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ORIGINAL PAPER

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Distraction osteogenesis with conventional external fixator for tibial bone loss

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Abstract Between 1991 and 2002, we treated 21 patients with tibial bone loss using a conventional external fixator. Nine patients had an infected open fracture and 12 patients an infected nonunion. After corticotomy, the bone was distracted at the rate of 1 mm (1 mm/step) on alternate days or every 48 h. The mean follow-up period was 18.7 (6–108) months after fixator removal. The mean new bone gained was 7.4 (2–17) cm. The mean healing index was 44.7 (17–86) days/cm. Total wound infection was resolved in 19 limbs (90.5%), and 11/12 (91.6%) nonunions united. Union with acceptable alignment (<7° of angulation) and limb-length difference (<2.5 cm) was achieved in 18 limbs (85.7%). The bone result was excellent in 17 tibiae, good in three, and poor in one. Eighteen limbs had an excellent and three a good functional result. This modified technique of distraction osteogenesis using AO/ASIF conventional external fixator is safe, cost effective, and a versatile tool in the management of tibial bone loss associated with infected nonunion and open fractures.

Résumé Entre 1991 et 2002 nous avons traité 21 malades avec perte osseuse tibiale en utilisant un fixateur externe conventionnel. Neuf malades avaient une fracture ouverte infectée et 12 malades une pseudarthrose infectée. Après corticotomie, l'os a été distrait au taux de 1 mm (1 mm/step) par jours alternatifs ou chaque 48 heures. La période de suivi moyen était de 18,7 (6–108) mois après ablation du fixateur. Le nouvel os formé était en moyenne de 7.4 (2–17) centimètres. L'index curatif moyen était de 44,7 (17–86) jours/cm. L'infection a totalement guérie pour 19 membres (90,5%) et 11/12 (91,6%) pseudarthroses ont consolidé. La consolidation avec un alignement acceptable (<7degrés d'angulation) et une faible différence de la longueur du membre (<2,5 centimètres) a été accomplie pour 18 membres (85,7%). Le résultat osseux était excellent pour 17 tibias; bon pour trois, et mauvais pour un. Dix-huit membres avaient un excellent résultat et trois un bon résultat. Cette technique modifié d'ostéogenèse par distraction qui utilise un fixateur externe conventionnel AO/ASIF est sűre, rentable, et c'est un outil pratique dans la gestion des pertes de substance du tibia associées aux pseudarthroses infectées et aux fractures ouvertes.

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Introduction

Bone loss in the diaphyseal shaft of long bones, particularly associated with nonunion, is extremely difficult to manage. The problem of nonunion is complicated by the presence of infection, deformity, disuse osteoporosis, and soft-tissue atrophy. Distraction osteogenesis by Ilizarov's method appears to be a most promising technique in treating these conditions [4, 6, 9, 12]. Currently, it is believed that the delicate distraction rate of 0.25 mm every 6 h is optimal for creating new bone and that acute correction impairs medullary blood supply, which in turn inhibits osteogenesis [7]. Therefore, sophisticated lengthening devices such as Ilizarov ring fixator are now commonly used [4, 6, 9, 10, 12]. Diaphyseal bone loss of any cause is a common problem in the developing countries where Ilizarov's apparatus is often not affordable.

Since 1990, the author has performed distraction osteogenesis using only a unilateral conventional AO/ASIF external fixator. This paper reports the results in 21 patients with tibial bone loss in infected open fractures and nonunions.

Patients and methods

The author conducted a retrospective analysis of 21 patients with tibial bone loss treated between October 1991 and June 2002 in the Police General Hospital, Bangkok. The mean time from removal of the fixator to review was 18.7 (range 6–108) months. In 12 patients, the bone loss was due to atrophic nonunion and in nine to an open tibial fracture. There were 19 men and two women whose mean age at the time of presentation was 32 (range 6–57) years. The open fractures were comminuted, severely contaminated, and required extensive debridement. Bone loss was classified in accordance with the criteria developed by Paley [12]. In 15 legs, there was a bony defect without shortening (type B1), in five shortening (type B2), and in one a bony defect with shortening (type B3). All legs had been previously operated on. The mean number of operations was 3.4 (range 1–10). All tibial defects were infected. The most common pathogens were *Staphylococcus aureus* and *Pseudomonas aeruginosa*.

