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# Minimally Invasive Percutaneous Plate Osteosynthesis (MIPPO) Combined with Onionskin-Like Autologous Bone Grafting: A New Technique for Treatment of Tibial Nonunion

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## Background:

Established tibial nonunions rarely heal without secondary intervention; revision surgery is the most common intervention. Herein, we evaluated the clinical outcomes of patients with tibial nonunion treated with a new technique – minimally invasive percutaneous plate osteosynthesis (MIPPO) – combined with a new onionskin-like autologous bone grafting method.

## Material/Methods:

From 2010 to 2013, 18 patients with tibial nonunions (average bone defect: 9.5 mm) were treated with MIPPO technology combined with onionskin-like autologous bone grafting. Indices for clinical evaluation included operative time, fluoroscopy time, blood loss, hospital stay, healing time, postoperative complaints, radiographic performances, the Short Musculoskeletal Function Assessment (SMFA) questionnaire, and the American Orthopedic Foot & Ankle Society (AOFAS) ankle-hindfoot score.

## Results:

The average operation and fluoroscopy times for tibial nonunion were 65 min and 15.5 s, respectively, with a total blood loss of 107.7 mL. The mean duration of hospital stay was 12.8 days. The mean follow-up time was 11.9 months, and all patients achieved radiologically confirmed bony healing in an average time of 13.1 weeks. No lower-leg deformity, fixation failure, infection, and vascular, or nerve injuries were recorded in any patient, and only 4 patients complained of slight limb pain upon total weight-bearing at the end of follow-up. The SMFA and AOFAS ankle-hindfoot scores of patients were graded excellent in 14 (77.8%) and good in 4 (22.2%), indicating high functional recovery.

## Conclusions:


MIPPO technology combined with onionskin bone grafting is an efficient method to treat patients with tibial nonunion, especially for patients with poor soft tissue condition.

## MeSH Keywords:

**Bone Transplantation • Fracture Fixation • Tibia**

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## Background

Bone nonunion is a major problem in orthopedics, and tibial nonunion is the most common type, with an incidence of about 12% [1]. When long-bone fractures are accompanied by open injury, the incidence of bone nonunion increases up to 17%, and the rate of delayed union of fracture is 5% [2]. The tibial nutrient artery provides two-thirds of the blood supply to the tibia, passes through the lateral third of the tibial shaft, and then enters the bone marrow cavity in the compact bone for a short distance. Factors such as high-energy trauma, infection, and iatrogenic factors (e.g., excessive periosteal stripping, blood supply destruction, and lack of soft-tissue protection) can cause tibial nonunion [3]. Patients with tibial nonunion usually present with concomitant muscle atrophy in the lower leg and require repeated surgeries, often leading to a complete loss of confidence, as well as discouragement and depression.

Conventional open reduction and internal fixation for the treatment of bone nonunion can result in many complications, including skin necrosis, soft-tissue infections, nerve and vascular injury, and delayed bony unions [4,5]. Minimally invasive percutaneous plate osteosynthesis (MIPPO) technology has been widely applied in the treatment of various cases of trauma, including tibial nonunion. The MIPPO technology can reduce major injury to soft tissues and exhibits good clinical outcomes without direct exposure of the fracture site [6–10].

As the criterion standard for treatment of bone nonunion, researchers have investigated the effect of various bone graft

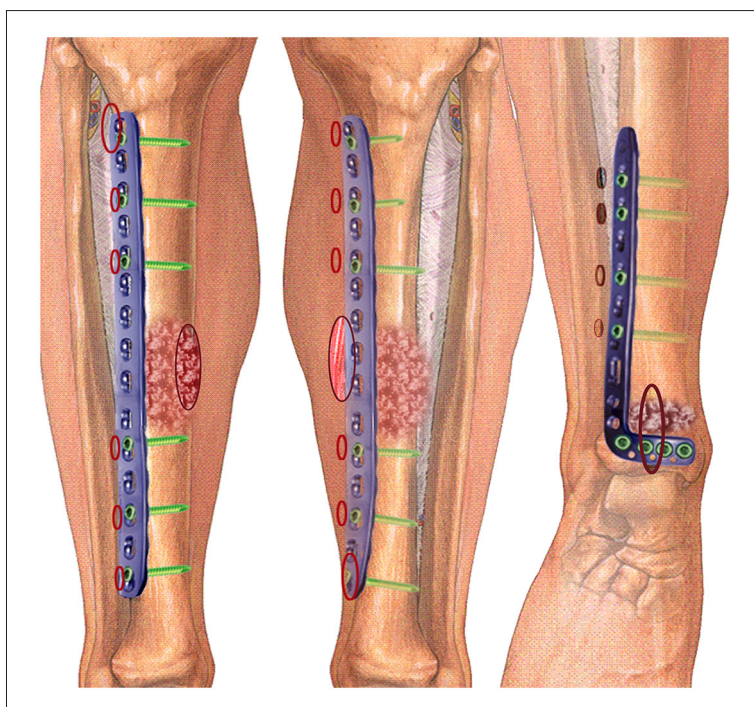
types to repair tibial nonunion [11]. Numerous bone grafting approaches have been advocated for the treatment of delayed union and nonunion fractures, including open bone grafting, minimally invasive bone grafting, and central bone grafting [12]. However, these techniques reportedly involve complications such as nerve injury, infection, iliac bony fracture, bone nonunion recurrence, poor soft-tissue condition, and painful scars [13–15]. Therefore, a new autologous bone grafting method to overcome the disadvantages of the present techniques is needed.

