Ipsilateral medial fibular transport using a circular external fixator for reconstruction of massive tibial bone defects in children and adolescents

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Background

Ipsilateral fibular transport is a novel option in limb salvage surgery for patients with large tibial defects. A less common application of the Ilizarov technique is transverse bone transport. The frame allows for gradual transport of the fibula into the adjacent tibial defect site, with precise proximal and distal alignment of the fibula, and compression at tibial contact sites. Here, we outline a method of limb salvage for large tibial bone loss using ipsilateral medial fibular transport using the Ilizarov apparatus in a group of children and adolescents.

Patients and methods

We retrospectively reviewed six consecutive patients, average age 8 years (range 3–18 years), with infection or trauma-related large tibial bone loss. All patients were treated using gradual medial transport of the ipsilateral fibula using the Ilizarov technique. The follow-up of the patients averaged 4 years, with a range of 4–7 years after removal of the circular external fixator. We reviewed patients' medical records and radiographs. We recorded the fracture type in trauma cases, length of the tibial segment replaced, time to union, additional procedures, knee and ankle range of motion, limb length, satisfaction with the reconstructive surgery compared with amputation, and possible complications.

Result

The Ilizarov ring fixation time to achieve fibular transport and bone union averaged 11 months (range from 7–17 months). The amount of tibial bone loss replaced using the Ilizarov frame with fibular transport averaged 9.8 cm, with a range of 8–11 cm. Hypertrophy of the transported fibula accompanied full weight bearing and satisfactory lower extremity joints motion occurred in all patients. Four of the six patients had a superficial pin-site infection. All patients and or parents were satisfied with the results, and none of them reported that amputation would have been a better option.

Conclusion

The Ilizarov technique of ipsilateral medial fibular transport to address massive tibial bone loss led to limb salvage for our six patients, with satisfactory functional results. Adolescent patients may require iliac crest bone grafting at the docking sites if the healing response is poor. Our work shows that ipsilateral fibular gradual transport in children and adolescents provides a reasonable alternative for surgeons addressing limb salvage in patients with large tibial bone loss. Patients should be treated by surgeons familiar and experienced with the Ilizarov method.

Keywords:
bone defect, fibular transport, Ilizarov

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Introduction

Segmental bone defects of the tibia represent a challenging problem to the orthopedic surgeon. Various techniques have been reported to treat bone loss in the tibia including autogenous cortical bone grafts [1], tibiofibular synostosis, ipsilateral fibular graft [2–8], allograft reconstruction [9], vascularized free fibula transfer [10–12], and bone transport. The combination of massive bone defects in the tibia with active infection is a more difficult clinical problem [13,14].

Ipsilateral fibular transport is a novel option in limb salvage surgery for patients with large tibial defects [14–17]. The ipsilateral and contralateral fibulae can be used to replace the missing segment using both vascularized [10] and nonvascularized grafts [18]. With vascularized grafts, specialized microvascular techniques are used to re-establish the blood supply. Free vascularized fibular grafting is a complex procedure that requires the expertise of a microvascular surgeon. Excellent results have been reported, but complications of thrombosis, nonunion, and deformity have been reported [10]. In addition, complications related to the fibula harvest include hematoma, nerve injury, infection, and valgus deformity of the ankle [19,20]. Chacha *et al*. [3] described a technique for medial fibular transfer in which the fibula is raised on a pedicle of peroneal and anterior tibial muscles and the peroneal vessels; this involves a significant dissection and can be difficult in cases of extensive scarring related to infection and trauma [13].

The Ilizarov method has been used to successfully transport bone and soft tissues longitudinally to treat tibial bone loss and, sometimes, to close an accompanying soft tissue defect [17,21–26]. A less common application of the Ilizarov technique is transverse bone transport [15,17,27]. The frame allows for gradual transport of the fibula into the adjacent tibial defect site, precise proximal and distal alignment of the fibula, and compression at tibial contact sites. This is a minimally invasive technique that requires little surgical dissection [14].

