Application of the Ilizarov Technique to the Correction of Neurologic Equinovarus Foot Deformity

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Abstract

Background The treatment of rigid equinovarus foot deformities caused by neurologic disorders is often difficult and relapse is common.

Questions/purposes We asked whether the Ilizarov technique could be used for correction of neurologic equinovarus foot deformities resulting in improved foot and ankle function and patient satisfaction.

Patients and Methods The neurologic equinovarus foot deformities of 26 patients (mean age, 18.7 years; 29 feet) were treated using the Ilizarov technique. Nine feet were treated by distraction histiogenesis only with limited soft tissue release, whereas 20 feet needed additional osteotomy and/or tendon transfer/lengthening. Minimum followup was 12 months (mean, 72.9 months; range, 12–155 months).

Results The mean time required for deformity correction was 27.1 days (range, 14–47 days) and the mean time for stabilization in the apparatus was 23.2 days (range, 7–53 days). A painless, stable, and plantigrade result was obtained by 22 patients (24 feet). Mild residual foot deformity was observed in the remaining five feet of four

patients. Six patients (six feet) experienced postoperative complications. Three patients (four feet) experienced recurrence of the deformity requiring surgical correction.

Conclusions Ilizarov soft tissue distraction with or without callotasis of tarsal bone(s) allows a greater degree of correction of neurologic equinovarus foot deformities. However, to reduce the risk of recurrence after fixator removal, it may be necessary to overcorrect the deformity while in the fixator, to use nighttime splinting, and most importantly, to eliminate neuromuscular imbalance, if necessary, by combining arthrodesis with or without tendon transfer.

Level of Evidence Level IV, therapeutic study. See Guidelines for Authors for a complete description of levels of evidence.

Introduction

Upper and lower motor neuron diseases such as cerebral palsy, spina bifida, arthrogryposis, and residual poliomyelitis often cause severe and rigid deformities in the foot and ankle [16, 17, 19]. Treatment of a rigid neurologic foot deformity is rather difficult and relapse of the deformity is a common problem [5]. The goal of treatment for a neurologic rigid foot deformity is to convert a deformed, rigid structure into a stable, plantigrade foot [5, 17]. Soft tissue release combined with osteotomies is the preferred treatment. However, the rigidity and complexity of this deformity often necessitate more radical procedures such as primary triple arthrodesis and occasionally talectomy [12, 20–22]. The potential disadvantages of these ablative procedures include reduction in foot height, low placement of the malleolus, and high complication rates, which suggest the need for an alternative treatment option.

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Each author certifies that his or her institution approved the human protocol for this investigation and that all investigations were conducted in conformity with ethical principles of research.

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The Ilizarov method and its application to the foot and ankle have dramatically expanded during the past two decades and have become an alternative to conventional extensive soft tissue release combined with osteotomies for treatment of neurologic rigid foot deformities [8–10, 15, 17]. Choi et al. reported that patients with complex deformities, multiple previous operations, compromised soft tissues, or deep ulcerations in the foot are most likely to benefit from the Ilizarov technique [4–6].

The goals of this study are to assess the ability of a modified Ilizarov method in neurologic foot deformities: (1) to correct rigid equinovarus deformities, (2) to improve patient function, and (3) to obtain patient satisfaction. We also tried to provide an algorithmic approach to the treatment of neurologic foot deformities based on our experience.

Patients and Methods

We retrospectively reviewed patients who underwent deformity correction for the rigid foot deformities using the Ilizarov technique between 1995 and 2006. Among 48 consecutive patients who underwent Ilizarov correction for rigid foot deformities, 30 patients (34 feet) had foot deformities of neuromuscular origin. Among them, 26 patients (mean age, 18.7 years; range, 5–51 years) (29 feet) with equinovarus deformity were included in this study (Table 1). Exclusion criteria were patients without neurologic disorders (18 patients), deformities other than equinovarus foot deformities (three patients), and medical records that were inadequate for assessment of the preoperative status (one patient). All cases were reviewed by two authors (DYL, SJL). Medical records including

