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ORIGINAL STUDY

Minimally Invasive Plate Osteosynthesis (MIPO) technique for complex tibial shaft fracture

Sungwook Choi, Tong Joo Lee, Shinil Kim, Changhee Cho, Seungjae Shim, Hyunseong Kang

From the Department of Orthopedic Surgery, Jeju National University School of Medicine, Jeju, South Korea

TTo evaluate the clinical and radiological results of the treatment of complex tibial shaft fracture (AO/OTA type 42-C) with minimally invasive plate osteosynthesis(MIPO).

Twenty patients diagnosed with complex tibial shaft fracture without extension to the articular surface and treated with MIPO, including 9 cases of AO/OTA type 42-C2 and 11 cases of AO/OTA type 42-C3, 6 of which were open fractures. External fixation was used for open fractures until the soft tissue damage had healed; then, 2nd stage operation with MIPO was performed to stabilize the fracture. Each patient was followed up for a minimum of 12 months.

The mean time to union was 20.1 weeks. Delayed union was observed in 4 cases. Angular deformity, length shortening and non-union were not observed.

Severely comminuted and open fractures of the tibial shaft may benefit from temporary external fixation prior to performing MIPO.

Keywords : Complex tibial shaft fracture, Minimally Invasive Plate Osteosynthesis, Temporary external fixation, Locking compression plate.

INTRODUCTION

Complex tibial shaft fractures are commonly caused by high-energy traumas, such as traffic accidents and fall from height. Tibial shaft fractures are among the most difficult injuries to treat because of the precarious blood supply to the tibia and the relatively low amount of soft tissue covering the tibia, which often leads to open fracture, severe complications and major disabilities *(14,1)*. Common issues in the treatment of tibial shaft fractures are nonunion, malunion, pain, osteomyelitis, infection, and/or broken implants *(28)*. A complex fracture is a fracture with one or more intermediate fragment(s) or with segmentation for which reduction does not generate contact between the main fragments

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■ Sungwook Choi[1], M.D., Ph.D.
■ Tong Joo Lee[2], M.D. Ph.D.*
■ Shinil Kim[1], M.D.
■ Hyunseong Kang[1], M.D.
■ Changhee Cho[1], M.D.
■ Seungjae Shim[1], M.D.

[1]*Department of Orthopedic Surgery, Jeju National University School of Medicine, Jeju, South Korea.*

[2]*Department of Orthopedic Surgery, Inha University Hospital, Incheon, South Korea.*

Correspondence : Hyunseong Kang, Department of Orthopedic Surgery, Jeju National University School of Medicine, Jeju, South Korea, Aran 13gil 15, Jeju, South Korea 690-767, Tel: +82-(0)64-717-1690, Fax: +82-(0)64-717-1131.

E-mail : oskanghs@gmail.com

(21). The management of such fractures remains controversial, but complex fractures with severe comminution and those treated with two-staged delayed reduction after soft-tissue healing has some intraoperative difficulties to do intramedullary nailing, despite some reports that have indicated satisfactory results in some of these fractures with the development of locking nails *(9,13)*. Known disadvantages of this approach include malunion with rotational and axial malalignment and knee pain *(11)*.

For open fractures, soft tissue injury should be managed primarily with temporary fixation, and delayed reduction can be considered after soft tissue healing *(7)*.

Minimally invasive plate osteosynthesis (MIPO) is a technique that aims to reduce iatrogenic soft tissue injury and damage to the bone vascularity and preserve the osteogenic fracture hematoma *(8, 12)*. In this retrospective study, we report our results and experiences with MIPO for the treatment of high-energy complex tibial shaft fractures, with a focus on fracture and soft tissue healing, infection rates and other observed complications.

MATERIALS AND METHODS

Patient and fracture characteristics

We reviewed 20 patients with complex tibial shaft fractures that occurred from March 2006 to March 2013 at two university hospital trauma centers. Patients with fractures marked as displaced on articular surfaces, ligament injury in the same limb, multiple fractures, poly-trauma with an injury severity score > 16, brain trauma and pathological fractures were excluded (Figure 1).

The 20 included patients (18 men and 2 women) had a median age of 48.2 years (range: 16–82 years). Fifteen patients were injured by traffic accidents, 3 patients fall from height, and 2 patients experienced a direct trauma (Table I).

Anteroposterior and lateral plain radiographs of the lower leg, including the ankle and knee joint and 3D reconstructed computerized tomography (CT) scan images were obtained to establish the fracture pattern, classify the fracture and perform pre-operative planning.

