Tibial lengthening using a reamed type intramedullary nail and an Ilizarov external fixator

Hayoung Kim · Sang Ki Lee · Kap Jung Kim ·
Jae Hoon Ahn · Won Sik Choy · Yong In Kim ·
Jea Yun Koo

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Abstract The aim of this study was to evaluate the efficacy of tibial lengthening using a reamed type intramedullary nail and an Ilizarov external fixator for the treatment of leg length discrepancy or short stature. This retrospective study was performed on 18 tibiae (13 patients) in which attempts were made to reduce complications. We used an Ilizarov external fixator and a nail (10 mm diameter in 17 tibiae and 11 mm in one tibia) in combination. Average limb lengthening was 4.19 cm (range, 2.5–5.5). The mean duration of external fixation was 12.58 days per centimetre gain in length, and the mean consolidation index was 40.53 (range, 35.45–51.85). All distracted segments healed spontaneously without refracture or malalignment. Gradual limb lengthening using a reamed type intramedullary nail and circular external fixation in combination was found to be reliable and effective and reduced external fixation time with fewer complications.

Résumé Le but de cette étude est d'évaluer l'efficacité de l'allongement tibial en comparant les allongements réalisés pour inégalité de longueur ou petite taille à l'aide d'un clou intra-médullaire associé à un fixateur externe de type Ilizarov. Cette étude rétrospective a été réalisée sur 18 tibias chez 13 patients. Nous avons utilisé un fixateur externe d'Ilizarov et un clou de 10 mm de diamètre sur 17 tibias et de 11 mm sur un seul tibia. L'allongement moyen a été de 4,19 cm (2,5 à 5,5). Le temps moyen de fixation

externe a été de 12,58 jours par centimètre d'allongement et l'index de consolidation de 40,53 jours par centimètre (35,45 à 51,85). Tous les segments osseux distractés ont consolidé de façon spontanée sans fracture du régénérat et sans cal vicieux. L'allongement progressif utilisant de façon conjointe le clou centro médullaire associé à une fixation externe circulaire est une technique fiable qui permet de réduire le temps de fixation externe tout en diminuant le nombre de complications.

Introduction

Since Codivilla [3] first described leg lengthening by distraction osteosynthesis in 1905, it has been widely used in children and adults. Distraction osteosynthesis has two distinct phases: distraction and consolidation. The consolidation phase is approximately twice as long as the distraction phase in children, and up to four times as long in adults, in whom periods required for external fixation vary between 30 and 50 days per centimetre gain in length [6, 13]. Patients often tolerate the consolidation period poorly, and complications such as pin-track infection, angulation, postoperative scar, and stiffness of the ankle joint can develop, particularly after tibial lengthening. Moreover, if the external fixator is removed too soon, newly formed bone may fracture [13]. Thus, it would be beneficial if the period of external fixation could be reduced without increasing the likelihood of such complications.

Paley [14] first described a technique of bone lengthening over an intramedullary nail to provide a more comfortable lengthening process, shorten the external fixation period, and support regenerated bone internally. Moreover, this technique is gaining wider acceptance because of the improvements in patient comfort it offers

H. Kim · S. K. Lee (✉) · K. J. Kim · J. H. Ahn · W. S. Choy ·
Y. I. Kim · J. Y. Koo
Department of Orthopedic Surgery,
Eulji University College of Medicine,
1306 Dunsan-dong, Seo-gu,
Daejeon 302-799, South Korea
e-mail: sklee@eulji.ac.kr

Table 1 Patient clinical and demographic data

Case	Age (yr)	Gender	Diagnosis	LLD (expected length)(cm)	Site
1	23	M	Short status (idiopathic dwarfism)	5.0	Bilateral
2	32	M	LLD (posttraumatic)	5.5	Unilateral
3	18	M	CP spastic type c familial short stature	5.5	Bilateral
4	38	M	LLD (posttraumatic)	3.5	Unilateral
5	17	F	Hypochondroplasia c genu valgum both	5.0	Bilateral
6	20	M	LLD (posttraumatic)	3.0	Unilateral
7	21	M	LLD (posttraumatic)	5.5	Unilateral
8	22	F	Short status (idiopathic dwarfism)	4.0	Bilateral
9	22	F	LLD (posttraumatic)	2.8	Unilateral
10	26	M	Short status (idiopathic dwarfism)	5.0	Bilateral
11	26	M	CP spastic type c LLD	3.0	Unilateral
12	23	F	Neurofibromatosis c LLD	3.0	Unilateral
13	35	M	LLD (posttraumatic)	5.5	Unilateral