Table 1. Pertinent data of patients

Case	Age (years)	Gender	Laterality	Underlying disease	Preoperative deformity	Combined osteotomy	Triple arthrodesis	Final deformity	Clinical outcome	Complication or sequelae
1	16	Female	Left	LMMC	Moderate	+		Mild	Good	Heel varus
2	20	Female	Right	LMMC	Severe	+	+	Postural	Good	DA (ankle)
3	11	Female	Right	LMMC	Severe			Postural	Poor	Recurrence (Ilizarov)
4	11	Female	Left	LMMC	Moderate			Postural	Poor	Recurrence
5	9	Male	Right	LMMC	Severe	+		Postural	Excellent	
6	12	Female	Right	LMMC	Moderate	+		Postural	Poor	Recurrence
7	5	Female	Left	LMMC	Severe			Postural	Poor	Recurrence (Ilizarov)
8	13	Female	Right	LMMC	Moderate	+		Mild	Good	Heel varus
9	11	Male	Right	LMMC	Moderate	+		Postural	Excellent	
10	15	Male	Left	LMMC	Moderate			Postural	Excellent	
11	14	Male	Right	LMMC	Moderate	+		Postural	Excellent	
12	10	Male	Right	CP	Severe			Postural	Good	DA (ankle)
13	42	Female	Left	CP	Moderate	+		Mild	Good	Pin site infection
14	20	Male	Right	CP	Moderate			Postural	Excellent	
15	35	Male	Right	CP	Severe			Postural	Excellent	Tarsal tunnel syndrome
16	51	Male	Right	RP	Severe	+	+	Postural	Good	DA (ankle)
17	46	Female	Left	RP	Severe	+	+	Postural	Excellent	
18	38	Male	Left	RP	Severe	+	+	Postural	Excellent	
19	42	Female	Left	RP	Moderate	+	+	Postural	Excellent	Tarsal tunnel syndrome
20	29	Female	Left	RP	Moderate	+	+	Postural	Excellent	
21	34	Male	Right	RP	Severe	+	+	Postural	Excellent	
22	7	Male	Left	Nerve injury	Severe			Postural	Good	Pin site infection
23	11	Male	Right	Arthrogryposis	Severe	+		Postural	Excellent	
24	9	Female	Right	Arthrogryposis	Moderate			Mild	Good	Flat-top talus
25	9	Female	Left	Arthrogryposis	Moderate			Mild	Good	Flat-top talus
26	6	Female	Right	Arthrogryposis	Moderate			Postural	Excellent	
27	6	Female	Left	Arthrogryposis	Moderate			Postural	Excellent	
28	5	Male	Right	Arthrogryposis	Severe			Postural	Excellent	
29	5	Male	Right	Arthrogryposis	Severe			Postural	Excellent	

LMMC = lipomyelomeningocele; CP = cerebral palsy; RP = residual poliomyelitis; DA = degenerative arthritis.

previous treatment history were reviewed and passive ankle ROM was recorded preoperatively and postoperatively. Minimum followup was 12 months (mean, 72.9 months; range, 12–155 months).

Equinovagovarus deformity was present in all 29 feet and forefoot adduction deformity was combined with equinovagovarus in six feet. The causes of the foot deformities were spinal dysraphism in ten patients (11 feet), arthrogryposis multiplex congenita in five patients (seven feet), residual poliomyelitis in six patients (six feet), hemiplegic cerebral palsy in four patients (four feet), and traumatic nerve injury in one patient (one foot). Although preliminary results were reported previously in four cases of arthrogryposis (Cases 26–29) [5], these data were included because long-term results after cessation of growth were assessed in this study. Twelve patients (14 feet: arthrogryposis multiplex congenita in seven, spinal dysraphism in six, hemiplegic cerebral palsy in one) had undergone previous surgery (average, 1.6 times) including plantar fasciotomy, various tendon lengthening, and posteromediolateral release. Nine feet in nine patients were treated by distraction histiogenesis only with limited soft tissue release, whereas 20 feet in 17 patients needed additional procedures such as osteotomy, arthrodesis, tendon transfer/lengthening, or a combination of these procedures to achieve a plantigrade status.

