The role of an Ilizarov external fixator in the treatment of post-traumatic tibial nonunion in children

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Received 3 October 2011
Accepted 15 October 2011

The Egyptian Orthopedic Association 2013, 48:295–300

Background
Tibial fractures are the third most common long bone fractures in children. Acutely, they can be treated conservatively with cast immobilization and also surgically with external fixation, plate, and screws' fixation or intramedullary implants. Post-traumatic tibial pseudoarthrosis as a complication is relatively uncommon in children. This article reports our experience with the use of the Ilizarov external fixator in the treatment of post-traumatic tibial nonunion in children.

Patients and methods
Between 2003 and 2010, 14 child with post-traumatic tibial nonunion were treated in our department. The ages of the patients ranged from 4 to 13 years (mean 8 years, 6 months). All patients had open physes at the time of injury. Twelve patients were boys and two were girls. Twelve fractures involved the diaphysis, where two were confined to the distal metaphysis. There were 10 open fractures. There were five type IIIA, four type IIIB, and one type IIIC fractures, according to the classification of Gustilo. Of the 14 patients, three had infected nonunion. In this study, stabilization with a bifocal Ilizarov external fixator (acute shortening and compression at the nonunion site, and distraction osteogenesis of the tibia through metaphyseal corticotomy) was performed in all cases.

Results
The average duration of follow-up was 20 months (range 12–36). Union was achieved in all cases. Time to union ranged between three debridement of the nonunion site and only one bone to 9 months, with an average of 5.5 months. Six patients had a gap range of 2–4 cm after transport was grafted using an autogenous graft from the iliac crest. All the patients had almost equal leg lengths (leg-length discrepancy <1 cm) at the time of the final follow-up. One patient had 15° valgus deformity. One patient developed mild graft site persistent pain, which was relieved by analgesics. Superficial pin-tract infections developed in all patients; they were treated with oral antibiotics. All superficial pin-tract infections resolved without sequelae. There were no persistent deep infections or nerve palsies. There were no other significant complications.

Conclusion
Treatment of post-traumatic tibial nonunion in children by an Ilizarov external fixator is effective in restoring length, correcting alignment, and achieving solid bony union through a one-stage operation.

Keywords:
Ilizarov, post-traumatic tibial nonunion, tibial nonunion in children

Egypt Orthop J 48:295–300

1110-1148

Introduction

Tibial fractures are the third most common long bone fractures in children [1]. Acutely, they can be treated conservatively with cast immobilization and also surgically with external fixation, plate and screws' fixation, or intramedullary implants. Post-traumatic tibial pseudoarthrosis as a complication is relatively uncommon in children with closed fractures of the tibia and has an incidence of 7.5–8.3% in association with open tibial fractures [2–4]. The Ilizarov device is the classic example of a circular external fixator [5,6]. The introduction of this device and its method considerably changed our understanding of deformities and fractures and our ability to manage them. This article reports our experience with the use of the Ilizarov external fixator in the treatment of post-traumatic tibial nonunion in children.

Materials and methods

Between 2003 and 2010, 14 children with post-traumatic tibial nonunion were treated El Menia university hospital. Nonunion was diagnosed if the fracture failed to show clinical and radiographic union after 6 months from the initial injury according to the study by Wyrsch *et al.* [7]. The ages of the patients ranged from 4 to 13 years (mean 8 years 6 months). All patients had open physes at the time of injury. Twelve patients were boys and two were girls. The fractures were caused by an automobile-pedestrian accident (seven patients), an automobile-bicycle accident (four patients), fall from a height (two patients), and gunshot wound (one patient). Eight of the fractures were comminuted, four were transverse, and two were spiral. Twelve fractures involved the diaphysis, where two were confined to the distal metaphysis. There

were 10 open fractures. There were five type IIIA, four type IIIB, and one type IIIC fractures according to the classification of Gustilo *et al.* [8,9]. Five patients had associated injuries, which included three other fractures, one closed head injuries, and one abdominal injury. Of the 14 patients, three had infected nonunion (Table 1).

Initial treatment

All patients were initially examined and stabilized in the emergency department. Prophylaxis for tetanus and parenteral antibiotics were routinely administered in open fractures. After resuscitation, if needed, and assessment, all fractures were irrigated and debrided in the operating room. Bone fragments without soft tissue attachments were usually discarded. Wound coverage was provided with split-thickness skin grafts in two patients and a local muscle flap in two patients. Eight fractures were initially immobilized with monolateral external fixation and six with an above-knee plaster cast.