LLD leg length discrepancy, CP cerebral palsy

[7]. On the other hand, Kristiansen [10] reported encountering a high rate of serious complications in patients treated by tibial lengthening over an intramedullary nail, which led them to abandon this technique and return to the classic Ilizarov method. The concept of lengthening over an intramedullary nail is not new. An unlocked nail was used at an early stage, but it was then replaced by a locking nail to allow earlier removal of external fixators. This modality provided additional axial and rotational stability to protect newly formed bone. However, various complications were reported, including cases of deep infection and breakage of nails and locking screws even when a locked intramedullary nail was used [10, 21]. The objective of this study was to evaluate the appropriateness and efficacy of a therapeutic approach in which the limb lengthening procedure was conducted through the combined use of an Ilizarov external fixator and a relatively large diameter intramedullary nail by intramedullary reaming in patients with leg length discrepancy or short stature.

Materials and methods

This retrospective study was performed from November 2000 to September 2005. Twenty limbs (15 patients) underwent a lengthening procedure involving use of the Ilizarov distraction technique combined with intramedullary nailing. The aetiologies of the leg length discrepancy were idiopathic dwarfism (4 patients), trauma (7 patients), sequelae of cerebral palsy (2 patients), hypochondroplasia (1 patient), and neurofibromatosis (1 patient). Of these 20 procedures involving 15 patients, 13 of the patients (18 procedures) were followed for a minimum of 2 years (range, 2.4–6.5) from the time of removal of the external fixator, and these 13 patients constituted the subject cohort. We excluded skeletally immature patients and limbs that

were too deformed to allow nailing. There were nine males and four females of average age 24 years (range, 17–38 years). The mean leg length discrepancy was 4.5 cm (range, 2.8–5.5) as measured on preoperative scanograms (Table 1). For three short stature patients, targeted limb lengthening was approximately that of the leg length discrepancy. An Ilizarov external fixator (Smith and Nephew, Memphis, TN) was used in all cases of tibial

Fig. 1 Tibial lengthening using an intramedullary nail and an Ilizarov external fixator in combination. Dashed line indicates the corticotomy site. 5/8R 5/8 ring, FR full ring, OP olive pin, SP smooth pin, HP half pin, T-F tibio-fibular fixation

Fig. 2 Serial anteroposterior and lateral radiographs of tibial lengthening in a 26-year-old man. **a** Immediate postoperative radiograph of nailing and external fixator application. **b** Radiograph taken at the completion of lengthening. **c** Radiograph taken during the consolidation period. **d** Radiograph taken after the completion of new bone maturation and screw and nail removal

lengthening over an intramedullary nail. A Dynamic Tibial Nail (DePuyACE, Warsaw, IN, USA) or a Metaphyseal-Diaphyseal Nail (Zimmer, Warsaw, IN, USA) of 10 mm diameter was used in 17 tibias (12 patients), and an 11 mm nail was used in one tibia.

Surgical technique and postoperative protocol

Under regional anaesthesia, proximal inlet for insertion of a guide wire into the medullary canal was created. Progressive reaming was done over the guide wire to enlarge the canal to a diameter 2 mm greater than that of the nail to be used. This process is of fundamental importance. The nail was then inserted temporarily and then removed leaving a guide wire in place. The bone was divided by careful corticotomy at the proximal meta-diaphyseal junction by making an incision of 1–2 cm. The nail was then driven into the canal until it reached the distal metaphysis, and the proximal end was locked using two cross locking screws. With the nail situ, an Ilizarov frame (one 5/8 ring, three full

rings, and four distraction rods) was mounted with one 1.8 mm wire and one half pin (the most distal ring was mounted with one wire and one half pin, or two wires) in

Fig. 3 Half pin and wire configuration of middle two rings on the coronal plane

each ring, taking care to avoid the nail (Figs. 1 and 2). Because of the relatively large diameter of the tibial medullary canal of the most proximal and distal ring portions, among the four rings in the Ilizarov frame, half pins and smooth wires could be inserted to both the near and far cortices without contacting the nail. Due to the relatively smaller diameter of the tibial medullary canal at the middle two ring portions, the half pin was placed in a location at 2/3 of the tibial anteromedial surface and inserted in the vertical direction to the cortical surface to penetrate two cortices without contacting the nail. The wire could penetrate two cortices without contacting the nail by being inserted in a horizontal direction to the near anterior cortex (Fig. 3).

