Minimally invasive plate osteosynthesis for the treatment of high-energy tibial shaft fractures

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Background

The most notable change in the treatment of fractures has been the shift from the mechanical aspects of internal fixation with absolute stability and primary bone union as the goal to the biological aspects of internal fixation with relative stability and healing with callus as the preferred method, with a huge focus on preservation of the blood supply of bone and soft tissue to ensure the continued vitality of the individual fragments to improve fracture healing. Percutaneous plate fixation minimizes soft tissue compromise with decreased incidence of wound breakdown and deep infection. It also preserves the vascularity of the bone fragments, and thus reduces the time for union, decreases the need for bone grafting even in comminuted fractures, and also decreases the incidence of nonunion, which requires a second major open intervention.

Aim

The aim of this study was to evaluate the outcome of minimally invasive plate osteosynthesis for the treatment of high-energy tibial shaft (upper and middle thirds) fractures in adults using conventional nonlocked plates through the medial approach.

Patients and methods

This prospective study included 16 adult male patients who had high-energy closed tibial shaft fractures (upper and middle thirds) with varying degrees of displacement and comminution. All patients were evaluated clinically and radiologically before and after surgery, followed up for a mean time of 14 months postoperatively, and evaluated radiologically and functionally according to the Association for the Study and Application of the Methods of Ilizarov (ASAMI) scoring system. All patients were treated using conventional nonlocked plates inserted percutaneously on the medial surface of the tibia.

Results

All the fractures united with a mean union time of 16.2 weeks, ranging from 13 to 36 weeks. Clinical and radiological outcomes according to the ASAMI scoring system in this study showed excellent results in 14 patients, representing 87.5% of the studied group, and good results in two patients, representing 12.5% of the studied group. No neurovascular complications, no persistent limitation of the knee or ankle motions, no deep wound infection, and no implant failure occurred in any of the patients until the last follow-up, and none of the patients required a second major open intervention.

Conclusion

The minimally invasive percutaneous plate fixation technique is an effective method of stabilization for closed tibial shaft fractures, yielding good bone alignment and protecting soft tissues, leading to higher union rates with good functional outcome. The use of conventional nonlocked plates applied through the medial approach decreases the surgical time and the risk of postoperative compartmental syndrome.

Keywords:

closed comminuted tibial shaft fractures, high-energy trauma, improved functional outcome, minimally invasive plate osteosynthesis

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Introduction

Plate osteosynthesis is recognized as the treatment of choice for most articular, many metaphyseal, and a few diaphyseal fractures. Biological plating techniques are those in which blood supply to the fractured fragments is maximally preserved. The objective of biologic fixation is to aid the physiological process of bone healing wisely and optimally, with minimal operative intervention [1,2].

Biological fixation focuses on soft tissues and vascularity of the bone. This technique described by Mast *et al*. [3] uses 'indirect reduction methods' using distractors, traction tables, or manual traction to minimize direct fracture exposure and soft tissue stripping. In 1997, Wenda *et al*. [4] and Krettek *et al*. [5] introduced a percutaneous plating technique called 'minimally invasive plate osteosynthesis (MIPO)'. Fractures fixed by MIPO do not show primary bone healing as found in rigidly fixed fractures with dynamic compression plate. The bone healing in case of MIPO depends on the formation of bridging callus. Minimally invasive plating techniques reduce surgical trauma and maintain a more biologically favorable environment for fracture healing, reducing the risks of infection and nonunion [6].

Patients and methods

Sixteen adult, male patients with closed tibial shaft fractures were included in this prospective study, which was carried out in the Orthopedics Department of Benha University Hospital from March 2012 to April 2014; the patients ranged in age from 23 to 49 years (mean 32 years). Fractures were classified according to the AO/OTA classification; all cases were complex multifragmentary, comminuted type C fractures. In terms of the fracture site, 12 patients, representing 75% of the studied group, had proximal one-third tibial fractures, whereas the remaining four patients, representing 25% of the studied group, had metadiaphyseal fractures mainly at the junction of the upper and middle thirds of the tibia. The injury/surgery interval varied from 1 to 12 days, with a mean of 4 days. Conventional nonlocked plates applied on the medial subcutaneous surface of the tibia were used in all patients. Patients were followed up for a mean time of 14 months postoperatively and the results were evaluated according to the Association for the Study and Application of the Methods of Ilizarov (ASAMI) scoring system.

Inclusion criteria were as follows: adult patients with high-energy closed tibia fractures, extra-articular proximal third, or diaphyseal fractures.