Definitive treatment

Resection of infected or devascularized bone at the nonunion site was performed (segments of bone were considered devascularized if the fragments were comminuted, stripped of all soft tissue attachment, and failed to bleed at exploration). Then, we applied an intramedullary free fibular graft from the same limb, followed by acute compression at the nonunion site. Pulses and capillary refill were checked for comparison. Intraoperative and postoperative Doppler were performed to monitor distal pulsation and detect any kinking of the blood vessels. If this was to occur, one would have to settle for less shortening until the pulse is returned again and then progressive shortening was continued. The wounds should be closed with nylon sutures before shortening the extremity to prevent wound gaping. Stabilization with a bifocaI Ilizarov external fixator (distraction osteogenesis of the tibia through metaphyseal corticotomy) was performed in six cases associated with bone gap and compression through excised nonunion site. Proximal corticotomy was performed if there was a residual gap at the nonunion site of more than 1 cm. The fracture was compressed 1 mm four times a day (Fig. 1). When union was achieved, the external fixator was progressively destabilized before removal. A plaster cast was applied to protect the limb as the callus consolidated. The process was monitored closely with serial radiographs.

Fracture healing was defined as bridging callus in a minimum of three cortices on anteroposterior and lateral radiographs. Fracture healed without deformity, defined as less than 10° of deformity in any plane, and less than 1 cm of shortening. Range of motion was measured in the ankle and knee joints.

Results

The patients were followed up both clinically and radiographically for at least 1 year. The average duration of follow-up was 20 months (range 12–36).

Fracture healing

Union was achieved in all cases. Time to union ranged between 3 and 9 months, with an average of 5.5 months.

Distraction osteogenesis

Six patients had a gap range of 2–4 cm after debridement of the nonunion site. In these patients, stabilization with a bifocaI Ilizarov external fixator was performed (acute shortening and compression at nonunion site, and distraction osteogenesis of the tibia through metaphyseal corticotomy).

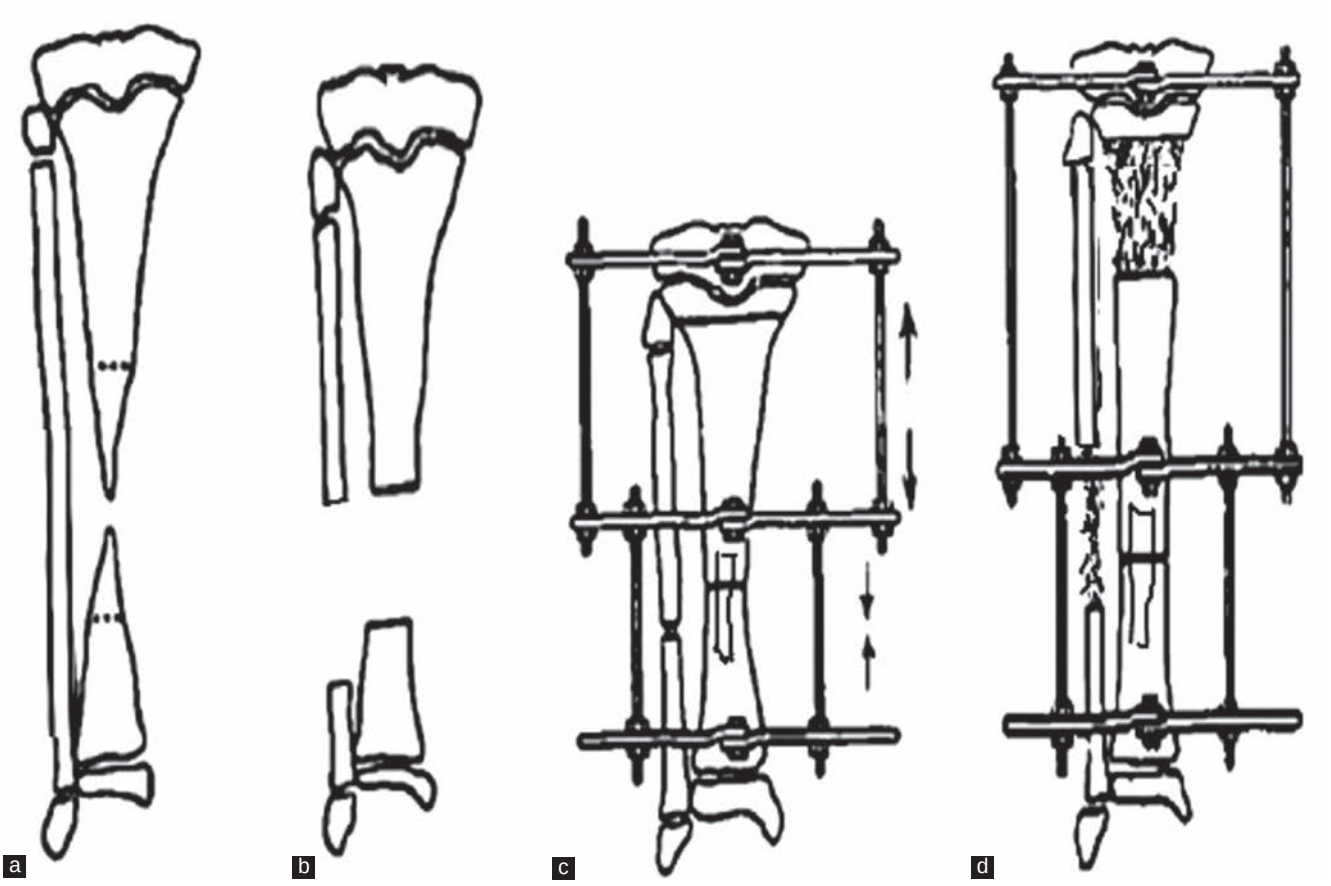
Only one bone transport was grafted using an autogenous graft from the iliac crest.