In this article, we retrospectively analyzed the medical records of 18 patients diagnosed with tibial nonunion and treated with MIPPO technology combined with a new bone grafting method – onionskin autologous bone grafting (Figure 1). Indices for clinical evaluation including operative time, fluoroscopy times, blood loss, hospital stay, healing time, postoperative complaints, radiographic performances, and limb function recovery were investigated to evaluate the clinical outcomes of this new treatment method.

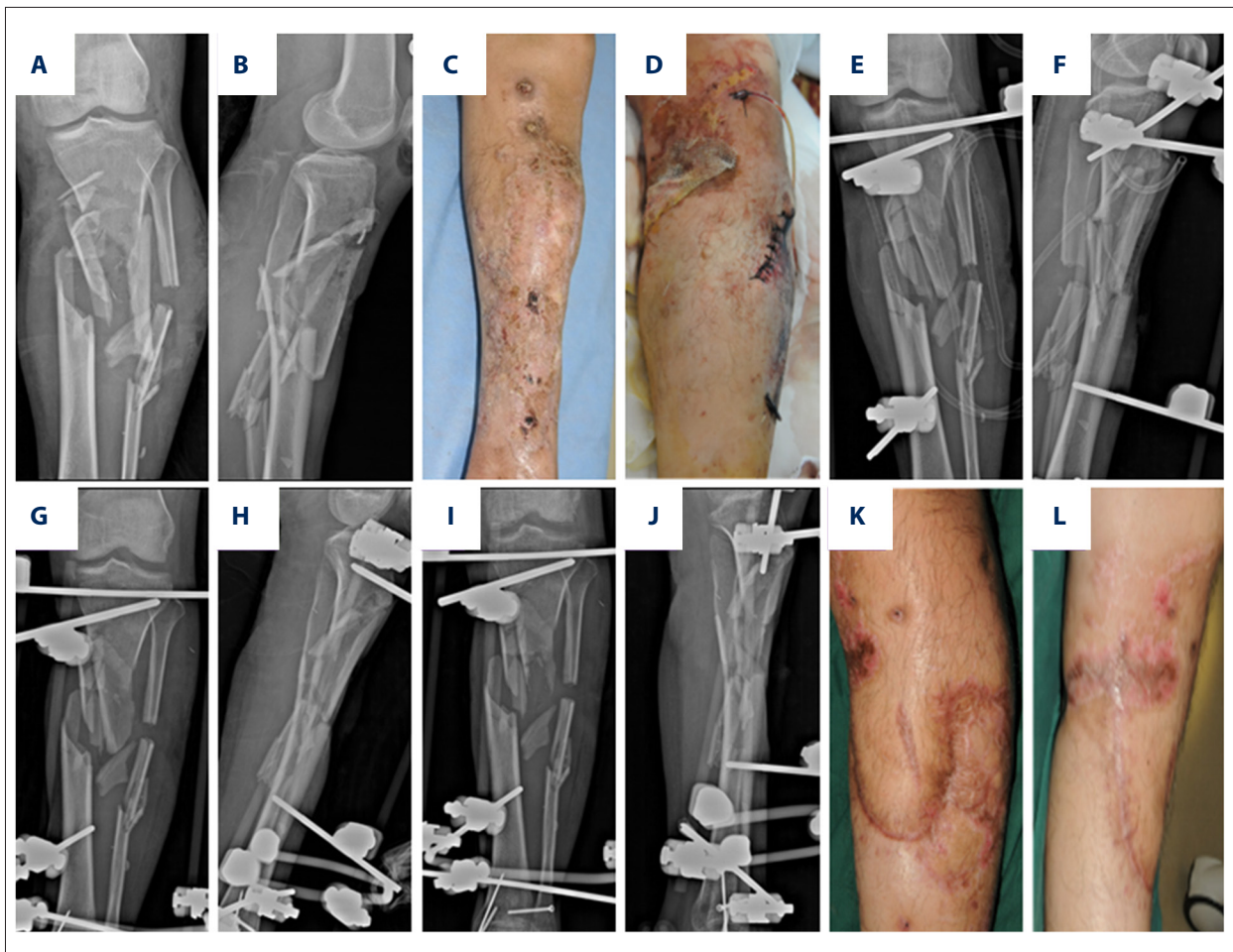
## Material and Methods

### Ethics approval and patient characteristics

The study was approved by the Ethics Committee of the Second Hospital of Jilin University. From 2010 to 2013, 18 patients admitted to our department with tibial nonunion (average bone defect: 9.5 mm) and treated with MIPPO technology combined



**Figure 1.** Scheme of minimally invasive percutaneous plate osteosynthesis (MIPPO) combined with onionskin-like autologous bone grafting in the treatment of tibial nonunion.