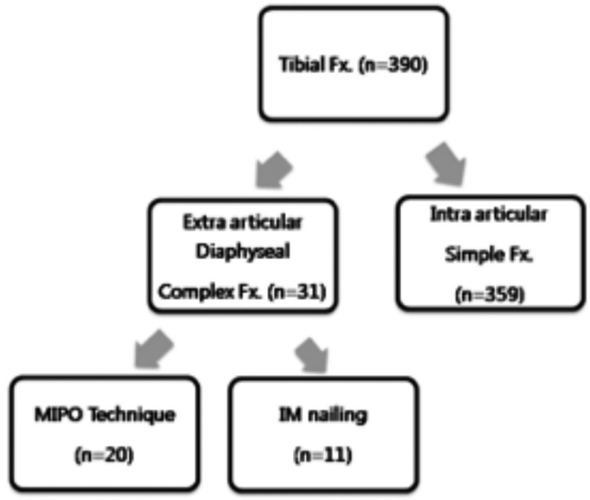

Fig. 1.

Based on the AO/OTA classification system, 9 cases were 42-C2 type and 11 cases were 42-C3type (23). Open fractures were classified according to the Gustilo & Anderson classification system, and there were 3 cases of type IIIA and 3 cases of type IIIB open fractures *(10)*.

Open fracture management

In the majority of open fracture cases, irrigation and debridement procedures were performed before stabilization. Patients received intravenous antibiotics initially, and surgery was performed following a period of temporary fracture stabilization with a bridge external fixator, to allow for soft tissue healing.

We utilized a two stage protocol: In the first stage, an external fixator was used for reduction of relative alignment, length and temporary fixation after debridement followed by soft tissue healing. In the second stage, locked plates were placed for definitive internal fixation, using MIPO *(7)*.

Surgical technique

All cases were operated on using the MIPO technique under fluoroscopic control. The patient was placed in the supine position on the operating table, and a tourniquet was applied without exsanguinating the leg. Indirect reduction of the fracture was achieved and maintained with calcaneal traction. The skin was incised approximately 2-4cm distal or proximal to the fracture site depending

Table I. — Demographic data

Case	Age	Gender	Injurymechnism	AO†	G-A‡	Plate position	Fibula Fracture	Associated injuries/ co-morbidities	Ex-Fix
1	66	M	Bike TA*	42-C2	IIIA	Lateral	O	Peroneal neuropathy	O
2	73	M	Bike TA	42-C2	IIIB	Lateral	O	Peroneal neuropathy	O
3	21	F	PedestrianTA	42-C2		Medial	O		X
4	41	M	PedestrianTA	42-C2	IIIB	Lateral	O		O
5	48	M	PedestrianTA	42-C2		Lateral	O	SDH§, bladder rupture	X
6	62	M	Slip down	42-C2		Medial	X		X
7	16	M	PedestrianTA	42-C3		Medial	O		X
8	57	M	PedestrianTA	42-C2		Lateral	X	liver laceration	X
9	53	F	Slip down	42-C3		Medial	O		X
10	62	M	Trauma	42-C2		Lateral	O		X
11	22	M	PedestrianTA	42-C3	IIIA	Medial	O		O
12	38	M	Fall from height	42-C3		Medial	O		X
13	40	M	Slip down	42-C3		Medial	O		X
14	82	M	PedestrianTA	42-C3	IIIA	Lateral	X		X
15	61	M	Bike TA	42-C3		Medial	X		X
16	32	M	PedestrianTA	42-C3	IIIB	Lateral	O		O
17	55	M	PedestrianTA	42-C2		Lateral	O		X
18	44	M	PedestrianTA	42-C3		Lateral	O		X
19	39	M	Slip down	42-C3		Medial	O		X
20	53	M	PedestrianTA	42-C3		Dual	O		X

* TA: Traffic accident, †AO: AO classification,‡ G-A: Gustilo-Anderson, §SDH: Subdural hemorrhage,|| Ex-Fix:External Fixation

on the fracture location, and the pre-contoured locking compression plate (LCP) (Synthes, Paoli, PA) was fed subcutaneously across the fracture site without dissection of the periosteum if it remains intact. A locking drill guide was introduced into the end of the screw hole and used as a "joystick" to push the plate and reduce the displacement *(2,30)*. Following insertion of the plate, correct positioning of the plate was confirmed by a minimum of two fluoroscopy views. One locked screw was placed in the end hole at the site of insertion. Fracture reduction was then reconfirmed by fluoroscopy before placing a second screw at the opposite end of the plate through a stab incision. Fluoroscopy was performed again to check alignment. With separate stab incision, additional fixation was achieved with screws at either end of the plate so at least three screws on either side.