All operations were performed by one surgeon (IHC). We first performed a combination of soft tissue release including percutaneous partial capsulotomy, plantar fasciotomy, abductor hallucis fasciotomy, and percutaneous tenotomy of tight tendon. Osteotomies such as Dwyer's calcaneal lateral closing wedge osteotomy, midtarsal opening/closing wedge osteotomy, first metatarsal dorsal wedge osteotomy, and/or tendon transfer/lengthening were combined, depending on the severity and rigidity of the subcomponents of deformities. In general, Steinmann pins and Kirschner wires were used for fixation of the osteotomies. Thereafter, we applied the preconstructed Ilizarov frame to the foot and lower leg to correct the soft tissue gradually [5]. A two-ring Ilizarov frame was applied to the proximal and distal tibia using small transfixion wires (1.5- or 1.8-mm in diameter) and half pins (5 mm in diameter). The foot assembly was constructed using one or two half rings for the hindfoot and another one or two half rings for the forefoot in the usual manner. Hinges and threaded rods then were assembled to allow concomitant correction of forefoot adduction, midfoot cavus, and hindfoot equinus and varus deformities. As reported previously [5], the use of a transfixing pin through the talar neck to derotate the talus and thus restore the talocalcaneal angle can be helpful in cases of talonavicular subluxation (Fig. 1A). A transfixing olive pin in the talar neck was inserted from lateral to medial to pull the externally rotated talar head medially

(Fig. 1B). Partial medial capsulotomy of the talonavicular joint was performed to facilitate reduction of the talonavicular joint, and then another transfixing olive pin was inserted from medial to lateral in the navicula, which was attached to the forefoot ring. The navicular olive pin therefore provides a counterforce against the talar pin during reduction of the talonavicular joint by pulling the medial rod to rotate the talus medially (Fig. 1C). Distraction of the medial rod was started on Day 0 postoperatively. Satisfactory reduction of the talonavicular joint was usually achieved during the first postoperative week. After reducing the talonavicular joint, the navicular stirrup wire was transposed to the tibial ring to allow distraction osteogenesis of the plantar-medial aspect of the cuneiform between the midfoot and forefoot (Fig. 1D) when cuneiform osteotomy had been performed. Thus, good hindfoot alignment is achieved (Fig. 1E).

When we had achieved correction of all components of a deformity, we removed the external fixator after an average of 23.2 days (range, 7–53 days) of stabilization and maintained the corrected position of the foot using a cast for an additional few weeks (range, 2–5 weeks) to provide sufficient time for soft tissue healing to help prevent recurrence. Special care was taken to maintain the plantigrade position by continuing with splinting and bracing and intensive physiotherapy, especially in growing children. To prevent recurrence, we tried to eliminate neuromuscular imbalance, if necessary, by combining arthrodesis with or without tendon transfer. In cases with preexisting bone and joint destruction, there is no alternative but to stabilize the foot by arthrodesis after correcting foot deformities.

Results were assessed by comparing appearance and function before and after surgery [5]. The severity of preoperative deformity was graded using the modified classification of Dimeglio et al. (Table 2). Dimeglio et al. [7] described a detailed scoring system for classification of congenital clubfoot based on measurement of four parameters: (1) equinus deviation in the sagittal plane; (2) varus deviation in the frontal plane; (3) derotation of the calcaneopedal block in the horizontal plane; and (4) adduction of the forefoot relative to the hindfoot in the horizontal plane. This system has been reported to be the most reliable for classification of the severity of equinovagovarus deformity [27]. In the current study, we modified the original 4-point scale and used a 2-point scale for each parameter. Instead of additional points in the original system of Dimeglio et al. (points for the presence of medial creases, a posterior crease, cavus, and poor calf musculature [7]), we measured a fifth parameter (cavus of the forefoot relative to the hindfoot in the sagittal plane) in a 2-point scale. Total scores ranged from 0 to 10 points and were allocated to four grades: severe, 7 to 10 points