Nonunion, infection, shortening, deformity and bone loss were all addressed simultaneously. An AO/ASIF monolateral external fixator was used for all limbs. No extra equipment, such as Alonso-Regazzoni special distraction rod [3], was used beyond readily available external fixation systems. All 15 tibiae with type B1 had treatment with the so-called "bone transport" technique. All five tibiae with type B2 had simultaneous compression of nonunion and distraction of the corticotomy in the healthy bone for lengthening. The tibia with type B3 infected open tibial fracture had only bone transport because shortening of the injured limb was overlooked. The patient had the initial treatment in a provincial hospital where the wound had been debrided and the fracture stabilized with an external fixator. The Trifocal technique [12], in which corticotomy was performed in each healthy bony segment, was used in four tibiae (type B1) with severe bone loss (9–17 cm). Seven patients required autologous bone grafting, harvested from the iliac crest, for promoting union at the docking site.

Surgical technique and lengthening protocol

After the preexisting deformity had been corrected, the bone was stabilized with the AO/ASIF external fixator. The fixator was placed on the medial aspect of the tibia. The osteomyelitic and necrotic bones were then resected. Corticotomy was performed at either the proximal and/or distal part of the healthy bone using the technique described by Aldegheri et al [1]. In cases of purulent discharge, the corticotomy was delayed until the infection had subsided. Generally, this took 2 weeks after debridement with administration of systemic antibiotics and local gentamicin-impregnated Polymethylmethacrylate beads. Systemic antibiotics were chosen on the basis of cultures. Corticotomy was then performed even in cases with persisting wound discharge. After corticotomy, all patients received prophylactic antibiotics with first-generation cephalosporin for 2 days. During distraction, no antibiotic was given. It was used only in case of pin-tract infection. After a waiting period of 5–7 days, distraction was started at the rate of 1 mm/48 h (1 mm in one step) or 1 mm on alternate day. The AO/ASIF tubular fixator lends itself for segment transport or diaphyseal lengthening, the fragment being pushed by means of the compressor device, which is normally available in the fixator system. If the distance between two clamps over the corticotomy site is not long enough to place the compressor device on the tube, a bone spreader was used. The case with type B1 nonunion was treated with bone transport. The corticotomy was performed at the healthy bone, and the middle bony segment was transported to the distal segment followed by compression at the docking site. In type B1 with a large segmental defect, the treatment time can be shortened by the Trifocal technique (Fig. 1). To accelerate healing at the docking site, an autogenous iliac bone graft may be added. Type B2 had simultaneous compression of nonunion and distraction of corticotomy at the healthy bone for lengthening. Four days after surgery, patients were encouraged to walk with partial weight bearing. Daily range-of-motion exercises began when pain had subsided. Postoperatively, pain management was accomplished with narcotics on the first postoperative day followed by oral acetaminophen. Once lengthening was completed, patients were encouraged to progressively increase weight bearing. Based on its monolateral mounting, the AO/ASIF fixator behaves like a forceps. It therefore lends itself for dynamization of the bony segments when weight bearing is progressively increased. Pins were removed when roentgenographic assessment revealed complete healing.

Table 1 Prevalence of complications in 16/21 patients

Complications		Number
Problems	Superficial pin-track infection	14
Obstacles	Axial deviation	8
	Premature consolidation	2
True complications	Axial deviation 7° or more	2
	Nonunion	1
	Infection	2
	Residual shortening	1