**Figure 2.** A male patient with open comminuted fracture of the left tibiofibular and upper leg degloving injury. (A, B) Radiography showed comminuted fracture of the upper segment of the left tibiofibula with obvious displacement. (C, D) Soft tissue condition indicated the anterior and lateral skins of the upper left leg were torn and sutured and extensively leathered. (E, F) Postoperative radiography after emergency second-stage clearance showed that the position of the external fixator was acceptable. (G–L) Radiographic examinations showed poor alignment, and no callus formation at 1 and 3 months after surgery, as well as extensive scarring on the medial part of the upper leg.

with onionskin-like autologous bone grafting were included in this study (Figure 2). The mean age of patients was 41.9 years (range: 24–57). Each case of nonunion was classified by its location in the tibia: proximal (4 patients), middle (4 patients), distal (9 patients), or middle and distal (1 patient) thirds of the tibia. Ten patients sustained multiple fractures, including femoral fracture and comminuted tibiofibular fracture. One patient had a nerve injury, 1 patient had a vascular injury, and 6 patients had open fractures of the tibia and fibula. Anterolateral plates were used in 11 cases, medial plates were used in 6 cases, and both anterolateral and medial plates were used in 1 case (Table 1).

All fractures were caused by high-speed injuries, including motor vehicle accidents (motorcycle or car) and falls from height. The patients were initially treated with external or internal

fixation, but tibial nonunion occurred 6 months later, making re-operation inevitable. According to the tibial fracture nonunion classification by Paley et al., 4 patients in our study were classified with type A1 (mobile nonunion with <1 cm of bone loss), 5 patients with type A2-1 (stiff nonunion with no deformity and <1 cm of bone loss), 5 patients with type A2-2 (stiff nonunion with a fixed deformity and <1 cm of bone loss), 3 patients with type B1 (bony defect >1 cm with no shortening of the limb), 1 patient with type B2 (bony defect >1 cm with loss of bone length), and no patients with type B3 (bone defect >1 cm and limb shortening) (Table 1).

#### Operative technique

Each operation was performed under general or epidural anesthesia with the patient positioned supine. To enhance the

**Table 1.** Patients' general characteristics.

Case	Age (years)	Sex	Side	Location in tibia	Grade	The initial operation	Bone defect(mm)
1	49	M	L	Distal	A1	External fixator	6
2	51	M	L	Distal	B2	External fixator	12
3	57	M	R	Distal	A2-1	External fixator	5
4	48	M	L	Mid-shaft	A2-1	Intramedullary nail	7
5	32	M	L	Mid-shaft	A2-1	Intramedullary nail	9
6	57	M	R	Mid-shaft/distal	A1	External fixator	8
7	46	M	R	Distal	A2-2	LCP	6
8	24	M	R	Distal	A2-2	External fixator	15
9	41	M	R	Distal	B1	LCP	17
10	40	M	L	Proximal	B1	External fixator	16
11	39	M	R	Distal	A2-1	External fixator	6
12	46	M	L	Proximal	B2	LCP	14
13	48	M	L	Mid-shaft	A2-1	External fixator	7
14	33	M	L	Distal	A2-2	Intramedullary nail	8
15	37	M	L	Proximal	B1	External fixator (with LISS plate)	18
16	43	M	R	Distal	A2-2	External fixator	6
17	36	M	R	Mid-shaft	A1	Intramedullary nail	8
18	28	M	L	Mid-shaft	A2-2	External fixator	4

presentation of the iliac crest and shift the bulk of the abdominal wall, a bolster was placed under the ipsilateral buttock. A 5-cm-long skin incision was made. Blunt dissection was carried out using a periosteum elevator to reach the iliac medial crest, cancellous and cortical bones were obtained from the inner table of the ileum, and the incision was closed. The obtained bone was cut into strips measuring 2–3-mm wide and 40–50-mm long.