Fig. 1A–E (A) Talonavicular joint subluxation is best seen in this projection of the plain radiograph. (B) A transfixing olive pin is inserted from the lateral to medial direction in the talar neck to pull the externally rotated talar head medialward. Then, another transfixing olive pin is inserted from the medial to lateral direction in the navicula, which is attached to the forefoot ring. (C) The navicular olive pin therefore provides a counterforce against the talar pin while reducing the talonavicular joint by pulling the medial rod to rotate the talus medially. (D) After reducing the talonavicular joint, the navicular stirrup wire position is transposed to the tibial ring to allow distraction osteogenesis of the plantar-medial aspect of the cuneiform between the midfoot and forefoot. (E) Talonavicular joint reduction and good hindfoot alignment were achieved.

Table 2. Rating system for evaluation of equinovarus deformity*

Deformity	2 points	1 point	0 points
Equinus deformity	> 10° plantar flexion	10° plantar flexion to 0°	> 0° dorsal flexion
Varus deformity	> 10° varus	10° varus to 0°	> 0° valgus
Supination deformity	> 10° supination	10° supination to 0°	> 0° pronation
Adductus deformity	> 10° adduction	10° adduction to 0°	> 0° abduction
Cavus deformity	> 10° cavus	10° cavus to 0°	> 0°

* Modified from the classification of Dimeglio et al. [7]. Total scores ranged from 10 to 0 points and were allocated to four grades: severe, 7–10 points; moderate, 4–6 points; mild, 1–3 points; and postural, 0 points.

(Fig. 2A–B); moderate, 4 to 6 points (Fig. 2C–D); mild, 1 to 3 points (Fig. 2E–F); and postural, 0 points (Fig. 2G–H).

Morphologic and functional outcomes were determined using the criteria reported by Kling et al. [14]. Excellent was defined as a plantigrade foot with no fixed or postural deformities or callosities, allowing the wearing of normal shoes. Good was defined as a residual deformity less than 5° varus, valgus, or equinus deformity. There were no

callosities and normal shoes could be worn. Recurrent equinovarus deformity or an overcorrection greater than 5° was considered a poor outcome. Patients' overall satisfaction also was investigated. Patient's (or parent's in some cases) satisfaction was determined by questionnaire that asked them whether they were satisfied with outcomes and whether they would undergo the operation again if they had the same preoperative deformities. Patients were

Fig. 2A–H The photographs show representative examples of neurologic equinovarus deformity according to the modified Dimeglio classification (Table 2). (A) Anteroposterior and (B) posteroanterior photographs show a severe deformity with a total score of 9. (C) Anteroposterior and (D) posteroanterior photographs show a moderate deformity with a total score of 5. These (E) anteroposterior and (F) posteroanterior photographs show a mild deformity with a total score of 2, and these (G) anteroposterior and (H) posteroanterior photographs show a postural foot with a total score of 0.

Fig. 3A–G A 10-year-old boy with spastic cerebral palsy, hemiplegic type, who had no previous operations, underwent correction of his deformity using the Ilizarov technique. (A) Anteroposterior and (B) posteroanterior photographs and (C) a preoperative lateral radiograph show his severe equinovarus foot deformity. (D) A

postoperative photograph taken just before removal of the Ilizarov fixator shows nice correction of the foot deformity. (E) Anteroposterior and (F) posteroanterior photographs and (G) a radiograph taken 4 years after surgery show excellent results with postural plantigrade feet.

considered satisfied when they replied they were satisfied and they would undergo the operation again.

Results

A modified Ilizarov method combined with soft tissue release and/or osteotomy enabled good correction of rigid neurologic equinovarus deformities in all feet (Fig. 3).

