h	3.57 ± 0.64
Intraoperative blood loss, ml	1025.2 ± 207.17
Incision length, cm	29.16 ± 2.06
Time to ambulation, weeks	8.15 ± 1.71
Duration of hospital stay, days	11.23 ± 3.56

Data presented as mean ± SD.

Instability and micro-motion of the fractured ends may be the main causes of nonunion in the patient population included in the present study, as the extent of transverse micro-motion at the fractured ends varied between all patients, with obvious scaring and ossified tissue. Rigid fixation is well known to be the foundation of successful treatment of femoral shaft nonunion, thus, stable internal fixation is recommended to solve transverse micro-motion. In the present series, most patients admitted to The Third Hospital of Hebei Medical University due to femoral shaft nonunion had undergone nail fixation. For these patients, inaccurate intramedullary nail fixation would have produced adverse effects on the stability of the fracture ends, or even have resulted in secondary surgery failure. Conversely, extramedullary plate fixation may have avoided the adverse effects, as it can create a thin supportive region at the front side of the femur following sliding bone grafting.[21] Fixation of a second plate can provide maximal stability to the fractured ends. Thus, double locking plate fixation possesses some advantages for femoral shaft nonunion,[22] and was used in combination with sliding bone graft in the present study. In all patients, the fractures being treated achieved bony union.

Common surgical techniques for the treatment of femoral shaft nonunion include conventional sliding bone graft, auxiliary plate fixation and intramedullary nail and bone plate replacement.[7] However,

Figure 1. Representative X-ray images from a 36-year old male patient (case 8) with a right femur shaft fracture that was initially treated by plate, and who was admitted to The Third Hospital of Hebei Medical University for nonunion, showing: (A and B) nonunion at 10 months postoperatively; (C and D) sliding bone graft and double plate fixation subsequently performed; and (E and F) subsequent fracture healing at 7 months postoperatively. At 13 months postoperatively, the instruments were removed and X-ray images showed good fracture healing (data not shown).

such techniques remain associated with several drawbacks. For example, in the process of traditional sliding bone graft, the periosteum around the fractured ends needs to be stripped, which increases damage to the blood supply. The technique used in the present study was modified based on these disadvantages, and a comparison between the present technique and other common techniques is shown in Table 3.

Compared with conventional surgical techniques, the present technique has

Figure 2. Representative X-ray images from a 35-year old female patient (case 7) initially treated by intramedullary nail, showing: (A and B) a clear fracture line at 3 months following the first fracture surgery; (C and D) poor fracture healing at 6 months following secondary bone grafting; (E) sliding bone graft and double plate fixation subsequently performed; (F and G) a blurred fracture line at 2 months following sliding bone graft; (H and I) fracture healing at 8 months following sliding bone graft; and (J) good fracture healing following removal of instruments at 8 months postoperatively.

several advantages: (1) Preservation of blood supply at the fractured ends by avoiding large-scale periosteal stripping; (2) Reasonable bone grafting, as gaps at each fractured end were all covered by grafted bone without increasing the local volume of the fracture site, which reduced the creeping substitution of external callus and helped in the revascularization of the fractured ends; (3) Direct visualisation during surgery, as the fractured end and medullary cavity were directly visible, creating a large surgical filed; (4) Stabilization of the fractured ends, as double plate fixation can offset the varus and valgus stresses of the fractured ends and provide increased stabilization once bone healing around the groove occurs, which avoids the occurrence of plate bending or screw loosening; and (5) Reduced bone-graft volume, as sliding bone grafting was mainly performed in the medullary cavity and only a small amount of bone grafts were needed for the fractured ends to form a bone bridge.

Particular attention should be paid to the present procedural steps: (1) Grooving should be performed after locking plate fixation to avoid displacement of the fractured ends, grooving deviation, and difficult reduction; (2) Gaps in the fractured ends should be removed through autogenous cancellous bone grafting to avoid primary

Table 3. Appraisal of the present technique compared with common surgical techniques for treating femoral shaft nonunion.

	Drawbacks of conventional techniques	Advantage of the present modified technique
Traditional sliding bone graft	1. The periosteum around the fractured ends needs to be stripped and the broken end of a dislocation fracture requires treatment, increasing damage to the blood supply. 2. The reduction and fixation of the fractured end needs to be repeated.	1. Large-scale periosteal stripping was avoided and damage to blood supply was reduced. 2. Lateral femoral fixation with locking plate was performed directly after exposure of the fractured end, which reduced the process and time for reduction, and avoided re-reduction.
Auxiliary plate fixation	1. The bone plate is fixed on the outside of the femur and the intramedullary nail is not removed, resulting in cleaning of fibrous scar tissue on the front, outside and part of the posterolateral side of the fractured end only, while the inner back, inside of the fractured end and inside of the medullary cavity cannot be cleaned. 2. Reduced amount of bone graft.	1. After lifting the bone slab, the fractured end and medullary cavity were directly visible. Fibrous scar tissue in the fractured ends and medullary cavity could be adequately cleaned. 2. Larger amounts of bone can be grafted inside and outside the medullary cavity or inside and outside the fractured ends.
Intramedullary nail and bone plates replacement	1. The periosteum around the fractured end needs to be stripped and the broken end of dislocation fracture requires treatment, increasing damage to the blood supply. 2. The reduction and fixation of the fractured end needs to be repeated. 3. Bone grafting can be done at and around the fractured end, but not inside the medullary cavity.	1. Large-scale periosteal stripping was avoided and damage to the blood supply was reduced. 2. Lateral femoral fixation with locking plate was performed directly after exposure of the fractured end, which reduced the process and time for reduction, and avoided re-reduction. 3. Larger amounts of bone can be grafted inside and outside the medullary cavity or inside and outside the fractured ends.

union of the fracture site; and (3) Postoperative function exercises should be performed to avoid joint stiffness and muscle atrophy, and to promote bone union. However, weight-bearing exercises should not be permitted in order to avoid instrument failure.

The present study results are limited by the fact that the study was retrospective in nature, only included a small cohort of patients and lacked a control group. However, considering the rarity and heterogeneity of femoral shaft nonunion, the results of a retrospective report may be helpful in treating femoral nonunion following femoral nail or plate failure. Additionally, although computed tomography may be more appropriate to assess the status of union, due to the high cost and long inspection time, X-ray was used in the present study. A prospective, large scale randomized trial investigating the treatment of femoral shaft nonunion is warranted.

Conclusion

Sliding bone graft combined with double locking plate fixation was shown to be a safe, effective, and convenient surgical option for treating nonunion of femoral shaft fracture. The technique involved reduced periosteal stripping, preservation of the blood supply of the fractured ends and provided high union rates with no complications.

Declaration of conflicting interest

The authors declare that there is no conflict of interest.

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ORCID iD

Changcheng Liu http://orcid.org/0000-0002-8322-7563

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