Table 1 Patients' and injury characteristics

Patients	Age	Sex	Mechanism of injury	Fracture shape	Fracture site	Fracture severity	Other injury	Infection
1	8	M	RTA pedestrian	Comminuted	Diaphysis	Open IIIB	–	No
2	4	M	RTA bicycle	Spiral	Diaphysis	Open IIIA	Fracture humerus	No
3	6	F	RTA pedestrian	Comminuted	Diaphysis	Open IIIA	–	No
4	8	M	RTA pedestrian	Comminuted	Distal tibia	Close	–	No
5	10	M	Fall from a height	Transverse	Diaphysis	Open IIIA	Forearm fracture	No
6	13	M	RTA pedestrian	Transverse	Diaphysis	Open IIIB	–	Yes
7	12	M	RTA bicycle	Transverse	Diaphysis	Close	–	No
8	5	M	RTA pedestrian	Comminuted	Diaphysis	Open IIIB	Fracture femur	No
9	6	M	RTA bicycle	Transverse	Diaphysis	Close	–	No
10	13	M	RTA pedestrian	Comminuted	Diaphysis	Open IIIA	–	No
11	9	M	Gunshot	Comminuted	Diaphysis	Open IIIC	Head injury	Yes
12	12	M	RTA pedestrian	Spiral	Distal tibia	Close	–	No
13	10	F	RTA bicycle	Comminuted	Diaphysis	Open IIIB	–	No
14	5	M	Fall from a height	Comminuted	Diaphysis	Open IIIA	Abdominal injury	Yes

F, female; M, male; RTA, Roads and Transport Authority.

Figure 1



Definitive treatment. (a, b) Resection of infected or devascularized bone at the nonunion site. (c) Stabilization by a bifocal Ilizarov external fixator and application intramedullary free fibular graft from the same limb, followed by acute shortening. (d) Distraction osteogenesis through metaphyseal corticotomy.

Leg-length discrepancy

All the patients had almost equal leg lengths (leg-length discrepancy <1 cm) at the time of the final follow-up (Fig. 2).

Deformity

One patient had 15° valgus deformity (Fig. 3).

Knee and ankle range of motion

The average knee flexion was 130° (range 120–145°). One patient had fixed flexion deformity at the knee of about 5°. The average range of motion at the ankle joint was dorsiflexion of 10° (range 0–15°) and plantar flexion of 30° (range 10–40°). One of two patients with distal tibial segment nonunion had limited range of ankle motion from 0° dorsiflexion to 10° plantar flexion.

Fibular graft problems

One patient developed mild, persistent pain at the graft site, which was relieved by analgesics.

Complications

Superficial pin-tract infections developed in all patients; they were treated with oral antibiotics. All superficial pin-tract infections resolved without sequelae. There were no persistent deep infections or nerve palsies. There were no other significant complications.

Discussion

As an uncommon complication of tibial fractures in children, nonunion presents a challenging clinical problem, especially when it occurs in association with angulatory deformity and leg-length discrepancy. Distraction osteogenesis in conjunction with compression, open reduction, and bone grafting has been described as a treatment for congenital tibial pseudoarthrosis [10–12].