In 1998, Catagni [28] introduced the method of ipsilateral fibular transport with the Ilizarov frame, describing its application in three patients with massive tibial bone loss (range, 13–28 cm). In the same year, Kim and colleagues reported the use of a ring fixator to transport a fibular segment to replace 17 cm tibial bone loss in one patient. Although this new technique has been receiving increased interest, there are few reports [13,14,28,29] on the use of the external circular fixator to transfer the ipsilateral fibula for massive tibial bone loss.

Here, we outline a method of limb salvage for large tibial bone loss using ipsilateral medial fibular transport by the Ilizarov apparatus in a group of children and adolescents.

Patients and methods

We retrospectively reviewed six consecutive patients. These included five male patients and one female patient, with an average age of 8 years (range 3–18 years), with infection or trauma-related large tibial bone loss. All patients were treated by a single surgeon using gradual medial transport of the ipsilateral fibula with the Ilizarov technique [30]. Four patients had chronic osteomyelitis with involvement of a large segment of the tibial diaphysis and two patients had high-energy trauma with severely compromised soft tissues. Our indication for ipsilateral fibular medial transport was massive segmental tibial bone loss with poor condition of residual bone as this situation would be unsuitable for osteotomies because the standard Ilizarov technique for bone lengthening would not likely result in bone formation. We performed the fibular transport when the extent of the bony loss and/or poor condition of the residual bone made it likely that insufficient regenerate bone would be achieved with the Ilizarov technique for bone lengthening. We also used medial fibular transport when there was infected pseudarthrosis or osteomyelitis. The prerequisites were acceptable blood supply and sole sensation of the foot [30]. The patients' follow-up averaged 4 years, with a range of 4–7 years after removal of the circular external fixator.

Surgical technique

All patients were subjected to resection of the nonviable infected diaphyseal tibial segments and an Ilizarov fixator or Taylor spatial frame was used. Vancomycin-impregnated cement beads or spacer were utilized for 4–6 weeks. Following this, Cement spacers were removed and a two-level fibular osteotomy for medial fibular bone transport was performed. The primary transport frame was a two-ring frame connected with threaded rods. This spanned the bone defect and stabilized the proximal and distal bone segments in line with each other, allowing control of the proximal and distal segments on either side of the defect. A long Ilizarov plate was then connected to the frame anteromedially in preparation for the fibular transport. A two-level osteotomy of the fibula was planned at the level of the tibial defect. Three pulling olive wires were placed through the fibula from the posterolateral to the anteromedial direction. The tails of the olive wires were cut at the level of the bead and the olives were positioned against the fibula. These wires were set up as pulling wires and were attached to the anteromedial plate by three short slotted rods that had the capacity to pull all three of these olive wires. The position of these wires was such that it would pull the fibula from the posterolateral position in an anteromedial direction into the tibial defect [14].

Fibular osteotomies were performed as follows: a 1 inch skin incision was made at the proximal margin of the fibula, where the proximal osteotomy was planned. Dissection was carried down out between the lateral and posterior compartments, and using a microsaggital saw, an oblique osteotomy of the fibula was performed. The osteotomy was completed using an osteotome. Similarly, at the distal end of the defect, a 1 inch incision was made. Dissection was carried down to the fibula, and using a microsagittal saw, an oblique osteotomy was performed. The osteotomy was completed using an osteotome. The osteotomies were not displaced. The wounds were irrigated and closed. The fibula transport was started 10 days postoperatively utilizing the principles of distraction osteogenesis at a rate of 0.5 mm/day. Axial compression between the tibia and the transported fibula was performed after full transport. Iliac crest bone grafting was needed only in case 1.

Seven days postoperatively, the fibular transport was started at a rate of 0.25 mm two times daily. Once the fibula reached the target position after compression on the two levels, open autogenous cancellous bone grafting was used at four docking sites in two of the seven patients to enable bone union. Our indications for autologous cancellous bone grafts from the iliac crest were delayed union at the docking site of the fibular transport or to enhance bone formation and union. Angiography to assess blood supply to the targeted fibula was not performed as the technique for fibular transport rarely could damage vessels. The patients walked throughout the course of treatment. Once consolidation was complete, the frame was removed and a patellar tendon bearing cast was applied for 3 months in most cases.