The original internal or external fixation was removed using minimally invasive techniques (external fixation was required to be removed 2 weeks before surgery, and the results of blood tests, erythrocyte sedimentation rate, and C-reactive protein levels indicative of no infection) and a 3–4-cm skin incision was made above the tibial nonunion. The surgeon removed the fibrous tissue from the nonunion; freshened the ends of the fragments; opened the medullary cavity; and stripped 1–2 mm of the broken end of the periosteum by using a pith nucleus clamp, bone knife, small spatula, and little bite forceps; and then filled the defect at the nonunion with corticocancellous bone obtained through the iliac bone by using hemostatic forceps. Six small incisions were required for the plate implantation, each of which was 8–10 mm long. Finally, the incisions were closed with sutures and a subcutaneous drain was inserted (Figure 3).

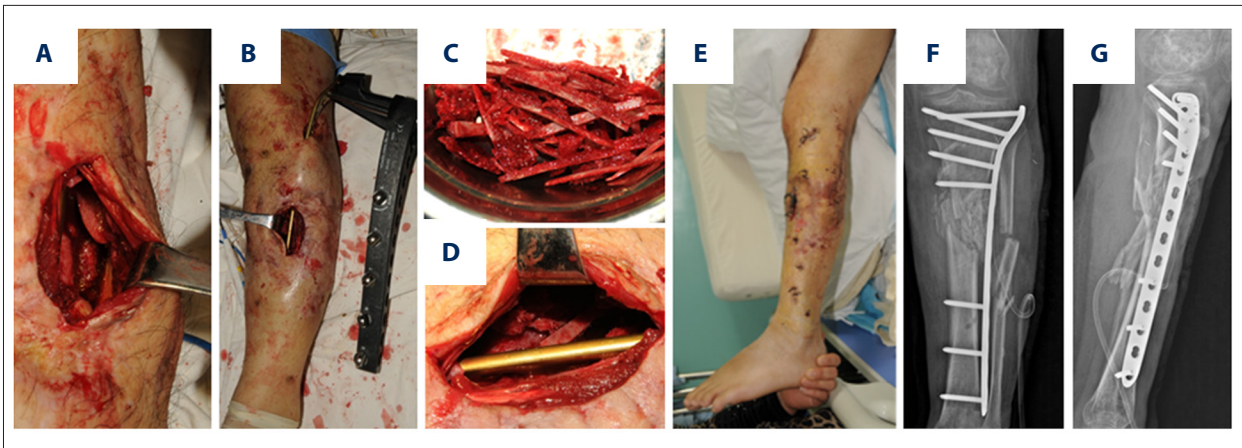
### Onionskin autologous bone grafting

The onionskin autologous bone grafting procedure included the following steps: (1) The periosteum and scar tissue around the broken end of the bone were peeled off by about 2.0 mm. (2) The region other than the cortical bone was implanted with cancellous bone particles (section A). (3) The area corresponding to the cortical bone at both ends was implanted with cancellous bone strips (section B). (4) The medullary cavity area, namely the area inside the cortical bone, was implanted with the elongated cancellous and cortical bone strips. Usually the cancellous bone faces outward and the length must exceed the gap of nonunion (section C). (5) The plate was percutaneously implanted (Synthes, Switzerland, section D). (6) The screws were inserted to bridge and fix the plate and bone graft area. (7) Finally, the cancellous bone was implanted into the gap next to the bone plate (section E) (Figure 4).