Exclusion criteria were as follows: open fractures, intra-articular fractures, distal third tibial fractures, pediatric fractures, pathological fractures, and patients with any other associated ipsilateral or contralateral long bone fractures.

Preoperative evaluation of the patients

Proper assessment of the history of the nature of injury and a careful evaluation of other associated injuries were carried out in the emergency room, with a focus on the affected leg. Examination of the soft tissue envelope was performed for the presence of ecchymosis, blisters, superficial abrasions, deep contusions, hemorrhagic blisters, or open fractures that can occur in such injuries (Fig. 1). Palpation for the distal pulse, capillary refill, swelling and tension of the calf muscles are important to exclude compartment syndrome. Radiological evaluation included the standard trauma survey for high-energy injured patients. Anteroposterior (AP) and lateral views of the affected legs were obtained to evaluate the fracture pattern and for classification (Fig. 2). Then, an above-the-knee slap was administered to relive pain and swelling.

Figure 1

Skin abrasions and ecchymosis in two patients with high-energy closed tibial shaft fractures.

Operative procedure

Under complete aseptic conditions, patients were operated on a standard radiolucent table to enable access to the image intensifier. Under spinal anesthesia, in the supine position and without a tourniquet applied, about 3 cm straight (Fig. 3a) or oblique (Fig. 3b) skin incisions were made opposite the tibial tubercle midway between the tubercle and the posterior edge of the tibia, starting at the level of the tibial tubercle and extending proximally toward the joint line. By using an oblique incision in line with the insertion of the pes anserinus, the infrapatellar branch of the saphenous nerve is much more protected and also the head of the plate either the L or the T buttress plate can be applied easily and placed on the medial surface of the proximal part of the tibia. A subcutaneous tunnel was created using a periosteal elevator extending distal to the fracture site. The appropriate length of the plate (L or T buttress plate) was determined by placing the plate along the medial aspect of the leg and adjusting it under the C-arm so that the proximal end of the plate was at least 1 cm below the joint line and the distal end extended at least three screw holes beyond the distal limit of the tibial fracture after the correct length of the leg was restored and maintained by closed indirect reduction using manual traction.

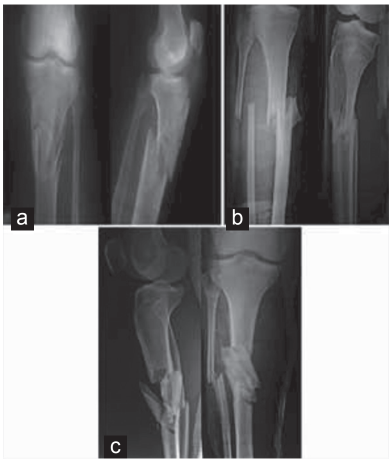
The chosen plate with an appropriate length, which usually does not need to be contoured, was then slid subcutaneously and extraperiostally across the fracture site to reach the distal fragment. Another 4 cm incision was made distally where the plate ended.

After proximal fixation of the plate by at least three cancellous screws, distal fixation was performed using another three or four cortical screws that were inserted while maintaining traction to correct both the length and the angulation in all planes before closure of wounds without suction drains (Figs. 4 and 5).

Before fracture stabilization, ligamentous injuries could be missed or underestimated because of movement at the fracture site, especially with upper third tibial fractures. Clinical evaluation of the ipsilateral knee ligaments after fracture fixation was performed while the patient was still anesthetized to detect and document any ligamentous injuries that could affect the postoperative regimen and functional recovery.

If the knee was stable, there was no need for a cast or a brace. In patients with ligamentous injuries and instability, an above-knee cast was applied for 4 weeks (Fig. 6) to relieve pain, swelling, and enable the ligaments to heal. An above-knee cast was also applied in one patient with a comminuted metadiaphyseal fracture to augment and protect the fixation, and then active range of motion (ROM) was initiated after 4 weeks.

Figure 2



(a) Case 1: multifragmentary, comminuted upper third tibial shaft fracture (4.1 c-3). (b) Case 2: comminuted upper third tibial shaft fracture (4.1 c-1). (c) Case 3: multifragmentary, comminuted middle third tibial shaft fracture (4.2 c-3).