We reviewed patients' medical records and radiographs. We recorded the fracture type in trauma cases, length of the tibial segment replaced, time to union (removal of the frame), additional procedures, knee and ankle range of motion, limb length, time using walking aids, satisfaction with the reconstructive surgery compared with amputation, and possible complications. The follow-up radiographs were assessed for increases in the width of the transported or the tibialized fibula. The amount of hypertrophy of the fibula was evaluated by measuring the bone diameter of the midshaft fibular diaphysis and by comparing successive periodic radiographs. Interviews with patients and or parents were conducted at the final follow-for their opinion on the results of the surgical intervention.

Result

The Ilizarov ring fixation time to achieve fibular transport and bone union averaged 11 months (range from 7–17 months). The amount of tibial bone loss replaced using the Ilizarov frame with fibular transport averaged 9.8 cm, with a range of 8–11 cm. The time using a walking aid device after frame removal averaged 6 months, with a range of 3–12 months. Hypertrophy of the transported fibula accompanied full weight bearing and satisfactory joint motion was achieved in all patients. Patients' data are summarized in Table 1. All patients and or parents were satisfied with their results, and none of them reported that amputation would have been a better option.

Four of the six patients had a superficial pin-site infection that developed during ipsilateral medial fibula transport. All pin-site infections responded well to local pin-site care and oral antibiotics. At the 2-year follow-up, all patients walked without wearing any protective orthoses. The total number of surgical interventions for the ipsilateral medial fibular transport was one procedure in four patients and two procedures in case one, in whom iliac crest bone grafting was

Table 1 Clinical details and outcome

Patient number	Sex	Age (years)	Cause of tibial bone loss	Amount of tibial bone loss replaced by fibular transport (cm)	Ilazarov fixation time to achieve fibular transport and bone union (months)	Follow-up (years)	Time using walking assist after frame removal (months)	Ankle dorsiflexion		Ankle plantar flexion		Knee motion
								Active	passive	Active	passive	
1	Male	17	Road traffic accident	11	17	5	12	10°	15°	40°	45°	Full ROM
2	Female	3	Infection	10	8	7	3	5°	10°	30°	35°	Full ROM
3	Male	5	Infection	8	9	5	4	20°	20°	40°	40°	Full ROM
4	Male	18	Pedestrian hit by car	10	15	4	12	10°	15°	40°	40°	Full ROM
5	Male	6	Infection	11	7.5	4	3	10°	15°	30°	35°	Full ROM
6	Male	7	Infection	9	10	5	4	10°	15°	35°	35°	Full ROM

ROM, range of motion.

performed after docking because of the lack of a good healing response, and three procedures in case 2, in whom an intramedullary wire aided fixation of the transported fibula, and later varus deformity of the distal tibia was treated by an opening wedge osteotomy and distal tibial and fibular epiphysiodesis.

Case histories

Patient 1

A 17-year-old adolescent male sustained an open comminuted fracture of the right tibia with Gustilo type IIIB [31] in a high-energy trauma in a road traffic accident. The patient underwent intramedullary nailing of his tibia and developed intramedullary sepsis with methicilin-resistant *Staphylococcus aureus*. The radiographs showed extensive bone necrosis, with evidence of chronic osteomyelitis and cystic bony changes in radiographs. The nail was removed, followed by irrigation and debridement with intravenous vancomycin. This failed to control the infection and the patient was referred to us; we used an Ilizarov frame. Eleven centimeters of avascular infected bone was removed, antibiotic-impregnated cement beads were applied, and intravenous vancomycin was administered for 6 weeks. Then, proximal and distal fibular osteotomies were performed. Olive wires were placed into the fibula and attached to the frame to enable gradual medial fibular transport. When the fibula was at its target position, compression through the Ilizarov frame was carried out and iliac crest bone grafting was performed. Once consolidation was radiographically and clinically complete, the frame was removed and the patient wore a patellar tendon bearing cast for 12 weeks. The fibula successfully replaced the large tibial bone loss and showed thickening of its cortices radiographically. The patient's functional outcome was full weight bearing and excellent joint motion after a total external fixation time of 12 months. The patient remained well at the 5-year follow-up. Treatment steps are presented in Fig. 1.