After surgery, patients were allowed to walk with partial weight bearing. In all cases, lengthening was started at the rate of 1 mm per day in increments of 0.25 mm on day 7 postoperatively, and lengthening was continued at this rate until the desired correction had been reached. Newly formed bone was assessed weekly by radiography. The rate of lengthening was adjusted to ensure that rapid bone formation was not accompanied by premature union. The second operation took place no later than 2 weeks after desired limb lengths had been achieved and involved inserting distal interlocking screws and removing the external fixation frame. It is important that these distal locking screws be inserted before

removing the external fixator to prevent loss of length. When radiographs showed remodelling of the two cortices, full weight bearing was permitted. Intramedullary nails were removed after bone remodelling at the patients' requests.

Two patients had cerebral palsy. In these cases a distal interlocking screw was inserted after limb lengthening and additional procedures were performed including Achilles tendon lengthening, distal hamstring release, tibialis posterior aponeurotic lengthening, and metatarsal extension osteotomy.

Outcome measures

Three indices were used to evaluate results, namely, percentage increase, the external fixation index, and the consolidation index. The percentage increases were defined as tibial length gained and expressed as a percentage of original tibial length; external fixation index was defined as the duration of external fixation divided by length gained; and consolidation index was defined as the quotient of consolidation time (measured from application of external fixation to radiographic consolidation of newly formed bone) and the tibial length gained. We considered consolidation complete when anteroposterior and lateral radiographs confirmed that three of the four cortices of newly formed bone in the distraction gap were intact.

Table 2 Results of 18 leg lengthening procedures over a reamed type intramedullary nail

Case	Tibial length (cm)	Tibial lengthening (cm)	Duration of external fixation (days)	Consolidation period (days)	PI (%)	EFI (days/cm)	CI (days/cm)
1	40.4	4.8	58	180	11.88	12.08	37.50
	41.6	4.9	58	180	11.78	11.84	36.73
2	41.2	5.1	60	185	12.38	11.76	36.27
	40.0	5.2	62	190	13.00	11.92	36.54
3	40.0	5.1	62	190	12.75	12.16	37.25
	36.0	3.1	40	135	8.61	12.90	43.55
5	34.2	4.9	60	185	14.33	12.24	37.76
	34.1	4.8	60	185	14.08	12.50	38.54
6	36.0	2.7	40	140	7.50	14.81	51.85
7	39.5	5.1	60	190	12.91	11.76	37.25
8	27.2	3.5	45	145	12.87	12.86	41.43
	27.5	3.5	45	145	12.73	12.86	41.43
9	37.3	2.5	35	120	6.70	14.00	48.00
10	35.5	4.7	55	180	13.24	11.70	38.30
	35.0	4.6	55	180	13.14	11.96	39.13
11	37.0	2.7	35	115	7.30	12.96	42.59
12	35.6	2.8	40	140	7.87	14.29	50.00
13	38.5	5.5	65	195	14.29	11.82	35.45
Mean $\pm$ SD	36.48 $\pm$ 4.09	4.19 $\pm$ 1.05	51.94 $\pm$ 10.36	165.56 $\pm$ 26.95	11.52 $\pm$ 2.62	12.58 $\pm$ 0.94	40.53 $\pm$ 4.92

PI percentage increase, EFI external fixation index, CI consolidation index

Results

Mean tibial length gain by the 18 limbs was 4.19 ± 1.05 cm (range, 2.5–5.5), which represented a mean percentage increase of $11.52 \pm 2.62\%$ (range, 6.70–14.33). Mean external fixation time was 51.94 ± 10.36 days (range, 35–65), giving a mean external fixation index of 12.58 ± 0.94 (range, 11.70–14.81). Mean consolidation time was 165.56 ± 26.96 days (range, 115–195), giving a mean consolidation index of 40.53 ± 4.92 (range, 35.45–51.85) (Table 2). Eight complications were encountered. These included seven problems resolved by medical treatment and one obstacle that was resolved surgically, no sequelae (continuing or permanent persistence after treatment) were encountered [13]. Two patients developed pin-track infections, which responded to antibiotics without interrupting the lengthening process. No case of deep intramedullary infection occurred. Although one patient complained of lower back pain, this symptom improved after completing limb lengthening and removing the external fixator frame.

Three ankle joint contractures occurred, and two of these recovered spontaneously. In the remaining patient, Achilles tendon lengthening and posterior capsulotomy were performed at 6 months postoperatively because of persistent ankle joint equinus contracture which did not respond to closed treatment. No case of delayed consolidation or premature consolidation occurred during lengthening. Another patient complained of paraesthesia of the plantar aspect of the associated foot, but this abnormal sensation was not evident 3 months after surgery.

No intramedullary nail or interlocking screw breakage and no fat embolism occurred. All 13 patients tolerated the entire treatment course well and were satisfied with the results, in addition to being pleased to have the bulky external device removed earlier than usual.

