DISTRACTION OSTEOGENESIS OF THE FIRST METATARSAL

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INTRODUCTION

Brachymetatarsia refers to a shortened metatarsal. The etiology may be congenital, iatrogenic or traumatic. Iatrogenic or traumatic brachymetatarsia may have concomitant joint destruction, whereas congenital brachymetatarsia usually spares the joint. In the past, the deformity has been corrected with lengthening metatarsal osteotomies, bone grafts, synthetic implants and combination procedures. One of the most innovative methods still in its investigational stages is distraction osteogenesis: bone lengthening by gradual distraction. The benefit of this procedure is the production of new bone without the need for additional bone transplantation. Two cases, traumatic brachymetatarsia, and iatrogenic brachymetatarsia will be presented. Both cases were treated with the EBI mini-external fixator.

Callotasis, as termed by DeBastiani and described and demonstrated by Ilizarov in 1969, involves osteogenesis after corticotomy and subsequent distraction by an external fixator.[1] Critical factors governing the rate and pattern of healing include stability, rate of distraction and blood supply preservation.[2] Ignoring these factors, and uncontrolled distractions, may lead to interposition of fibrous tissue and eventual non-union.

Historically, Codivilla was the first to describe lengthening by skeletal traction in 1905. Then in 1951, Ilizarov pioneered percutaneous osteotomy with gradual distraction.[3] Malev was the first to lengthen a metacarpal secondary to traumatic amputation in 1967.[4] DeBastiani in 1977 introduced a rigid fixator with a telescoping component that could be released for dynamic loading.[5]

The mini-external fixator (Orthofix M-100), used in the following cases, is a dynamic axial fixator with 4 self-tapping screws which are tapered from 3.0 mm to 2.5 mm. (Figures 1A, 1B) The screws are placed at right angles to the bone's long axis through a special screw guide. The osteotomy is performed after placement of the

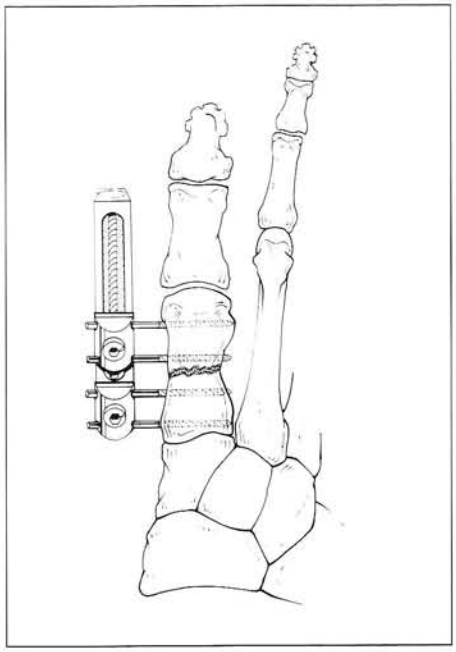

Figure 1A. Callus distraction can be performed using the Orthofix M-100 mini-fixator in adults or children to lengthen the first metatarsal.

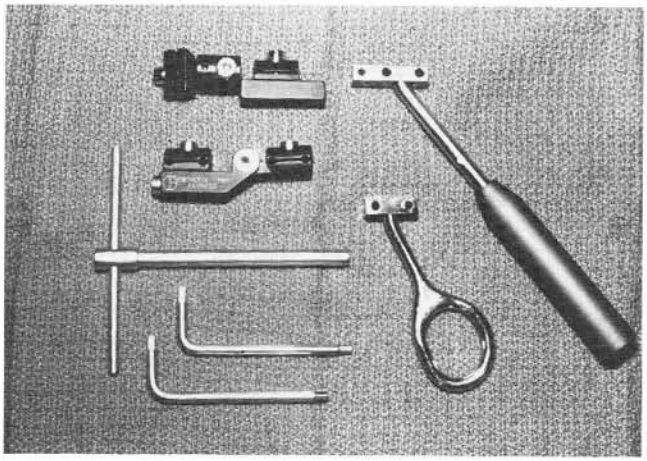

Figure 1B. Orthofix M-100 instrumentation. Minifixators (top), T-wrench (middle), Allen wrench (bottom), Guide templates (right).

device. The proximal and distal clamps are then connected to a ball joint which permits motion in two planes and some rotation.