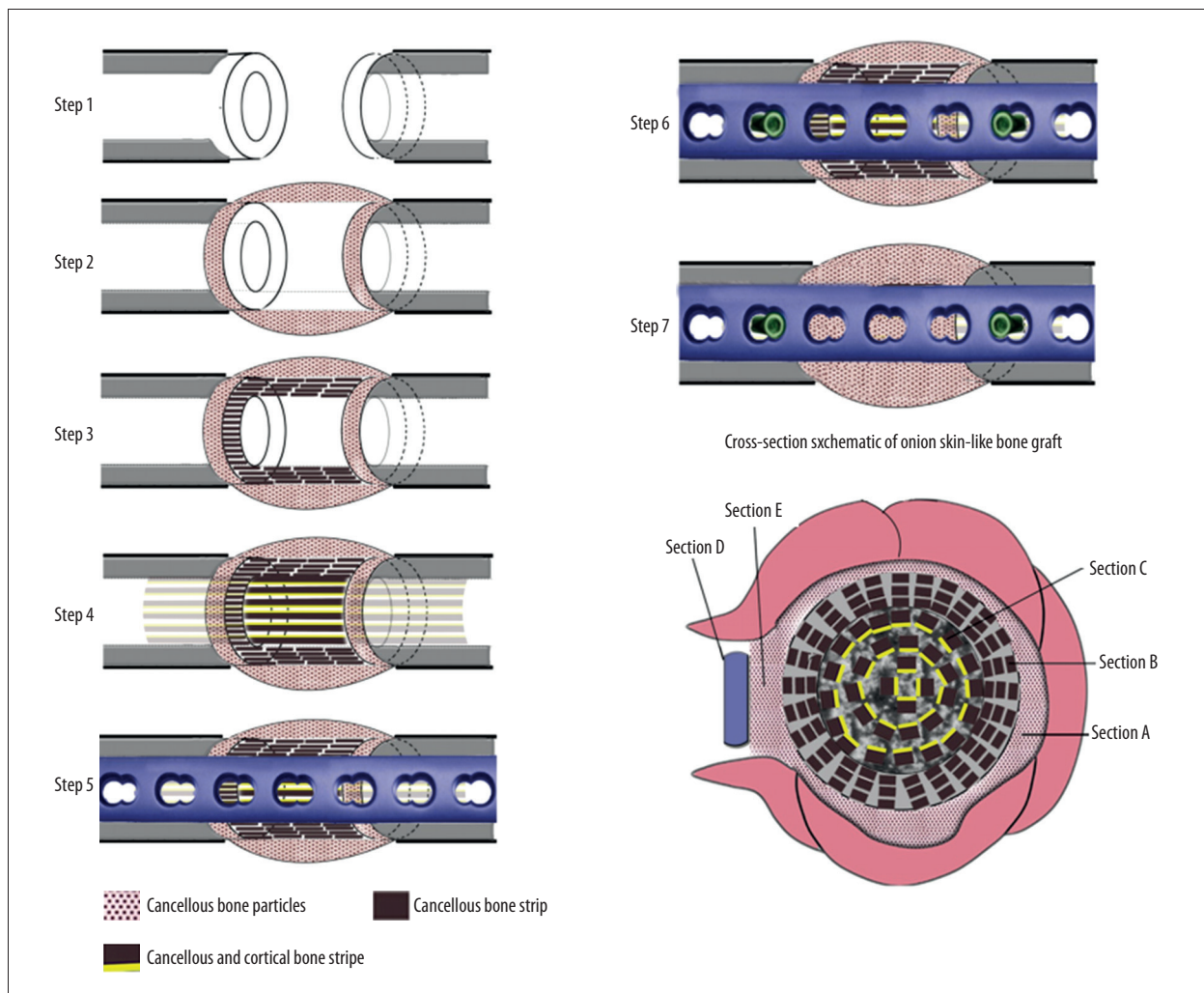
### Postoperative attention and follow-up

After surgery, each patient was discharged, with permission to walk with crutches, but no weight-bearing was allowed on the involved leg for 2 weeks. Partial weight-bearing was allowed after 2 weeks and gradually increased until the radiographic





**Figure 3.** Intraoperative images: (A) A small incision to remove the regenerated tissue from the nonunion location, (B) MIPPO technique was used to insert the plate, (C, D) onionskin-like bone grafting was performed, (E) postoperative incision image showed minimal invasion. (F, G) Postoperative radiographic examination showed that the plate was in good position with well-reduced tibiofibula fracture, and sufficient bone grafting.



**Figure 4.** "Onionskin" bone graft procedures and cross-sectional schematic of onionskin-like bone graft.

**Table 2.** The operation and hospital stay information summary.

Case	Plate position	Bone graft incision	Incision length (cm)	Relationship between incision and plate	Operative time (min)	Fluoroscopy times	Blood loss (mL)	Hospital stay (days)
1	Anterolateral	Anterolateral	4.0	Ipsilateral	90	15	130	12
2	Anterolateral	Anterolateral	5.5	Ipsilateral	70	17	100	15
3	Medial	Anterolateral	5.5	Contralateral	65	10	90	18
4	Anterolateral	Anterolateral	5.0	Ipsilateral	85	13	90	17
5	Anterolateral	Anterolateral	4.0	Ipsilateral	50	18	100	8
6	Anterolateral/medial	Anterolateral	5.0	Ipsilateral	60	12	105	8
7	Medial	Anterolateral	5.5	Contralateral	55	24	110	9
8	Anterolateral	Anterolateral	4.0	Ipsilateral	45	14	120	9
9	Anterolateral	Anterolateral	5.0	Ipsilateral	70	16	130	10
10	Anterolateral	Anterolateral	5.5	Ipsilateral	55	18	130	15
11	Medial	Anterolateral	4.5	Contralateral	60	19	95	16
12	Anterolateral	Anterolateral	4.5	Ipsilateral	75	21	105	10
13	Medial	Anterolateral	5.0	Contralateral	80	11	95	15
14	Medial	Anterolateral	5.5	Contralateral	75	16	100	14
15	Anterolateral	Anterolateral	5.5	Ipsilateral	55	12	120	14
16	Anterolateral	Medial	5.0	Contralateral	45	10	105	9
17	Anterolateral	Anterolateral	4.5	Ipsilateral	60	12	120	17
18	Anterolateral	Anterolateral	5.0	Ipsilateral	75	22	95	15

criteria for early consolidation were met. Full weight-bearing was allowed 6–8 weeks later.