Discussion

In this study an external fixator was applied over an intramedullary nail in patients requiring tibial lengthening to reduce the duration of external fixation. This procedure secured axial alignment, maintained length gained, and prevented refracture after external fixator removal. Some authors have expressed concern that intramedullary nailing may compromise the endosteal blood supply of diaphyseal bone and thus affect the quality of newly formed bone during leg-lengthening procedures [8, 15, 18]. However, it has been shown that the periosteum and surrounding soft tissue can support osteogenesis and permit new bone formation, and it is also known these issues are particularly important for effective distraction osteogenesis [9, 19, 20]. In addition, Rhinelander [16] noted that reconstitution of

the medullary vasculature is most likely complete within 2 weeks after reaming. Furthermore, medullary callus may contribute to vascular regeneration despite reaming, whereas plugging the canal with cement would prevent this response. Kojimoto [9] demonstrated in a rabbit model that the periosteum plays a more important role in the regeneration of distraction-callus than the endosteum.

Complications related to nails have been reported, e.g., deep infection, breakage of nails or interlocking screws, and protrusion of nail heads [10, 21]. These complications most commonly occur when the nail diameter is less than 8 mm, in particular when a 6.7 mm unreamed humeral nail is used in the tibia. These complications are believed to be due to nails that are incapable of bearing body weight after external fixator removal. In our series, nails of 10 mm minimum diameter were used (i.e., 10 mm in 17 tibias and 11 mm in 1 tibia), and reaming was performed to create an internal diameter 2 mm greater than the nail diameter. This procedure allowed the use of larger, stronger nails, which

Fig. 4 Lateral radiograph showing a procurvatum deformity after proximal tibial corticotomy and lengthening

enable the lengthening to be done smoothly without nail impingement in the canal. In addition, it also prevented nail and interlocking screw breakage and newly formed bone fracture after external fixator removal. Furthermore, it facilitated earlier external fixator removal and rehabilitation.

Fat embolism is a major concern of combined intramedullary nailing and external fixation, especially for simultaneous bilateral procedures. To prevent this complication, we avoid the use of a tourniquet and perform the reaming carefully to reduce the likelihood of heat-induced osteocutaneous necrosis [11]. In our series, no fat embolism was observed among the five patients that underwent simultaneous bilateral surgery. Deep infection is also a cause of concern. Paley [14] recommended that there should be no contact between the pin of the external fixator and the intramedullary nail. In our case, one wire and one half pin were used for each ring to minimise the likelihood of nail to Ilizarov external fixator wire contact, and no intramedullary deep infection occurred. In addition, the use of half pins improved the firmness of fixations.

Antoci [1] noted that larger lengthening percentage correlated well with a higher neurological complication rate, residual deformity rate, broken pin rate, joint contracture rate, and hypertension rate and can be used to predict the complication rate. Generally, longer lengthening periods are associated with more joint contracture, and in cases of tibial lengthening, ankle joint contracture may develop. In this study, 5/8 rings were applied as proximal Ilizarov rings to reduce patient discomfort and to prevent knee joint contracture. Postoperatively, it was found that the ankle joint range of motion recovered to the preoperative level. We believe that earlier release from external fixation (mean external fixation index, 12.58) enabled all patients to fully exercise ankle joints before joint contracture became irreversible. From the first case of our procedure, a postoperative procurvatum occurred (Fig. 4). We believe that this occurred because of the larger diameter of the proximal tibia medullary canal, corticotomy at the proximal metaphysis, and weak fixation of the Ilizarov external fixator. Therefore, we performed corticotomy at the meta-diaphyseal junction, and the problem was resolved by placing a half pin when applying the external fixator. In the tibia, where mechanical and anatomical axes coincide, lengthening over an intramedullary nail is indicated, as opposed to the femur, where the two axes are different and would cause additional translation [2, 14]. The limitation of this study was that the intramedullary nail could not be used for cases of severe deformity combined with shortening. Several reports have affirmed the usefulness of an external fixator in the treatment of deformity combined with shortening [4, 5, 17]. Moreover, gradual correction may represent a better approach than acute correction with the use of an external fixator to treat deformity combined with shortening [12]. Thus, we excluded

the cases of limbs that were too deformed to allow nailing. In our case, the callus initiated from the posterolateral aspect of the tibia after limb lengthening may have been caused by superior vascularity in the posterolateral aspect of the tibia, which contains major neurovascular structures that provide blood supply to the distraction gap during the early stages before regeneration of the endosteal circulation. According to our experience and findings, we believe that the combined use of a large diameter nail by reaming of the intramedullary canal and an Ilizarov external fixator during tibial lengthening provide a safe and reliable approach to successful lengthening.

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