The surgical procedures described involved a dorsal linear skin incision with dissection to deep fascia and periosteum. The periosteum is carefully peeled and preserved for visualization of screw placement and osteotomy. (Figure 2) The 4 self-tapping screws are inserted; two distal and two proximal to the proposed osteotomy. The screws are placed perpendicular to the diaphyseal axis, crossing both cortices with 2 to 3 threads across the second cortex. This placement is verified by Xi-Scan fluoroscopy.

The authors prefer to place the external fixator parallel to the diaphysis, and use the template for placement of the screws. Next, with the power oscillating saw and rapid cooling with water, the osteotomy is performed from dorsal to plantar at the proximal diaphysis. (Figure 3) Final positioning of the screw may be performed with a T-wrench. Careful reapproximation of the deep fascia and periosteal layer is performed, followed by closure of the subcutaneus layer and the skin.

Distraction is begun after a latent period which is dependent on the patient's age, vascularity, specific diagnosis and degree of surgical trauma.[6] Better bone formation is evidenced in children and adolescents because of thicker, more active periosteum. Best results are seen between ages 8 to 20.[5]

The latency period and rate of daily distractions are extremely variable. Ilizarov begins at seven days in adults and sooner in children.[6]

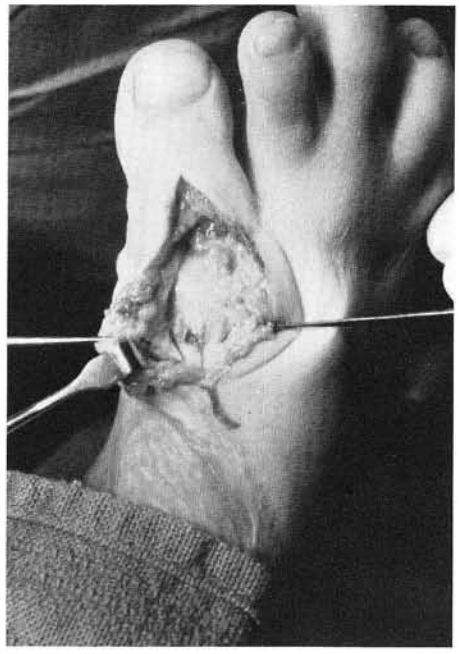

Figure 2. Surgical dissection with reflection of periosteum.

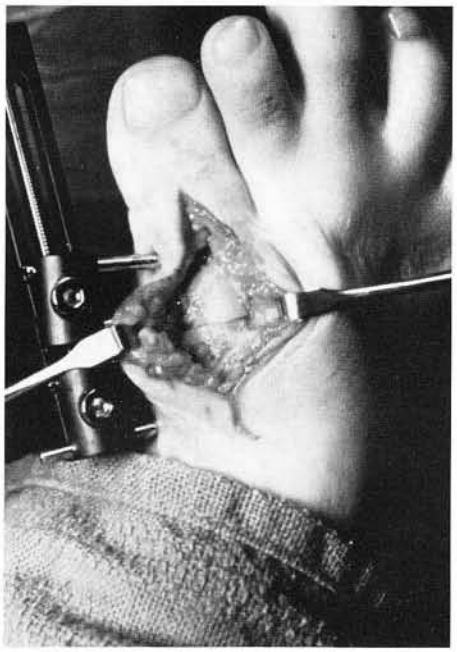

Figure 3. Transverse osteotomy performed from dorsal to plantar at proximal diaphysis.

Amillo et al. lengthened the first metatarsal of a 14 year-old boy with 2 mm of initial distraction followed in one week by gradual distraction of 0.5 mm twice a day for three weeks, followed by 0.25 mm twice daily.[7] Wakisaka et al. lengthened bilateral 4th metatarsals in a 14 year-old girl after

a three week latent period and a rate of distraction of 0.25 mm twice daily.[1] Kojimoto et al. experimented with rabbit tibias and used a ten day latent period with a 0.25 mm twice-daily distraction.[8] All of the cases used the dynamic mini external fixator (Orthofix M-100).