The placement of a locking compression plate (LCP) using the MIPO technique minimizes the trauma to the injured zone, preserves the circulation around the fracture site and provides better fixation in the osteoporotic bone. The plate was placed on the medial or lateral aspect of the tibia depending on the level of the fracture, and dual plating was used to increase the stiffness of the construct in

Fig. 2.

1 case for which a single plate did not provide sufficient stiffness of the construction due to severe comminution and bone loss *(4)*.

Postoperative assessment

Radiologic examinations were performed at the time of initial callus formation and bridging of the callus. Radiological bone union was defined as bridging of the callus in 3 or 4 cortices on follow up radiographs. If a fracture was in the process of union but had not completely united at six months, it was considered a delayed union. Nonunion was defined as a fracture that did not heal within 9 months. Malunion was defined as a rotational deformity of

Table II. — JEJU- LOWER EXTREMITY TRAUMA SCALE (JLETS)

Subject	Range	Points
I. PAIN : VAS SCORE (10 points)	0~1	10
	2~3	8
	4~5	6
	6~7	4
	8~9	2
	10	0
II. Activity Score (30 points)	1.Standing	0 1 2 3
	2. Walking	0 1 2 3
	3. Ascending stairs	0 1 2 3
*Scale of difficulty:	4. Descending stairs	0 1 2 3
3 = None	5. Running	0 1 2 3
	6. Sitting	0 1 2 3
2 = Mild	7. Rising from sitting	0 1 2 3
	8. Rising from bed	0 1 2 3
1 = Moderate	9. Bending to floor	0 1 2 3
0 = Extremely	10. Heavy deomestic duties	0 1 2 3
III. ROM – flexion contracture	< 5°	10
	5°~9°	8
affected joint	10°~14°	6
	15°~19°	4
: hip / knee/ ankle (10 points)	20°~24°	2
	25°	0
IV. Tenderness at fractured site (5 points)	No	5
	Yes	0
TOTAL Points	( )/ 55	
*Additional questions		
IV. Full Weight Bearing period (weeks)	( )Weeks	

more than 10° or an angulation deformity of more than 10° or shortening by more than 20 mm.

To assess functional outcome, we developed an evaluation system for lower extremity trauma called JLETS (JEJU- LOWER EXTREMITY TRAUMA SCALE) (Table II). The questionnaire examines the following 3 categories: pain, assessed by the visual analogue scale (VAS) pain scoring system (10 points), activity score (30 points), range of motion (ROM) (10 points), and tenderness of the fractured site (5 points).

Full weight bearing period was also included in this questionnaire. Functional outcome measures were examined at a final follow-up at a minimum of 12 months after surgery.

Table III. —Follow-up for open fracture patients

Case	G-A*	Interval to MIPO (weeks)	Callus (weeks)†	Union (weeks)‡	Angulation	FWB (weeks)§	JLETS//
1	IIIA	5.8	22	30	1.74	22	19
2	IIIB	5.1	9	14	4.72	12	19
4	IIIB	4	13	24	0	14	21
11	IIIA	3.7	13	20	2.1	13	25
14	IIIA	3	12	14	1.5	13	23
16	IIIB	13	26	35	6.06	30	19

* G-A: Gustilo-Anderson, †Callus formation, ‡Union time, §Full weight bearing after 1st stage operation, // JEJU- LOWER EXTREMITY TRAUMA SCALE

Table IV. — Follow-up for closed fracture patients

Case	Callus (weeks) *	Union (weeks) †	Angulation	FWB (weeks)‡	JLETS§
3	20	32	1.83	24	25
5	11	21	2.17	12	25
6	6	18	2.3	8	25
7	6	12	1.72	8	25
8	7	11	2.7	8	25
9	11	24	0.17	13	25
10	11	20	1.95	18	23
12	10	18	4.3	12	25
13	12	24	0.3	16	25
15	11	19	2.3	14	23
17	8	12	1	10	25
18	14	26	3.2	18	25
19	8	14	4.56	10	25
20	8	12	3	10	25

*Callus formation, †Union time, ‡Full weight bearing after operation, §JEJU- LOWER EXTREMITY TRAUMA SCALE

Other complications were neurologic deficits directly related to the procedure, presence of infection sign, and any other complaints of patients.