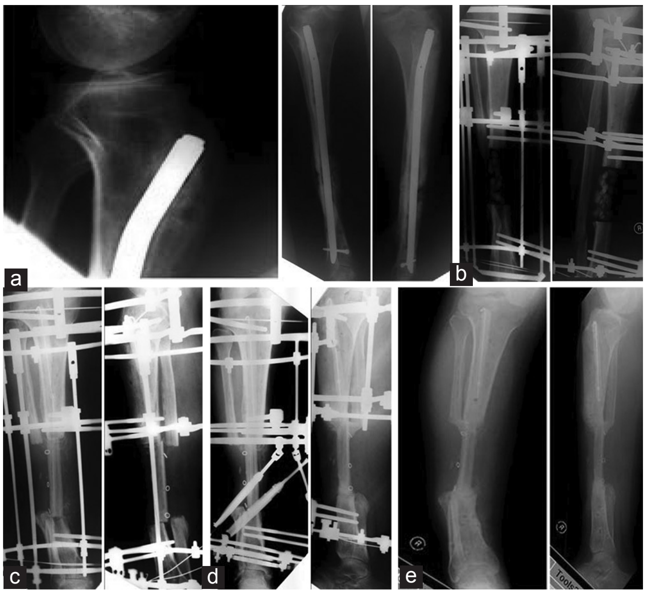
Patient 2

A 3-year-old girl sustained an insect bite in her left leg, after which she developed fever and extensive osteomyelitis of most of her tibia, in addition to involvement of the distal tibial physis. She lost most of her tibial diaphysis. She received intravenous antibiotic treatment and lavage, debridement, application of antibiotic-impregnated cement beads, and application of an Ilizarov external fixator. After 6 weeks, antibiotic beads were removed and proximal and distal fibular osteotomies were performed. Olive wires were placed into the fibula and attached to the frame to enable gradual medial fibular transport. When the fibula was at its target position, compression through the Ilizarov frame was performed. After the transport was completed, a wire was passed in the intramedullary canal of the transported fibula, fixing it to the proximal and distal tibia. Once consolidation was radiographically and clinically complete, the frame was removed and the patient wore a patellar tendon bearing cast for 6 weeks. The external fixator was removed after 8 months. The patient was able to bear full weight despite 2 cm of residual tibial shortening. The knee motion was normal and ankle dorsiflexion was limited to 10° of dorsiflexion. Because of the previously mentioned distal physeal injury, the distal tibia drifted into varus deformity, which was treated by an opening wedge osteotomy and distal tibial and fibular epiphysiodesis. The patient underwent lengthening of the transported fibula 4 years after the index operation and remained well at the 7-year follow-up. The treatment steps are presented in Fig. 2.

Patient 3

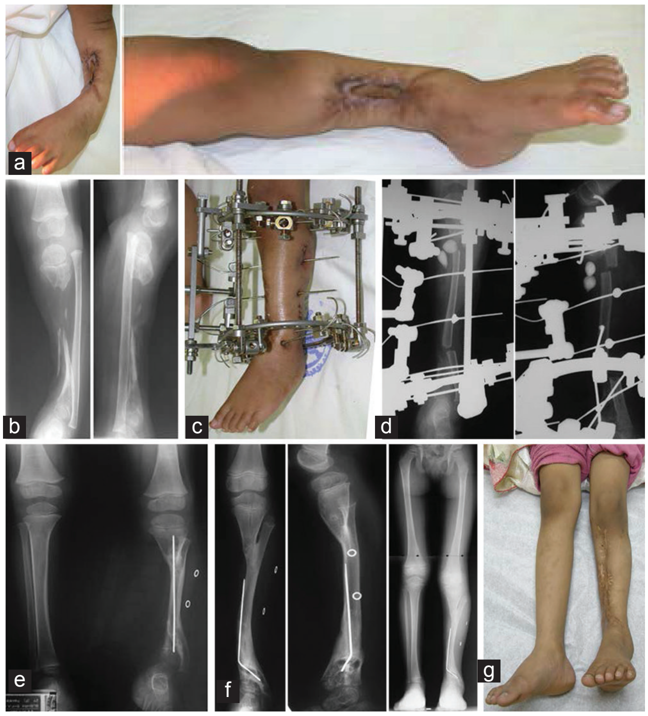
A 5-year-old boy developed high fever and leg pain, which was complicated later by the development of chronic osteomyelitis with a draining sinus. After extensive lavage, irrigation, and debridement, an Ilizarov apparatus with resection of the diseased 8 cm segment was performed, followed by the administration