The postoperative regimen

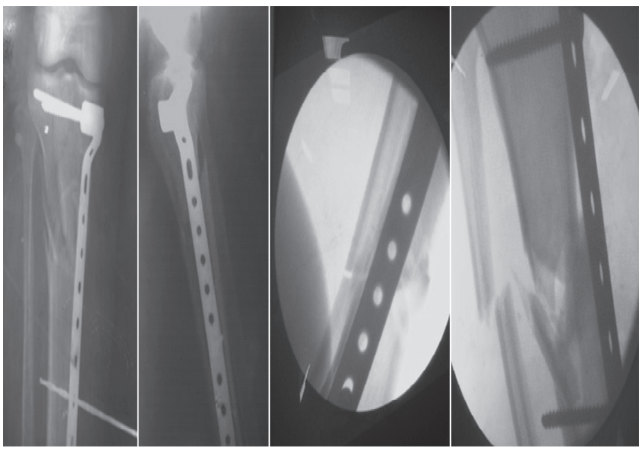
After recovery from spinal anesthesia, examination was performed for active movements of the ankle and toes. Compartment syndrome should be kept in mind in the postoperative period, with a special focus on distal pulse, capillary refill, and calf muscles' tension. Quadriceps strengthening exercises along with active range of movements of the knee and ankle joints in cases not protected in casts were started the day after surgery.

Wound inspection was performed on the second postoperative day before discharge. Third-generation intravenous cephalosporins, antiedematous injections, and analgesics were administered for 7 days, followed by oral antibiotics for another 7 days until removal

Figure 3

(a) Straight proximal skin incision for plate insertion. (b) Oblique proximal skin incision for plate insertion.

Figure 4



Intraoperative radiological assessment of fracture reduction either by a C-arm or with a portable radiograph.

Figure 5

Small surgical wounds after minimally invasive plate osteosynthesis for tibial shaft fractures (closed without drains).

of sutures. AP and lateral views of the affected legs were obtained to assess the adequacy of reduction and fixation of the fracture in terms of alignment in both planes, restoration of length, proper length of the plate, and proper distribution of the screws proximal and distal to the fracture site.

No weight bearing for 4 weeks postoperatively was advised for all patients, followed by partial weight bearing as tolerated by each patient until early radiographic evidence of healing (appearance of callus both in the tibia and in the fibula) was observed (Fig. 7). Then, safe, nonprotected, full weight bearing was allowed. Regular follow-up was performed at 3-week intervals to assess progression until complete union, and then every 3 months, with evaluation of the clinical and radiological outcomes according to the ASAMI scoring system.

Results

The results were assessed according to the criteria of the ASAMI [7], which include both radiological and functional scoring systems.

Patients were followed up for a mean period of 14 months postoperatively (range 9–21 months). Radiologically, a fracture was considered united when bridging callus was present in at least three of the four faces of the fracture on AP and lateral radiographs.

All fractures united with a mean union time of 16.2 weeks, ranging from 13 to 32 weeks, with acceptable alignment in both AP and lateral views. According to the ASAMI, points to be considered radiologically are union, infection, deformity, and limb-length discrepancy, and cases are classified as excellent, good, fair, and poor.

Functionally, the results were evaluated according to four criteria, which included return to activity, pain, limping, range of motion of adjacent joints, and sympathetic dystrophy, and cases were also classified as excellent, good, fair, and poor.

Radiologically, excellent results were obtained in 16 patients (representing 100% of the studied group), with no patients with fair or poor results (Table 1).

Functionally, excellent results were obtained in 14 patients (representing 87.5% of the studied group). Good results were obtained in two patients (representing 12.5% of the studied group), with no patients with fair or poor results (Table 2). Thus, satisfactory results (excellent and good results) were

Table 1 Radiological results of patients in this study according to the association for the study and application of the methods of ilizarov scoring system

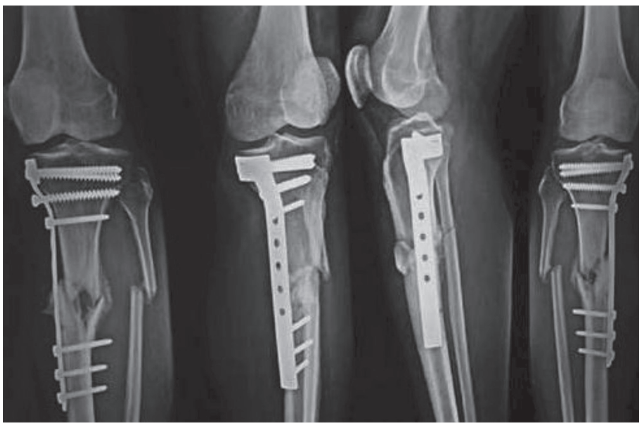
Bone results	Criteria	Number of patients
Excellent	Union No infection Deformity<7° LLD<2.5 cm	16
Good	Union+any two of the following: Absence of infection Deformity<7° LLD<2.5 cm	0
Fair	Union+any one of the following: Absence of infection Deformity<7° LLD<2.5 cm	0
Poor	Nonunion/refracture/union+infection+deformity>7°+LLD>2.5 cm	0

LLD, limb length discrepancy.