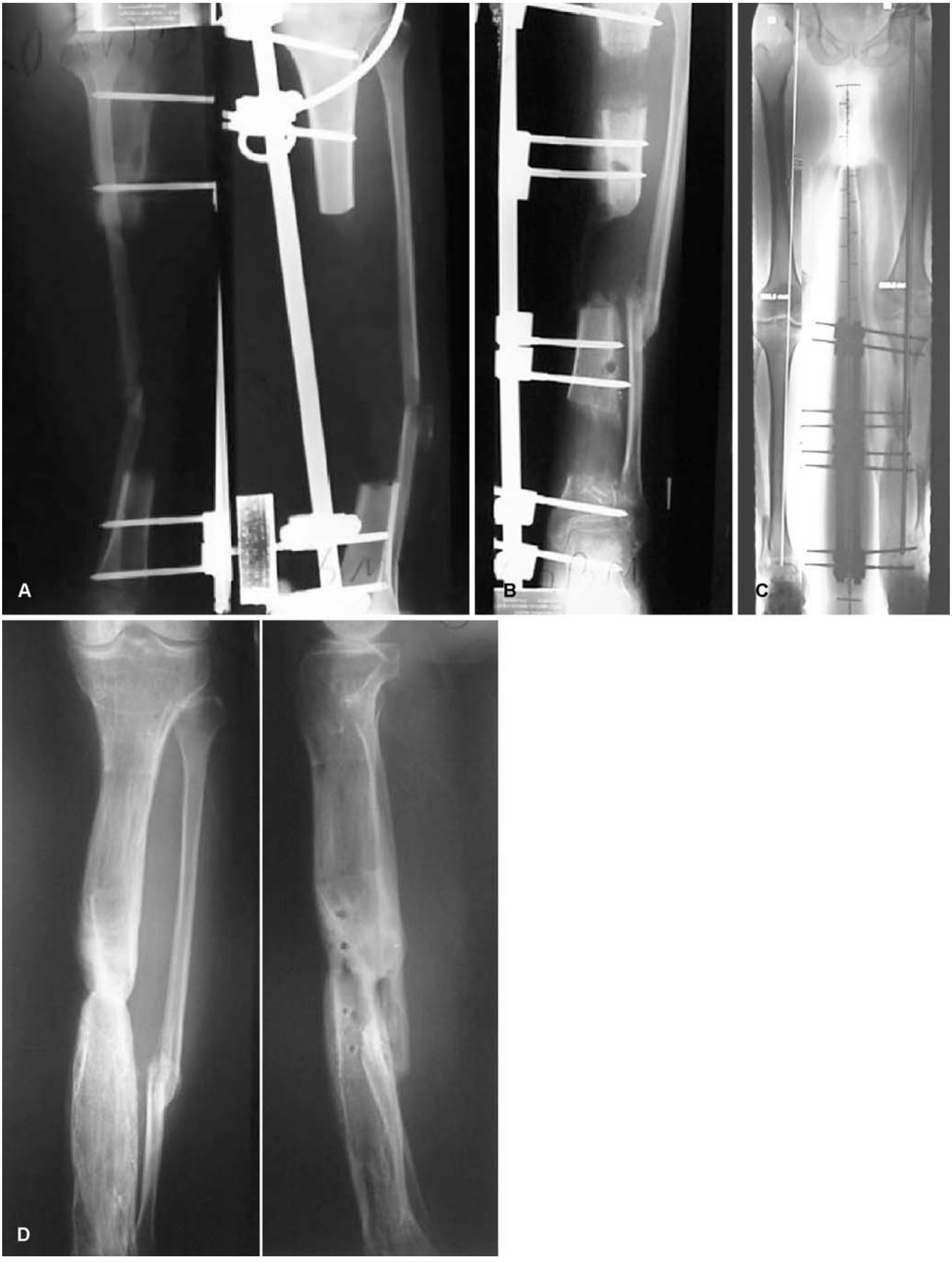
Results

Mean healing time (time in the external fixator) was 286.4 (range 154–647) days. Mean healing index [1] (the range of time needed to achieve 1 cm of mature new bone) was 44.7 (range 17–86) days/cm. Mean new bone gained from distraction osteogenesis was 7.4 (range 2–17) cm. Wound infection was eradicated in 19 infected tibiae. Treatment was effective in uniting 11 out of 12 nonunions. Union with acceptable alignment (less than 7° of angulation) and less than 2.5 cm shortening was achieved in 18 limbs. The results were classified in accordance with the criteria developed by the Association for the Study and Application of the Method of Ilizarov (ASAMI) [12]. Bone results were determined according to four criteria: union, infection, deformity, and leg-length discrepancy. Functional results were based on five criteria: significant limp, equinus rigidity of the ankle, soft-tissue dystrophy, pain, and inactivity (unemployment or inability to return to daily activities because of the injury). The bone result was excellent in 17 tibiae, good in three, and poor in one. Functional results were excellent in 18 tibiae and good in three.

Complications

Complications were classified as problems, obstacles, or true complications [11]. Sixteen of the 21 patients had a total of 30 complications, an overall rate of 1.9 complications per patient (Table 1). There were no neurovascular complications and no compartment syndromes. No case underwent amputation. Problems were superficial

Fig. 1 A Anteroposterior and lateral radiographs of a 34-year-old man who sustained an infected nonunion with bone loss. After debridement, there was a 17-cm bony defect (type B1). **B** Radiograph during distraction with Trifocal procedure: The bone was corticotomized at the proximal and distal tibia.;the two middle bony segments were transported towards each other simultaneously. **C** Scanogram of both lower limbs showing normal axial alignment of the transported limb as the transport was achieved. **D** Anteroposterior and lateral radiographs 10 months after fixator removal. The new bone was created and the docking site was healed without bone grafting. The healing index was 17.2 days/cm. Functional and bone results were excellent


A
B
C
D

pin-track infection and premature consolidation. The superficial pin-track infection occurred in 14 patients, all of which resolved with local care and oral antibiotics. There was no pin breakage and none had to be removed because of infection. No pin-track infection led to a ring sequestrum or chronic bone infection. Premature consolidations occurred in two patients who were managed by osteoclasis and increase in the rate of distraction to 1 mm/24 h (1 mm in one step). Obstacles were axial deviation during lengthening or transport of bony segment. Axial deviation was encountered in eight patients, which was corrected by acute reduction and changing the pin site. Four patients had six true complications: Gradually deformed new bone in the distraction gap occurred in two patients after premature removal of the fixator, resulting in axial deviation of more than 7°. These two patients had axial deviation of the tibia: one had a varus angulation of 15° and shortening of 2.5 cm; the other had varus angulation of 11°. Both were successfully treated with distraction osteogenesis. One patient had a fracture of the new bone after a minor trauma. It united after treatment with a functional cast. One patient had persistent nonunion located at the supramalleolar region: At the end of treatment, it functioned as a painless false joint; persistent infection occurred in the distal tibia.