Figure 1



(a) Preoperative Lateral knee radiograph showing cystic changes in a case of intramedullary sepsis and anteroposterior and lateral radiographs of the tibia showing diaphyseal nonunion with evidence of chronic osteomyelitis of the tibia. (b) Postoperative anteroposterior and lateral radiographs after resection of the infected nonunion and insertion of antibiotic beads. (c) Postoperative anteroposterior and lateral radiographs during medial fibular transport. (d) Postoperative anteroposterior radiograph after docking of the medial fibular transport. (e) Final postoperative anteroposterior, lateral radiographs after medial fibular transport maturation.

Figure 2



(a) Case 2 preoperative clinical pictures showing tibial shortening, varus, and sinus formation. (b) Preoperative anteroposterior and lateral radiographs showing large bone loss in the left tibia. (c) Clinical picture showing Ilizarov fibular transport frame. (d) Postoperative anteroposterior and lateral radiographs during medial fibular transport. (e) Postoperative anteroposterior radiograph after medial fibular transport with distal varus deformity Related to distal tibial physis asymmetrical growth arrest. (f) Final postoperative anteroposterior, lateral and standing long film radiographs after medial fibular transport maturation and hypertrophy with correction of distal varus deformity. (g) Clinical picture of patient lower extremities after completion of treatment.

of intravenous antibiotics. Then, 6 weeks later, proximal and distal fibular osteotomies and gradual medial fibular transport using the Ilizarov apparatus were performed. The fibula consolidated successfully with the tibia after a total external fixation time of 9 months. The final functional outcome allowed full weight bearing and the patient remained well at the 5-year follow-up.

Patient 4

An 18-year-old male patient was hit by a car. The patient sustained a left tibia open fracture Gustilo type IIIB [10], a large wound with soft tissue, and bone loss. The patient underwent irrigation and debridement of the tibial fracture and application of a monolateral external fixator at another institution. Debridement of soft tissues and resection of the necrotic and infected 10 cm of tibial bone were performed, followed by application of antibiotic beads and later a rotational flap. An Ilizarov apparatus was applied. The antibiotic beads were removed after 6 weeks, and fibular transport was started and iliac crest bone grafting was performed after docking. The Ilizarov frame was removed after 15 months. The transported fibula hypertrophied well. At 4 years, the patient walked unaided with complete knee and ankle range of motion, and was pain free.

Patient 5

A 6-year-old boy presented to us after undergoing a resection of 11 cm of infected tibial bone with an antibiotic spacer in place. He had undergone the procedure in another facility after developing chronic osteomyelitis with sinus formation over a large segment of his tibia. After 6 weeks of administration of an intravenous antibiotic, removal of the spacer was performed and an Ilizarov apparatus was applied and proximal and distal fibular osteotomies and gradual medial fibular transport using the Ilizarov apparatus were performed. The fibula consolidated successfully with the tibia after a total external fixation time of 7.5 months. The final functional outcome allowed full weight bearing and return to previous daily activities. The patient remained well at the 4-year follow-up.

Patient 6

A 7-year-old boy developed chronic osteomyelitis of his left tibia with a draining sinus. Most of the diaphyseal segment was involved and his infection failed to improve after irrigation and debridement at the referring facility. An Ilizarov apparatus with resection of the diseased 9 cm segment was performed, followed by administration of intravenous antibiotics. Then, 6 weeks later, proximal and distal fibular osteotomies and gradual medial fibular transport using the Ilizarov apparatus were performed. The fibula consolidated successfully with the tibia after a total external fixation time of 10 months. The final functional outcome enabled full weight bearing and return to previous sporting activities. The patient remained well at the 5-year follow-up.