Before surgery, there were 16 moderate and 13 severe deformities (average preoperative scores, 6.3), according to the modified system of Dimeglio et al. (Table 2). All were converted to postural feet or very mild foot deformities (average short-term postoperative scores, 0.4) by distraction histiogenesis with soft tissue release and osteotomy. The mean time required to correct a deformity was 27.1 days (range, 14–47 days) and the mean time for stabilization in the apparatus was 23.2 days (range,

7–53 days). Additional procedures were required to eliminate neuromuscular imbalance in 12 patients (12 feet). Seven patients (seven feet) (six patients [six feet] with residual poliomyelitis and one patient [one foot] with spinal dysraphism) needed triple arthrodesis after correction of the equinovarus deformity and the rest needed tendon transfer. In this series, postoperative complications occurred in six patients (six feet: two pin site infections, one bullous skin lesion, two tarsal tunnel syndrome, and one anterior impingement syndrome of the ankle).

Recurrence of deformity requiring surgical correction occurred in four feet of three patients younger than 14 years (all patients with spinal dysraphism with an average modified Dimeglio et al. score of 6.8). One patient (two feet) required reapplication of the Ilizarov apparatus, and the remaining two patients (two feet) required corrective osteotomy or soft tissue surgery at an average of 42.8 months (range, 29–53 months) after initial Ilizarov application. Mild recurrent or residual deformity was treated nonoperatively in two patients (two feet).

At latest followup (mean, 72.9 months), clinical outcomes and patient satisfaction were considered acceptable. A postural plantigrade foot with no fixed or postural deformity was obtained in 24 feet. According to clinical outcome assessments, 15 patients (16 feet) achieved an excellent outcome and eight patients (nine feet) had a good outcome. Four feet in three patients needing surgical correction for recurrent deformity were classified as having a poor result despite a final postural plantigrade appearance. Mean ankle ROM improved from 29.5° preoperatively to 35.6° postoperatively. Nearly 80% of patients (19 patients; 22 feet) were satisfied with their outcomes and replied they would repeat their procedure if they had the same preoperative deformities.

Discussion

The treatment of rigid equinovarus foot deformities caused by upper and lower motor neuron lesions is often difficult and relapse is common. We asked whether the Ilizarov technique was applicable for correction of rigid equinovarus foot deformities caused by neurologic disorders.

Although outcomes in our study generally suggested a modified Ilizarov method can be a viable option, the outcomes must be interpreted in light of our study limitations. This study was retrospective and the patient group had several confounding variables: etiologies of deformity, severity of deformity, and age of patients. A followup of a minimum of 12 months might be insufficient to assess clinical outcomes of neurologic foot deformities, although the majority of patients were followed more than 5 years.

Furthermore, we could not apply a prospective protocol and the surgical technique we used evolved with time, although the decision-making process had not substantially changed. Further study using a prospective protocol would be needed to overcome these limitations.

Generally, the Ilizarov procedure is selected for complex foot deformities with rigid hindfoot deformity and/or a severe cavus component to maintain foot length in the process of deformity correction [4, 6, 8–10, 15, 17]. It has advantages over ablative procedures because it is less invasive and allows for simultaneous correction of all components of a deformity without bone resection or foot shortening. Furthermore, soft tissue viability and function can be assessed directly, and the rate of correction can be adjusted accordingly [5]. In case of acute correction combined with talectomy, the talus should be removed completely and sometimes all or part of the navicula also should be removed to achieve adequate correction [17, 22]. Although it was reported [18, 22] that walking ability could be preserved after talectomy, movement of the foot at the tibiotalar pseudarthrosis and midtarsal joint was severely limited and the foot height was low and the foot length was short.