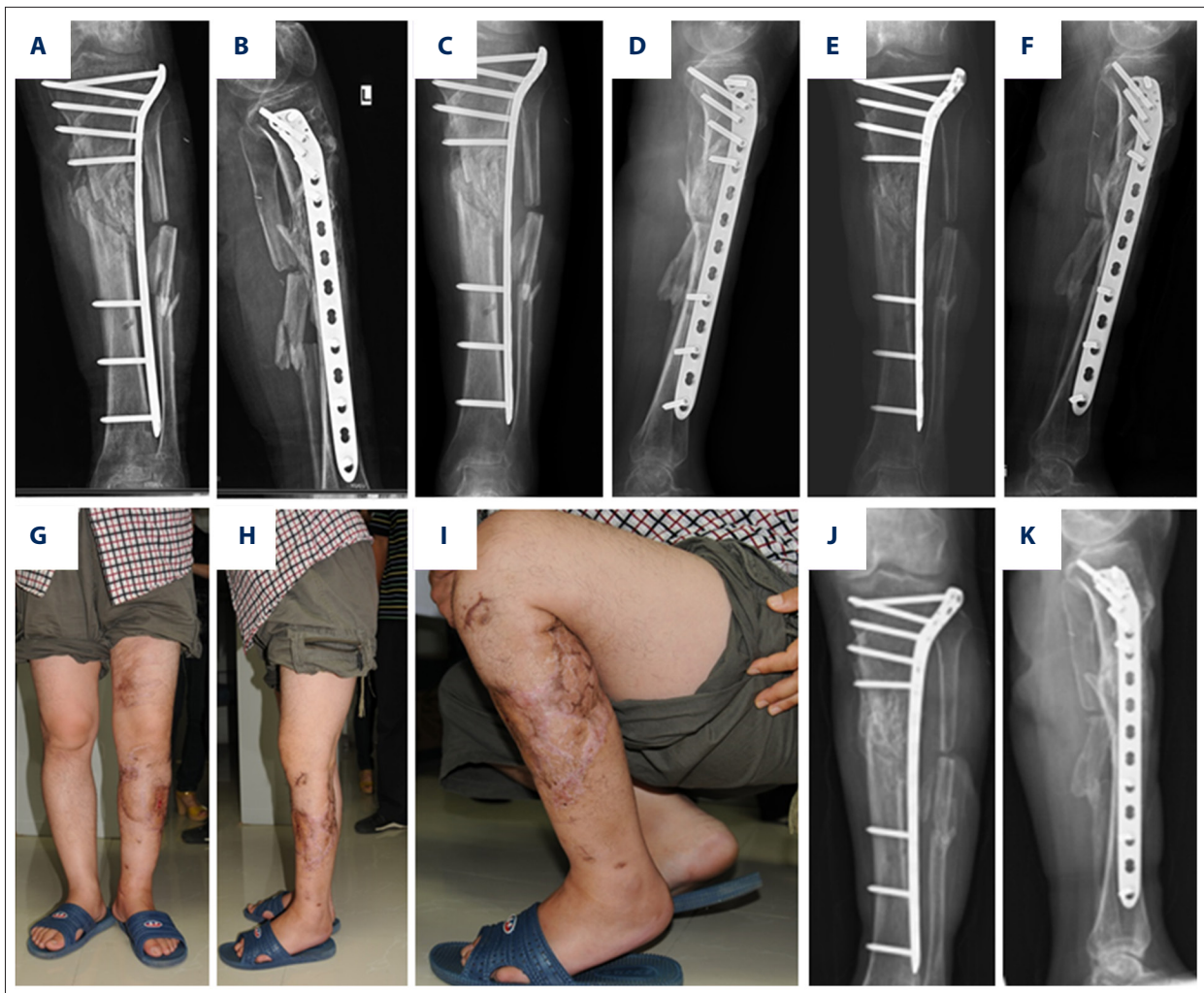
All patients required limb function investigation and radiographic examinations at 1, 3, 6, 12, and 24 months postoperatively. Clinical healing was defined as the ability of the patient to bear weight painlessly on the affected limb and a lack of pain response when manual stress was applied across the site of nonunion by an examiner. Radiographic results were assessed by measuring tibial angulation, shortening, and healing at the last follow-up. The Short Musculoskeletal Function Assessment (SMFA) questionnaire and American Orthopedic Foot and Ankle Society (AOFAS) ankle-hindfoot score were used to evaluate the postoperative function outcomes of patients at each visit [16].

## Results

A total of 18 patients underwent MIPPO combined with a new onionskin-like autologous bone grafting intervention for tibial

nonunion and completed the follow-up until at least 3 months postoperatively. The average operation and fluoroscopy times for tibial nonunion were 65.0 min (range: 45–90 min) and 15.5 s (range: 10–24 s), respectively, with a total blood loss for 107.7 mL (range: 90–130 mL). The average hospital stay was 12.8 days (range: 8–18 days) (Table 2).