Postoperative management

A long leg splint or removable long leg splint was applied and follow-up X-rays were reviewed 14 days postoperatively. Patients were reviewed at intervals of 4 weeks until bone union and intervals of 3 months after bone union. The day after the operation, patients were encouraged to start ROM exercises of the joint (after 2nd stage operation in case of external fixation has done primarily. Toe-touch mobilization with a non-weight bearing crutch support was permitted at approximately 1 week. Partial weight bearing with crutch support was permitted at 4 weeks. Full weight bearing was permitted when pain was absent and callus formation was radiologically confirmed.

RESULTS

Six patients with open fractures underwent temporary fracture stabilization with AO/ASIF external fixator (Synthes, Paoli, PA) or Illizarov external fixator (Smith & Nephew, Memphis, TN) within 24 hours after the trauma and the MIPO technique was performed to stabilize the fracture after the soft tissue had completely healed (Table III).

The mean time between the performance of external fixation and definitive MIPO was 5.8 weeks (range: 3~13 weeks).

The mean time to union was 20.1 weeks (range: 11–35 weeks) and four patients had delayed union (2 patients with open fracture and 2 patients with closed fractures). There was no case of nonunion.

Anatomical alignment was achieved in all cases. At the time of this report implant removal had been carried out in 13 patients, and the mean time until removal was 23.6 months (range: 12~86 months). We have not encountered any problems with plate removal and no implant have failed.

Final functional outcomes were assessed with the JLETS system: The mean VAS score was 0.4 point (range: 0-2 points) and the mean activity score was 27.5 points (range: 18-30 points). Among 20 patients, 17 patients had no pain with VAS score categories and rest of them (3 patients) scored 8 of 10 with light pain (VAS score: 2). 12 patients had no difficult on daily activity even running and heavy domestic duties (activity score: 30 points) and 7 patients had no complaint on walking and ascending stairs but had difficulties on running or/and bending to floor or/and heavy domestic duties (activity score: 22-28 points). A patient with peroneal neuropathy had difficulty on descending stairs and bending and heavy domestic (activity score: 18 points). 1 patient had focal tenderness on fractured site.

On a scale of 0 to 55, the mean score was 51.3 points (range: 38–55 points). And the mean range of motion at the knee was extension 1.3 to flexion 133.8 and the mean ankle range of motion was dorsiflexion 13.7 to plantar flexion 39.6. Average time to full weight bearing was 14.3 weeks (range: 8-30 weeks) (Table III and IV).

Prophylactic fasciotomy was performed in one patient; a 32-years old male with open tibial fracture (AO/OTA type 42-C, Gustilo type IIIB) (case 16) initially had lateral fasciotomy at the emergency room to prevent compartment syndrome. The fracture was stabilized with Illizarov external fixator. With continuous wound care, soft tissue healed in 3 months and MIPO was done after 13weeks from days of external fixation (Figure 3).

Superficial wound infection also occurred after MIPO in one case; a 22-years old male with Gustilo type IIIA (case 11) and with continuous care, wound healed after 3 months.

DISCUSSION

Proximal femoral fracture fixation, despite being the use of external fixation for the initial management of severe open tibial fractures has been proven to be successful in providing adequate skeletal stability and access to the wound *(22)*. External fixation may also be helpful in the treatment of high-energy trauma patients with multiple injuries or comorbid medical problems, which can delay

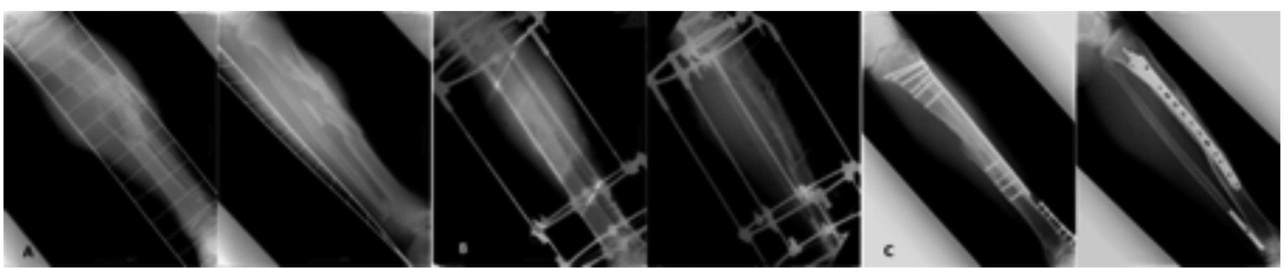

Fig. 3.

definitive internal fixation. In our study, the mean time between external fixation and definite internal fixation was 7.3 weeks. It is comparable with other reports of two staged operations for the treatment of open tibia fracture *(22, 29)*.