Based on our experience in this study, we suggest an algorithmic approach to the treatment of neurologic equinovarus foot deformities using Ilizarov methods (Fig. 4). Although it had not been followed strictly for the patients in the study, we are now following this algorithmic approach. First, we check hindfoot flexibility. If the hindfoot is not flexible and the heel varus deformity cannot be corrected completely, a Dwyer osteotomy (lateral calcaneal closing wedge osteotomy) is performed first. If the hindfoot deformity is completely correctable or corrected by the Dwyer osteotomy, we examine the cavus subcomponent of the foot deformity. In some patients with mild cavus, soft tissue release including partial capsulotomy may be sufficient. If the cavus deformity is very rigid and severe, midtarsal dorsal closing wedge osteotomy along with plantar fasciotomy and abductor hallucis fasciotomy is needed. In this situation, gradual Ilizarov correction might be used for correction of severe equinovarus deformities only (dotted arrow in Fig. 4). However, it has been our experience that most neurologic equinovarus feet can be corrected without a midtarsal dorsal closing wedge osteotomy. Instead, we perform a first cuneiform plantar opening wedge osteotomy along with plantar fasciotomy and abductor hallucis fasciotomy. For forefeet with a severe pronation deformity, a transcuneiform plantar opening wedge osteotomy is beneficial for complete correction of forefoot pronation, as reported by others [23]. Thereafter, if the cavus deformity remains, a first metatarsal base dorsal closing wedge osteotomy may be combined. When residual forefoot adduction remains, a

Fig. 4 A flowchart shows an algorithmic approach in decision-making for the treatment of neurologic equinovarus foot deformities using Ilizarov methods.

cuboid closing wedge osteotomy is added in a sequential fashion. Gradual correction using Ilizarov methods after a cuneiform osteotomy and/or soft tissue release provides a foot elongation effect when compared with that of a midtarsal dorsal closing wedge osteotomy. However, in specific cases, triple arthrodesis and/or tendon transfers can be added after the deformity correction in addition to this algorithmic approach to prevent recurrence.

In terms of technical issues regarding the Ilizarov procedure, the use of a transfixing pin through the talus to derotate the talus was helpful for restoring the talocalcaneal angle in cases with subtalar and midtarsal malalignment, as reported previously [5]. This is based on the concept that the deformed foot approaches a normal appearance with medial rotation of the talus and reduction of the head of the talus to the navicula [2, 3, 24, 25]. After reducing the talonavicular joint, pin position can be changed to maintain talonavicular joint reduction and allow distraction osteogenesis of the plantar-medial aspect of the cuneiform. This sequential correction is worthwhile because the effect of first cuneiform opening wedge osteotomy without fixing the navicula may cause medial displacement of the navicula on the talar head, which may aggravate heel varus deformity [26].

All substantial recurrences of deformity needing additional surgical correction (mean interval, 42.8 months) occurred in patients younger than 14 years with lower motor neuron disease (spinal dysraphism). Thus, the use of nighttime splinting is of utmost importance in younger patients who have not reached skeletal maturity. To reduce the risk of recurrence, it is essential to correct completely all components of a deformity. Sometimes overcorrection of a deformity during the external fixation period is helpful. Finally, and most importantly, elimination of neuromuscular imbalance is essential to prevent recurrence by combining arthrodesis with or without tendon transfer, especially in patients with lower motor neuron diseases. We think that a triple arthrodesis after a modified Ilizarov method is not considered a failure in the correction of neurologic foot deformities. In our series, we needed triple arthrodesis in seven feet after the correction of cavovarus deformity owing to muscle imbalance. Nevertheless, we were able to minimize bone resection to maintain foot height and length and reduce complication rates as compared with primary triple arthrodesis.

Our patients experienced several complications, including pin tract infection and dysesthesia, which have been reported when the Ilizarov external fixator is used to correct foot deformities [1, 11, 13, 28]. Generally, complications were minor and were managed nonoperatively. Incidence and prognosis of perioperative complications were similar to those in previous reports of Ilizarov correction of neglected clubfoot deformities [11, 13]. However, in one case of anterior impingement syndrome, which can be considered a degenerative change, we resected the osteophyte of the talus.

Ilizarov soft tissue distraction with or without callotasis of tarsal bones allows a greater degree of correction of neurologic rigid foot deformities while minimizing further surgical intervention and scarring. However, to reduce the risk of recurrence, it is essential to correct all components of the deformity completely and to eliminate neuromuscular imbalance by combining arthrodesis with or without a tendon transfer.

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