Distraction osteogenesis is used to create new bone, which can reconstruct massive defects in the tibia. Local reconstruction can be facilitated with the technique of acute shortening. Combining acute shortening with

Figure 2

An 8-year-old boy had a grade IIIB open tibial diaphysis fracture initially managed by a monolateral fixator. (a) Anteroposterior and lateral radiograph showing nonunion. (b) Intraoperative photograph shows a 4-cm gap. (c) Bifocal circular fixator was applied. (d) 18-month follow-up anteroposterior radiograph shows healing of the fracture, equal leg length, and no deformity. (e) Clinical follow-up photograph shows equal leg length and no deformity.

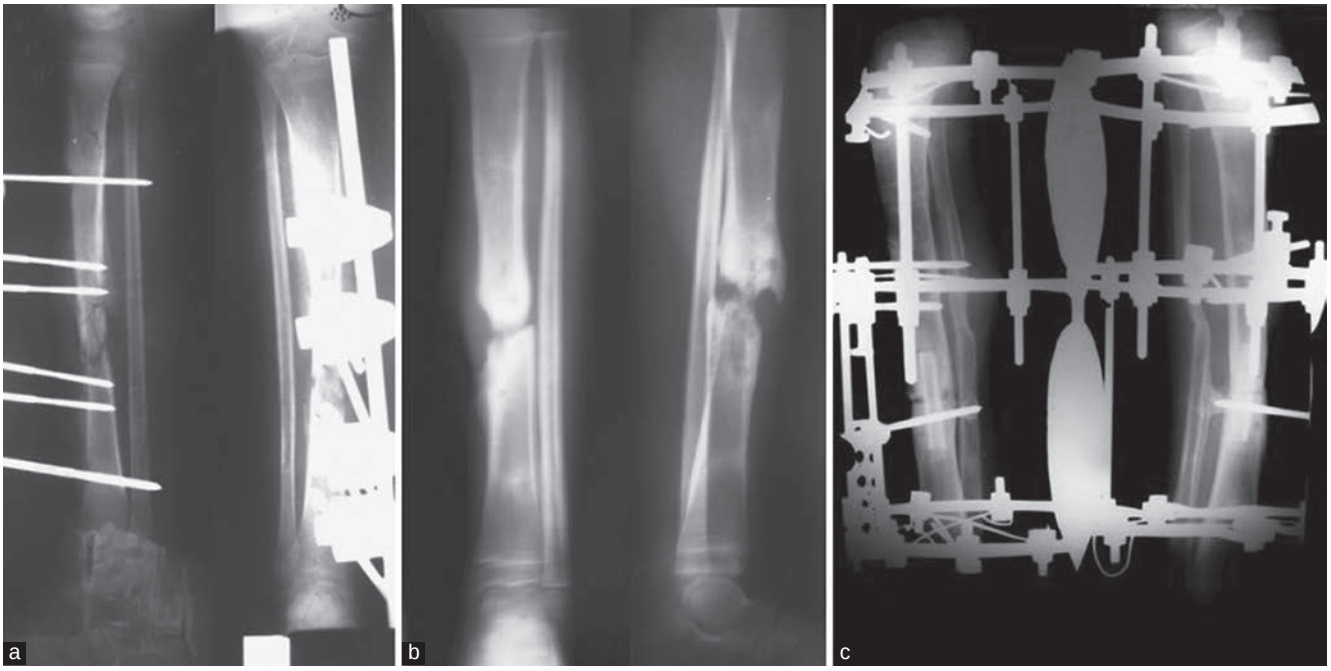
distraction histogenesis can solve bone loss and soft tissue dilemmas associated with tibial fractures [13].

In all patients of our study, acute shortening after debridement of the nonunion site was performed. The advantages of acute shortening are the ability to acutely transport local viable bone into the fracture site, acute alignment of the fracture is established with compressed bone surfaces, which promotes healing, and recruitment of soft tissues into the zone of injury [14].

The disadvantages to acute shortening are the risk of kinking of the vasculature, removing part of the fibula, which often does not regenerate with secondary lengthening, and the bulbous expansion of the soft tissues, which distorts the contour of the leg and can place tension stress on suture closures causing dehiscence of the wound [15]. The wounds and surgical extension should be closed with nylon sutures before shortening the extremity to prevent gaping wounds at the fracture site. Acute shortening also directly causes leg-length discrepancy that may need secondary lengthening [14].

We found in the literature that the maximum distance suitable for acute shortening in adult without major complications was 5 cm [14]. However, this figure is not well defined for children.