Although intramedullary nailing is considered the treatment of choice for most displaced tibial shaft fractures, tibial fracture stabilization, especially of the proximal or distal fragment, is associated with a high incidence of rotational malalignment. This is attributed to muscular forces that displace the fracture and to instability of the fracture due to the play of the nail along the interlocking screws *(15)*. Krettek described the clinical application of blocking screws, termed ‘Poller screws’, as a tool for the prevention of axial deformities of proximal and distal fractures of the tibia during intramedullary nailing *(18,19).* Additionally, intramedullary nailing is a biological method of fixation, it suffers from the limitation of inadequate fixation due to a small fragments, and this is even more of an issue in the presence of comminution *(16,25)*. Sargeant et al. suggested that cortical necrosis is less likely to occur with a loosely fitted intramedullary nail than with a snugly fitted reamed nail. Reaming of open fractures has been found to spread contamination from the open wounds along the medullary canal and to strip the small fragments of bone from the soft tissue attachments *(27)*.

Usually in the classic parapatellar or patellar tendon-splitting approach, tibial intramedullary nails are inserted with the patient’s hip and knee hyperflexion (> 90°). But there are difficulties to maintain the fracture reduction with knee flexion when inserting tibial nails in complex tibial shaft fracture *(24)*.

Suprapatellar approach in a semi-extended position place the knee in 15-30° flexion helps to prevent malalignment and maintains the mechanical axis of the lower extremity *(26)*, but it has difficulties in surgical technique during fracture reduction and tibial nail insertion.

Conventional plate osteosynthesis (CPS) of long bone fractures is highly focused on anatomical reduction of the fracture and the generation of absolute stability; thus, CPS is especially suitable for type A and B fractures. Nevertheless, for complex fractures, blindly pursuing anatomical reduction without treating the soft tissue damage will decrease the blood supply to the area of the fracture resulting in extension of the operation time and increased risks of infection and nonunion.

Over the past ten years, bridging plate osteosynthesis has been developed for the treatment of multi-fragmentary shaft fractures. The technique minimizes the soft tissue trauma to the injured zone, which theoretically provides better preservation of the blood supply around the fracture area *(20)*. Even though MIPO requires greater exposure to radiation because of the performance of closed indirect reduction, it may be advantageous for the treatment of multi-fragmentary shaft fractures because it minimizes soft tissue damage and revascularization of the fracture fragments and lowers the risks of infection, nonunion and other complications. We preferred MIPO technique because of easier approach than IM nailing which requires pollar screw or additional mini-plate fixation in tibial shaft fracture with extension to proximal or distal 1/3 level.

Collinge and Sanders described indirect fracture reduction and percutaneous plating techniques for the treatment of fractures in the lower extremity as novel biological plating techniques *(6)*.

However, some studies have also revealed disadvantages of the MIPO technique. Hasenboehler et al. reported that although MIPO seems more advantageous for soft tissue and bone biology, prolonged healing times were observed in patients with simple fracture patterns *(11)*. Khoury et al. noted that for the MIPO technique, reduction should be performed cautiously due to the tendency of sagittal plane malreduction *(17)*. The MIPO technique only requires realignment of the tibial mechanical axis, and clear exposure of the fracture is not necessary. An intraoperative image intensifier may help with the closed reduction and avoids excessive disturbance of the fracture fragments. Cadaver research suggests that the MIPO technique may carry a higher risk of injury to the saphenous nerve and long saphenous vein *(5)*.

Currently, there is no appropriate tool for evaluating the clinical outcome after surgical treatment for tibial shaft fracture. There are some outcome assessment scales for the lower extremity, but they are difficult to apply to tibial shaft fractures because they are specific questionnaires for the region of each joint. Therefore, we developed an evaluation system for lower extremity trauma called JLETS based on the visual analogue scale (VAS) pain scoring system and modification of Western Ontario and McMaster Universities Arthritis Index (WOMAC) *(3)*.

The limitations of our study include the small number of patients, its retrospective nature and potential user bias because the surgeon could not be blinded to the locking plate used in the treatment; however, the plate used was largely dependent on the availability of implants. And, utilizing our new functional outcome scoring system which relatively lack of validated evidence also limitation of our study.

In conclusion, our findings indicate that the MIPO technique is a reliable alternative method of stabilization for high-energy complex tibial shaft fractures with a satisfactory rate of union and low complication rate.

Severely comminuted and open fractures of the tibial shaft in the presence of extensive soft tissue and bone damage may benefit from external fixation for initial management followed by delayed internal fixation after the completion of soft tissue healing.

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