Discussion

It was observed in this study that with 1-mm distraction per 48 h (1 mm/step), new bone formation was created in the distraction gap. This new distraction rate could be achieved with the AO/ASIF conventional external fixator. The history of development of this technique was delineated elsewhere [14]. Ilizarov has shown in his study, using a canine tibial model, that a distraction rate at 1 mm/day in one step failed to form a new bone in the distraction gap and caused focal swelling with damage of nerve fibers [7]. However, clinically, Wagner demonstrated that the bone could be lengthened at a rate of 1.5 mm/day in one step without neurological damage. In addition, in children, spontaneous regeneration of bone may occur in the distraction site [15]. In an animal experiment, Alho et al. found that gradual distraction of tibiofibular bone at the rate of 1 mm/week stimulated endosteal and periosteal callus formation, which resulted in filling of the distraction gap [2]. Similarly, Delloye et al. could create bone regeneration in the distraction gap of osteotomized canine limbs with an average distraction rate at 0.8 cm every 36 h [5]. From these studies, the author interpreted that if the osteotomized bone was distracted at the rate at 0.8, or 1 mm each time, the bone and soft tissues, including neurovascular structures, might have at least 36 h for adaptation to create bone in the distraction gap without neurovascular damage. Based on this interpretation and the results of the present series, the new technique of distraction osteogenesis has been verified. Healing index of the present technique (distraction rate of 1 mm/48 h) would seem to be longer than that of Ilizarov's technique (distraction rate of 1 mm/24 h). However, the healing index in the present series of 44.7 days/cm compared favorably with those of others using Ilizarov's distraction rate of 1 mm/24 h. In those series, the healing index was reported to be 32–51 days/cm [1, 8, 11, 13]. It might be possible that the neutralization phase of the present technique was shorter than that of Ilizarov's technique.

The AO/ASIF external fixator is a monolateral fixator, which is simpler to apply and is better tolerated by patients compared to the Ilizarov ring fixator. In the present series, the Alonso-Regazzoni special distraction rod was not used because the diameter of its distraction rod was smaller than the tubular rod of the AO/ASIF conventional fixator. In the author's experience with long-standing nonunion, the Alonso-Regazzoni distraction rod bent, which in turn hindered distraction. Moreover, the Trifocal technique, in which two bony segments are transported simultaneously, cannot be performed by Alonso-Regazzoni rod.

The present method could simultaneously address all of the various combinations of infection, bone loss, disuse osteoporosis, soft-tissue atrophy, nonunion, and shortening while at the same time maintaining articular function and permitting partial weight bearing. Using the criteria of ASAMI the results of the author's technique compared favorably with those of the Ilizarov's technique. Paley et al., using Ilizarov 's technique in treating 25 patients with tibial nonunions and bone loss, reported 92% good-to-excellent bone and functional results [12]. Dendrinos et al. studied 28 patients with bone loss associated with infected tibial nonunions treated with Ilizarov's technique. They achieved 82.1% good-to-excellent bone results and 64.3% good-to-excellent functional results [6]. In the present study, bone results were good to excellent in 20 cases (95.2%) and functional results good to excellent in all cases. Complications of the present series are comparable with those of Dendrinos et al. In the current series, 16 out of the 21 patients had an overall rate of 1.9 complications per patient. Dendrinos et al. reported 2.7 complications per patient (16 problems, 11 obstacles, and 44 true complications) [6].

The cost of AO/ASIF is much lower than that of the Ilizarov lengthening device (US $2,000 versus US $5,000 respectively). As Thailand is a developing country and most people are not rich, many cannot afford the high medical expenses. The author tried to use available resources and applied them effectively. Based on the distraction rate of 1 mm/48 h, or 1 mm on alternate days (1 mm in one step), the delicate distraction or telescopic rod is no longer necessary. With the new distraction rate, not only AO/ASIF conventional external fixator but also simple, locally made external fixators may be used for distraction osteogenesis. The technique is not only useful in developing countries, it can also be used in the developed countries.

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