Figure 6

Above-knee cast applied in patients with ligamentous injuries and instability for 4 weeks with regular wound care.

Figure 7



The radiological clue for safe, nonprotected, full weight bearing is early healing (callus formation) of both fractures (tibia and fibula) in all views.

Table 2 Functional results of patients in this study according to the association for the study and application of the methods of ilizarov scoring system

Functional results	Criteria	Number of patients
Excellent	Active	14
	No limp	
	Minimum Stiffness (loss of<15° knee extension/<15° ankle dorsiflexion)	
	No RSD	
	Insignificant pain	
Good	Active with one or two of the following:	2
	Limp	
	Stiffness	
	RSD	
	Significant pain	
Fair	Active with three or all of the following:	0
	Limp	
	Stiffness	
	RSD	
	Significant pain	
Poor	Inactive (unemployment or inability to return to daily activities because of injury)	0

RSD, reflex sympathetic dystrophy.

obtained in all patients in the studied group (Figs. 8a and b and 9a and b).

There was persistent limping in the two patients with good functional results; in one patient, limping was because of limb-length discrepancy with shortening of about 1 cm because of inadequate restoration of tibial length. In the other patient, there was persistent knee instability that was only supported by a knee brace.

None of the patients developed iatrogenic neurovascular complications, deep wound infection, compartment syndrome, reflex sympathetic dystrophy, persistent limitations of knee and ankle motions, and implant failure until the last follow-up, and none of the patients required a second major open intervention to induce union.

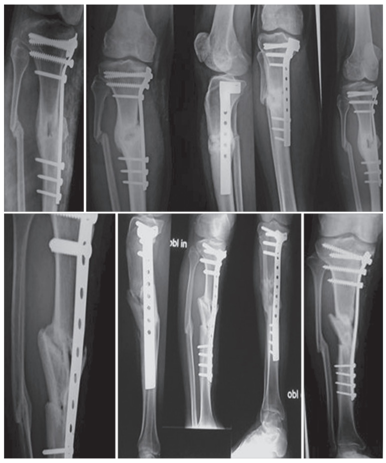
In one patient (case 3 presented in this study with a multifragmentary, comminuted, metadiaphyseal fracture at the junction of the upper and middle thirds of the tibia), no progression of union had occurred in three successive visits and by the 24th week of follow-up, it was considered delayed union that required an intervention. The fixation was stable with no infection or reflex sympathetic dystrophy; thus, a trial of a bone marrow injection was attempted to improve the fracture environment biologically and hence enhance the healing process.

Ten centimeter of bone marrow (aspirated from the iliac crest using the trocher and cannula of the bone marrow injection) was injected into the fracture site, piercing the fibrocartilaginous tissue at the comminuted area of delayed union after preparation of the leg and proper identification of the fracture site under the C-arm (Fig. 10). A sterile

Figure 8

(a) Case 2: full knee and ankle ROM, completely healed scars, and proper alignment with no limb-length discrepancy (LLD), the arrows represent no limb-length discrepancy (LLD). (b) Case 3: full knee and ankle ROM, completely healed scars, proper alignment, 1 cm LLD, the arrows represent 1 cm LLD.

Figure 9



(a, b) Case 2 and case 3, respectively: complete union with bridging callus in all views, no deformity, and no radiological signs of infection.

Figure 10

Bone marrow aspiration, percutaneous injection at the site of delayed union under the C-arm.

dressing was applied and the patient was advised to continue weight bearing. Radiological progression of healing was obvious over the next few visits until complete union with bridging callus in all views occurred after 36 weeks of fixation.

Discussion

It's very important to answer three questions that can help understand, analyze, and discuss the results of this study. The first question is why biological fixation? The second question is why use plates and not nails for such cases? The last question is why apply the plates on the medial surface of the tibia?

Why biological fixation?