Figure 3



A 13-year-old boy had a grade IIIB open tibial diaphysis fracture that was initially managed by a monolateral fixator. (a) Anteroposterior and lateral radiograph showing initial fixation with a monolateral fixator. (b) Anteroposterior and lateral radiograph showing nonunion. (c) 3-month follow-up anteroposterior and lateral radiograph shows healing of the fracture with valgus deformity 15°.

We found 5 cm to be almost equal to the breadth of three fingers in adults. Thus, we consider the breadth of three fingers in the child as the maximum distance for planning for acute shortening in children.

In all cases, we applied an intramedullary free fibular graft from the same limb. Cortical bone confers good mechanical stability and strength to bony fixation constructs as compared with cancellous bone grafts. Intramedullary placement of the fibula prevents angulations or displacement at the docking site, and consequently correction by appropriate hinge placement, and lengthening of the treatment period. A fibular graft was added at the time of open reduction to augment the volume of bone at the nonunion site [16].

Aronson [17] reported that distraction osteogenesis could increase the blood flow by three to ten times in the affected extremity. Removal of all infected bone fragments and the significant increase in blood flow help to eradicate bone infection.

In our small series, the three cases of infected nonunion showed optimal healing, with no recurrence of infection observed during the follow-up period.

In the present study, the results were compared with those of published series on the same method of treatment for the treatment of bone loss using the Ilizarov method. Metin *et al.*, [18] reported on their series on the management of childhood chronic tibial osteomyelitis with the Ilizarov method; the mean bone defect was 7.4 cm (range 3.5–12). Follow-up time was 4.6 years (range 2.7–5.8). At the time of fixator extraction, complete consolidation was achieved in all the patients. The healing index was 32.3 days/cm (range 28–44). Bone grafting was not required at the docking site in any of the patients. Functional and radiologic results were judged excellent according to Paley's criteria in all patients at the last follow-up. This study indicates that the bifocal method of the Ilizarov treatment is the best alternative for the bone defect caused by chronic hematogenous osteomyelitis in children.

Gordon *et al.*[19] reported in their series three consecutive cases of distraction through an angulated, shortened, hypertrophic, post-traumatic nonunion to achieve successful union and concurrent correction of deformity. Distraction was carried out using a ring fixator with computer-guided correction. The mean age at the time of definitive treatment was 13.8 years (range 11.6–17.7). The mean time from injury to fixator placement was 13 months (range 8–20). The mean limb-length discrepancy was 21 mm (range 8–31). Union was achieved in each of the three patients, with complete correction of deformity and length. The length of time in the external fixator ranged from 7 to 27 weeks. Pin-tract infections developed in all patients; they were treated successfully using oral antibiotics. No deep infections or

other significant complications developed. Each patient was followed up for at least 1 year.

Cierny and Zorn [20] compared the Ilizarov method with conventional methods for the treatment of segmental tibial defects in adults. Although they found that the final results were the same for the two groups, the complication rate, length of stay, operating time, and morbidity were higher using the conventional method. Marsh *et al.* [21] compared the conventional techniques with the bone transport technique for the management of chronic infected tibial nonunions with bone loss. They pointed out that the final limb-length discrepancy was significantly less in the bone transport group.

Treatment of bone loss with the Ilizarov method has some problems, such as joint luxation or stiffness, axial deviation, neurologic and vascular injury, delayed consolidation of the distraction site, pin-site problems, and nonunion at the docking site [22–24]. All complications were favorably influenced by the surgeon's experience, except nonunion at the docking site [25,26]. In adult patients, bone grafting is recommended at the time of docking to prevent the common complication of nonunion (two). In children, however, there is no evidence of whether bone grafting is necessary at the docking site. Our results indicate that bone grafting is not required at the docking site. Thus, we believe that the Ilizarov method reduces donor-site morbidity compared with conventional methods.

Complications such as joint luxation and stiffness are caused by muscle contractures, which result from the tension generated on the muscle because of distraction. One of the major advantages of the Ilizarov method compared with the conventional methods is the ability of the child to ambulate early during the treatment. Functional loading and weight bearing of the extremity prevent disuse osteoporosis, soft tissue atrophy, and joint complications [18].

Conclusion

Treatment of post-traumatic tibial nonunion in children was performed by resection of infected or devascularized bone, and application of an intramedullary free fibular graft, followed by acute compression at the nonunion site. Then, stabilization was performed with a bifocaI Ilizarov external fixator. This method of treatment through a one-stage procedure is effective in restoring length, correcting alignment, and achieving solid bony union.

Acknowledgements

Conflicts of interest

There are no conflicts of interest.

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