The mean follow-up time was 11.9 months (range: 7–23 months), and all patients began partial weight-bearing ambulation at 3–4 months postoperatively. The radiological examinations confirmed that all patients achieved bony healing by an average time of 13.1 weeks (range: 4–24 weeks). On the basis of the radiographic assessment, no patient experienced loss of reduction or loss of fixation (Figure 5). Meanwhile, no lower-leg deformity, fixation failure, infection, and vascular or nerve injuries were recorded in any patients, and only 4 patients (22.2%) complained of slight limb pain upon full weight-bearing at the end of the follow-up period. Furthermore, implant removal was done in 11 patients (61.1%), and 16 patients (88.9%) resumed work at the end of the follow-up period (Table 3).



**Figure 5.** Postoperative radiographic examinations and functional status: (A, B) Extensive callus formation in the nonunion space seen 1 month after surgery, (C, D, and G–I) Tibial nonunion almost healed, with good functional status. (E, F) The regenerated bone seen in good shape at 7 months after surgery. (J, K) The shape of regenerated bone was almost normal at 17 months after surgery.

The SMFA scores were collected from the six-week postoperative follow-up. According to the questionnaire, the average bothersome, activities of daily living (ADL), emotion, arm and hand, mobility, and function scores were 22.7, 50.9, 39.7, 5.3, 42.6, and 35.4, respectively. Meanwhile, the AOFAS ankle-hindfoot scores were assessed at the final follow-up. The result showed that the average score of these patients was 91.9, and were graded as excellent in 14 cases (77.8%, 90.0–100.0) and good in 4 cases (22.2%, 75.0–89.0) (Table 4).

## Discussion

In the treatment of bone nonunion, bone grafting has irreplaceable functions, including stimulating the fracture end, filling the tissue defect, and producing new blood to promote

fracture healing [11]. Autologous bone grafting is the criterion standard and is the most frequently applied method in the treatment of nonunion because of its osteoinductive and osteoconductive properties and the capacity of introducing new osteogenic bone marrow cells to the fracture site [17].

Traditional open bone grafting usually requires a large incision, wound debridement, opening of the medullary cavity, bone transplantation into the fracture end, and stabilization of the fracture end with internal fixation. The incision is usually 10–20-mm longer than the plate and requires extensive periosteal stripping, although there are advantages of clear exposure and effective anatomical reduction of open bone grafting, with bone union rates of 70–95%. However, obvious weaknesses are observed, including major operation trauma, significant bleeding, long healing time, and a higher risk of

**Table 3.** Follow-up of the involved patients.

Case	Union	Infection	LLD	Deformity	Pain	Implant remove	Back to work	Healing time (weeks)	Follow-up time (months)
1	Yes	No	No	No	No	No	Yes	4	7
2	Yes	No	No	No	No	Yes	Yes	18	18
3	Yes	No	No	No	No	Yes	Yes	16	15
4	Yes	No	No	No	Slightly	Yes	Yes	12	9
5	Yes	No	No	No	No	Yes	Yes	14	9
6	Yes	No	No	No	No	No	Yes	24	10
7	Yes	No	No	No	Slightly	Yes	Yes	12	8
8	Yes	No	No	No	No	Yes	Yes	12	12
9	Yes	No	No	No	Slightly	Yes	Yes	16	15
10	Yes	No	No	No	No	No	Yes	7	9
11	Yes	No	No	No	No	No	Yes	12	7
12	Yes	No	No	No	No	No	No	12	8
13	Yes	No	No	No	No	Yes	Yes	13	14
14	Yes	No	No	No	No	No	No	8	8
15	Yes	No	No	No	No	Yes	Yes	8	11
16	Yes	No	No	No	No	Yes	Yes	12	12
17	Yes	No	No	No	Slightly	No	Yes	24	12
18	Yes	No	No	No	No	Yes	Yes	12	23

LLD – leg-length discrepancy.

surgical complications, rendering this procedure especially unsuitable for patients with poor soft tissue condition [18,19].

Minimally invasive bone grafting methods obtain bone grafts from the iliac crest and drive them into the hole across the fracture line using complicated equipment. Its advantages, such as small incision, faster recovery, and less trauma and pain, make it a good choice for surgeons. However, the high cost of the complicated equipment and high technical requirements are widely criticized [20]. Central bone grafting places the cancellous graft in the newly created central space between the tibia and fibula. By reducing the risk of neurovascular injury, this method is relatively simple and safe. However, major operative trauma, significant bleeding, and longer healing time are observed and limit its wide application [15].