Biological fixation can be defined as a method of fixation of fractures in which greater importance is given to the soft tissues and vascularity of bone during a surgical intervention to ensure the continued vitality of the individual fragments and to achieve improved fracture healing [8]; it also follows the biomechanical principles, which enhance bone healing and enable early mobility of the joints [9]. Biological fixation also reduces surgical trauma and maintains a more favorable environment for fracture healing, thus reducing the risks of infection and nonunion [6]. Biological fixation has the following advantages:

(1) Improved rates of fracture healing with decreased incidence of nonunion.
(2) Decreased incidence of infection.
(3) Decreased need for bone grafting or a second major open intervention.
(4) Ideal technique for the treatment of patients with multiple injuries.
(5) Early mobilization of the extremity is not only possible but also preferable.
(6) Decreased incidence of refracture after plate removal because of callus formation.

Why use plates and not nails?

Extra-articular proximal third tibial shaft fractures are challenging injuries and are notoriously difficult to treat, with higher rates of complications than those of diaphyseal tibial fractures, irrespective of the method used for treatment [10]. However, only a few studies comparing the biomechanical properties of the intra medullary (IM) nail versus plates for the treatment of a comminuted fracture of the proximal tibia have been published [11].

The natural bony anatomy and muscular attachments of the proximal tibia offer the perfect setup for a number of common deformities after fracture, with subsequent malalignment during intra medulary nai (IMN) placement. Muscular stresses through tendinous attachments contribute considerably toward producing these deformations [12]. The dynamic forces through the patellar tendon pull the proximal fragment into an apex anterior angulation, whereas the attachment of the pes anserinus usually causes valgus stress on the same fragment [13,14]. Before operative fixation, these forces create the potential for improper reduction and difficult reaming and suboptimal nail placement. During nailing of proximal fractures with the knee in hyperflexion, the patellar tendon again draws the proximal fragment into a procurvatum deformity [12]. Lang *et al.* [13] reported poor results with conventional techniques for IMN of proximal third tibial fractures: 84% of patients had 5° frontal or sagittal plane deformity; 59% had 1 cm or greater displacement; 25% had loss of fixation; and 28% required exchange nailing. Also, extensive damage to intramedullary circulation and local as well as general intravascular thrombosis because of tissue damage and fat intravasation because of high intramedullary pressure were observed during reaming and insertion of nails [15]. The IMN is associated with other complications such as compartment syndrome and anterior knee pain [16,17]. These early poor results led surgeons to shift away from the use of IMN for proximal third tibial fractures [18].

Several studies have reported high success rates with MIPO in complex periarticular fractures as well as comminuted metaphyseal and some diaphyseal fractures. Low-quality evidence suggests that MIPO could reduce fracture healing time, decrease the rate of postoperative delayed union and malunion, and decrease pain levels compared with interlocking intramedullary nailing [19,20].

Why apply plates on the medial surface of the tibia?

In a study carried out by Lee *et al.* [11] discussing the biomechanical analysis of operative methods in the treatment of extra-articular fracture of the proximal tibia, they found the IM nail to be the most stable implant for use in the treatment of comminuted extra-articular fractures of the proximal tibia. However, when it is difficult to achieve satisfactory reduction by nailing, dual locked plates may be a stronger implant for use in MIPO compared with lateral locked plating, which is currently being used.

During biomechanical testing of a simulated comminuted proximal tibial fracture model, the dual plates (DPs) proved to be stronger than the lateral plate in terms of ultimate strength. The performance of the DP construct may lend credence to the additional use of a medial locking plate [11].

The traditional lateral-plating systems offer little resistance to varus deformity; thus, adjuvant medial neutralization plating has been advocated to increase stability in fracture patterns with metaphyseal comminution. Gosling *et al.* [21], in a multicenter study, reported 23% postoperative malalignment and 14% loss of alignment when high-energy bicondylar proximal tibia fractures were treated only with a laterally placed less invasive stabilization system (LISS) plate. Phisitkul *et al.* [10] reported immediate postoperative and delayed loss of alignment in 22 and 8% of patients, respectively, when a lateral LISS plate was used in similar fractures. Egol *et al.* [22] carried out a laboratory study comparing dual plating with a single lateral LISS plate and similar results were reported by Ratcliff *et al.* [23]; in their cadaveric biomechanical study, they reported that the medial buttress plate provides significantly greater stability in static loading and improved stability with cyclic loading in comparison with a single lateral locking-plate stabilization.