Discussion

Large tibial bone defects are rare in children and represent a challenging problem [13]. Amputation rather than reconstruction may be proposed as a cost-effective method [13,32,33]. However, there has been considerable debate on the long-term disability after amputation as well as the cost of repeated prostheses [13,30,34]. In agreement with Williams [34], we believe that the long-term costs of amputation with a need for repeated prostheses are considerably greater than for a successful reconstruction using the Ilizarov method.

Many techniques have been described for the reconstruction of lower limbs in which active infection or septic nonunion is present with large bone loss from the tibia. The use of vascularized fibular transfer from the contralateral side results in morbidity to the normal limb, is time consuming, requires a specialized microsurgical team [13,35,36], and the possibility of microvascular occlusion should be considered; also, possible complications include deep infection, peroneal nerve injury, and ankle instability on the contralateral previously unaffected limb [30,37,38]. In addition, in patients with polytrauma, injuries at the donor sites may preclude the use of a vascularized fibular graft [30,38,39]. Tibiofibular synostosis as a treatment option causes eccentric loading through the fibula, which may fail in the presence of a large tibial bone defect [3,13,29]. Other treatment options may involve a vascular pedicle graft as described by Chacha *et al.* [3], but this requires considerable dissection to free the fibula, with identification of the peroneal vessels, which may be impossible in the presence of an infection [13]. Bone transport using monofocal or simultaneous bifocal distraction-compression osteogenesis Ilizarov techniques are also used for massive tibial bone loss, but if there is huge bone loss, the time to achieve the desired length of regeneration can be very long and may involve many complications [25,28,30].

Gradual medial ipsilateral fibular transport has many potential advantages compared with other methods of limb salvage described in similar patients. Gradual ipsilateral fibular transfer using the Ilizarov apparatus avoids donor-site morbidity distant from the injured limb [30,31,40]. Most importantly, it avoids threat to the unaffected contralateral limb. The circular external fixator for ipsilateral medial fibular transport allows for stability and longitudinal compression without internal fixation [14–16,21,23]. Furthermore, operative dissection of the fibula is minimal, and the bone remains well vascularized as both sources of blood supply are neither defined nor dissected [24–26]. Muscle attachments are maintained without dissection and the overlying free flap remains undisturbed. The fibular segment is central and is held by the tibial remnants in a mechanically advantageous position in the line of the axis of the tibia. Weight bearing can begin almost immediately after surgery, and the proximal and distal joints are mobilized satisfactorily. Further, limb lengthening may be carried out through a separate corticotomy of either the proximal or the distal tibial remnant. However, this procedure has its limitations. It requires a suitable length of uninjured fibula to be available in the same leg, and although this may be present in most tumor cases, it is not always the case in trauma-related injuries.

Conclusion

The Ilizarov technique of ipsilateral medial fibular transport to address massive tibial bone loss provided limb salvage for our six patients, with satisfactory functional results. Compared with the cases reported by Shiha *et al.* [13], we did not find significant ankle stiffness. Adolescent patients may require iliac crest bone grafting at the docking sites if the healing response is poor. Our patients were informed of the possible need for future lengthening as one of our patients had an injury to his distal tibial growth plate as a result of chronic osteomyelitis and was expected to develop leg-length discrepancy.

Our proposed method is technically demanding, and the Ilizarov method has theoretical risks of complications that may occur even when performed by experienced orthopedic surgeons. Complications include neurovascular injury, infection, muscular damage, refractures, deformities, and scarring [25,30,41–43]. Our work shows that applying the Ilizarov frame for ipsilateral fibular gradual transport in children and adolescents provides a reasonable alternative for surgeons addressing limb salvage in patients with large tibial bone loss. Patients should be treated by surgeons familiar and experienced with Ilizarov methods.

Acknowledgements

Conflicts of interest

There are no conflicts of interest.

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