To overcome these problems, we developed a new method, called onionskin bone grafting. In this method, the surgeon can choose the regions with good skin or muscle tissue condition. By effectively removing fibrous scar tissue and bone sclerosis

of the bone defect area, as well as protecting the blood supply of the bone defect area, the risk of infection is reduced, and the bone defect repair process is accelerated. The average incision length is about 3–4 cm (the incision should be appropriately extended as needed). The main tools used in onionskin bone grafting are common, including a pith nucleus clamp, small knife, small spatula, and little bite forceps. Compared with other bone grafting methods, the benefits of our technique include small incision, less physiological interference, faster healing, and use of simple and convenient surgical instruments.

Bone nonunion is usually accompanied by fixation failure such as plate breakage and screw loosening, which both require replacement involving internal fixation [21]. Here, we removed the original plate by using a minimally invasive method consisting of percutaneous removal of the screws and plate through small incisions. A new plate was implanted using MIPPO technology from another small incision, which effectively protected the blood supply of the bone periosteum, stabilized the fractured end, and provided favorable conditions for nonunion healing.



**Table 4.** Functional outcome scores on the SMFA questionnaire assessed at 6 weeks and AOFAS ankle-hindfoot score assessed at final visit.

Case	Bothersome	ADL	Emotion	Arm & hand	Mobility	Function	AOFAS ankle-hindfoot score
1	22	64	35	7	42	43	98
2	34	62	42	3	41	34	92
3	20	48	42	6	48	36	95
4	36	43	31	3	37	24	76
5	18	51	47	6	47	39	97
6	14	50	46	7	44	36	93
7	27	61	33	7	36	30	90
8	20	40	42	6	45	35	94
9	31	39	40	6	35	24	78
10	28	48	46	3	48	42	97
11	15	52	43	5	46	46	100
12	10	49	41	6	47	36	93
13	27	57	37	4	44	34	92
14	20	60	38	5	40	30	89
15	16	43	41	7	45	38	95
16	19	48	40	3	44	43	97
17	30	52	32	5	34	26	82
18	22	50	38	6	43	41	96

ADL – activity of daily living.

Various treatment methods have been attempted to cure tibial nonunion. For instance, reamed intramedullary exchange nailing including correction of axis alignment was shown to be a safe and effective treatment for tibial nonunion, with a high rate of bone healing and good functional long-term outcome [22]. Richmond et al. reported that patients with distal tibial nonunions treated with statically locked intramedullary nails achieved high healing rate (29/32, 90.6%) [23]. Bryce et al. reported that 87 of 94 patients who had aseptic tibial nonunions (92.6%) healed following slow gradual compression across the nonunion site with a circular external fixator [24]. Our results showed MIPPO technology combined with onionskin bone grafting in all 18 cases achieved clinical bony healing (100%), indicating a higher healing rate than that reported in previous studies. The average healing time was 13.1 weeks (range: 4–24 weeks) with scarified SMFA scores and no obvious complications including deformities, fixation failure, infection, vascular or nerve injuries, or skin necrosis. These data verified that this novel method is a safe and effective intervention for the treatment of tibial nonunion, even if the treated patients have poor soft-tissue condition.

The previously mentioned mainstream bone grafting technique includes structural bone grafting, iliac bone grafting, and granule bone grafting. MIPPO combined with onionskin-like autologous bone grafting has several advantages: (1) A limited small incision is applied to clean the end of the bone nonunion leading to less bleeding. (2) The periosteum and scar are not removed and hence, the local soft-tissue blood supply is protected. (3) Autologous iliac bone graft can provide bone conduction matrix, osteoinductive factors, and osteoblasts to achieve bone conduction, osteoinduction, and osteogenesis, respectively. (4) The technique of onionskin bone grafting can provide sufficient mechanical support, and the implanted cancellous bone strip acts as a bridge, which is conducive to fracture healing. (5) The overall infection rate is low, as supported by no reports of infections in our study. (6) No skin necrosis occurred in this study, and patients were very satisfied with the length of the incision. (7) The patients' postoperative function was good and the nonunion healing rate was high with limited complications, which significantly shortened the duration of hospital stay and reduced costs.

Our study has several limitations. First, the technique is slightly complicated, as it is a combination of MIPPO technology, small-incision end-cleaning technology, minimally invasive bone grafting technology, and bone nonunion technology. Hence, it is only suitable for very skilled practitioners. Second, the formation of callus is mostly limited to the end of the bone, with much less external callus formation around it. The bone strength is slightly lower than normal bone tissue after healing of the nonunion. Third, this study's retrospective design prevents comparisons with other technical groups. Lastly, the sample size of this study was small and the follow-up period was short.

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## Conclusions

The innovative application of MIPPO technology combined with a new onionskin autologous bone grafting technique can preserve bone blood supply, promote fracture healing, and reduce the risk of infection and re-fracture. This is a very promising treatment for tibial nonunion, and it is especially suited for patients with poor soft-tissue condition.

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