The fibula carries 6–15% of the load of the lower extremity. A fracture of the fibular shaft associated with a tibial fracture usually heals in 6 weeks; thus, a healed fibula distracts a high percentage of the load as well as resisting compression at the tibial nonunion site [24].

The principle is that if the healed fibula distracts a high percentage of the load, it resists compression at the fracture site, which means that at the same time, it partially unloads the implants applied, which is undesirable in some cases; this could be beneficial in other situations in which the rapidly healing fibula can act as a lateral column strut, providing protection and support for a comminuted tibial fracture fixed medially by a MIPO nonlocked traditional plate. Therefore, theoretically, if the fixation is protected until early appearance of callus in both the tibia (medial column) and the fibula (lateral column), this could equal dual plating (DP), which was proved to be stronger than the lateral plate in terms of ultimate strength, without the hazards of dual plating (more soft tissue trauma medially and laterally, more affection of the blood supply of the fracture, longer operative time, more expensive procedures).

In all the patients studied, once callus appeared medially (tibial fracture) and laterally (fibular fracture), nonprotected, full weight bearing was found to be safe, with no complications in the form of loss of reduction, varus malalignment, and implant failure. Progressive weight bearing in the presence of biological, bridging, and nonrigid fixation leads to progressive formation of bridging callus.

According to the strain theory, an elastic flexible fixation that produces very small amounts of strain is compatible with the indirect type of healing with callus formation, provided that very small unstable gaps of high strain are avoided [25]. This condition is usually present in MIPO with indirect closed reduction, extraperiosteal dissection, anatomic alignment, and relative stability, which enables limited motion at the fracture site that creates secondary bone healing with callus formation.

The amount of this elastic motion is determined by the length, cross-sectional area, material properties of the plate, and the density and diameter of the inserted screws as well as the use of unicortical or bicortical screws [22,26].

In-vitro biomechanical studies [27,28] have made recommendations that long plates with limited number of screws are essential to achieve a sound, flexible fixation and to reduce implant failure. Despite the lack of so-called medial support, loosening and/or fatigue of the implant can be avoided by the production of early bridging callus, which yields efficient biological medial reinforcement. On the basis of the observations of Hente *et al.* [29], the effects of strain may be summarized as follows: the presence of dynamic relative deformation results in mechanical induction of callus formation.

The satisfactory results of this study are similar to the preliminary results obtained with the use of the medial approach and MIPO for complex proximal extra-articular fractures of the tibia in other studies of Krettek *et al.* [30] and Sirbu *et al.* [31]. In this study, in addition to the fact that the absence of the so-called medial support does not cause loosening and/or fatigue of the implant with subsequent loss of reduction or displacement once the fixation is performed biologically by bridging plates placed laterally because of the formation of early bridging callus, which results in efficient biological medial reinforcement, placement of the plate medially protects the comminuted fractures in the early postoperative period before the early appearance of bridging callus. Therefore, none of the patients developed early loss of reduction or varus angulation even before the appearance of callus.

The results in this study are also comparable with those presented by Oh *et al.* [32], who used double plating for unstable proximal tibial fractures using a minimally invasive percutaneous osteosynthesis technique; this supports the importance of the healed fibula, which augment, protect the fixation, and improve the mechanical properties of the entire construct, which includes a bridging tibial plate (medially) and a long, strong lateral strut formed by the healed fibula (laterally).

This biologically addressed double-column construct prevents varus malalignment, protects against implant failure, enables early ROM with full weight bearing, and reduces the healing time, leading to better functional outcomes.

The mean fracture healing time in this study (16.2 weeks) is also comparable with the fracture healing time in other patients in whom the same procedure was used and also comparable with other patients treated by interlocking intramedullary nailing; three studies reported that the fracture healing time was significantly shorter in the minimally invasive percutaneous plates group compared with the interlocking intramedullary nailing group [33–35]. Three other studies reported no significant differences in fracture healing times [36–38]. However, another study carried out by Hasenboehler *et al.* [39] documented prolonged healing time in simple-fracture patterns fixed using a bridge-plating technique. They explained and concluded that an absolute stable osteosynthesis is important in fracture management [39].

Conclusion

MIPO is an effective method of stabilization that can ensure both a mechanical and a biological environment needed for fracture healing. MIPO for the treatment of high-energy upper tibial shaft fractures in adults using conventional nonlocked plates through the medial approach is an easy, effective, and safe procedure with higher union rates, minimal complications, and good functional outcome.

Acknowledgements

Conflicts of interest

There are no conflicts of interest.

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