Distraction occurring immediately after osteotomy results in retardation of callus formation, whereas an excessive delay or latent period allows premature bone fusion.[6] If pain, neurovascular changes or early radiographic stagnation of osteogenesis is noted, the distraction rate is decreased or stopped temporarily. The length of metatarsal lengthening achieved in the cases reviewed varied. Amillo et al. achieved 28 mm on the first metatarsal.[7] Wakisaka achieved 14 mm and 12 mm on bilateral 4th metatarsals.[1] Kojimoto et al. lengthened rabbit tibias 2.4 cm.[8] The risk of damaging the epiphyseal plate is minimal as reported by Peltonan et al. in 1988.[9] Total lengthening of between ten and twenty percent of the bone's original length has been described by Coleman and Noonan in 1967.[10]

DISCUSSION

Osteogenesis occurs at the sclerotic zones which are seen radiographically. The central radiolucent gap ("the interzone" as described by Ilizarov) is filled with elongated cartilage, areas of fibrous tissue and hemorrhage. Bone formation is a combination of intramembranous and enchondral formation.[6] It is thought to resemble a growth plate with evidence of both osteogenesis and chondrogenesis. The periosteum, endosteum and medullary structures contribute to osteogenesis in the distraction gap.[1] Both the periosteum and endosteum form callus which fills the gap leaving a non-calcified zone in the middle which showed the strongest osteogenic activity in this "growth zone" with some evidence of chondrogenesis.[10] Delloye attributes no advantage of corticotomy to rapid-cooling osteotomy. He concluded that disrupted endosteal blood supply regenerates rapidly and does not need to be preserved at the time of the osteotomy.[2]

A corticotomy is performed with limited penetration of the cortex, thus preserving the nutrient artery and medullary canal. A series of drill holes are made around the anterior two thirds of the bone circumference and joined with scalpel or osteotome. This procedure automatically breaks the posterior cortex maintaining the posterior periosteum.[11]

Kojimoto osteomized rabbit tibias and concluded that periosteum removed at the time of operation significantly disturbed new bone formation with a failure of lengthening. Scraping the endosteum, in contrast, did not have a pronounced effect on the degree of osteogenesis. Therefore periosteum preservation appears to be more important than careful corticotomy.[6]

Soft tissue responds to distraction osteogenesis when placed under the laws of tension stress. Ilizarov found that with slow lengthening in dogs, ultrastructural activation similar to that in bone and skeletal muscle occurs. In arteries, activated smooth muscle cells become oriented longitudinally and provide increased intracellular contacts and increased elastic structures. Myogenesis begins after ten percent of lengthening of the resting length, with growth occurring at the myotendinous junction.[6] Hypertrophy of the soft tissue and increased diameter of the operated and distracted bone may result from the increased vascularity in the distraction area and proliferation of the periosteal callus. Distraction itself may have a stimulating effect on tissue regeneration in general.[9]

Linear elongation of soft tissue and bone occurs in response to the stress stimuli. Fracture repair callus is bulbus in appearance and lacks striations compared to the regenerated bone formed from continued distraction. Bone formed in response to distraction will demonstrate more defined lateral margins and a cylindrical appearance.[6]

CASE 1

An 8-year-old female presented with deformity of the distal medial right foot secondary to a 1986 lawn mower injury. Since the incident, the patient has received two skin grafts and four debridements with resection of bone. In 1990, the patient had a Valenti STJ arthroereisis inserted to correct a severe pes valgus deformity. The patient continued to have a shortened first and second metatarsal with an increasing adductus of the forefoot at Lisfranc's joint and the medial three digits. The distal 1/3 of the first metatarsal, along with the proximal 1/2 of the proximal phalanx

Figure 4. Preoperative radiograph of right foot. Note the significant shortening of the first metatarsal secondary to a previous history of a lawn mower injury and subsequent debridements. The growth plate is open on the base of the first metatarsal. Note the damage to the base of the proximal phalanx of the hallux and the second toe, as well as resultant growing of the second metatarsal medially, and complete loss of the growth plate.

Figure 5. AP radiograph showing ossification occurring at the distraction site two months postoperative.

Figure 6. Final distraction at three months postoperative showing a resultant increase in length of 2.3 cm (42% increase in length).

were absent. (Figure 4) The distal aspect of the second metatarsal was squared with an absent physis.

The goal of surgical intervention included restoration of the length of the medial column for its weight bearing and digital buttressing effect. The first metatarsal would be lengthened by the process of distraction osteogenesis using the EBI mini external fixator. The surgery was performed on July 15, 1992, and the right leg was placed in the modified Jones splint with non-weight bearing instructions. The latent period was five days, after which the patient was instructed to turn the device 1/4 clockwise (0.175 mm) daily. Twelve days later, the distraction rate was decreased to 1/8 turn (0.087 mm) daily, secondary to stagnant radiographic appearance of the osteotomy site.

On August 31, the rate of distraction was increased to 1/2 turn (0.35 mm) everyday. On September 18, 1/2" of distraction was noted. (Figure 5) On September 25, the rate of distraction was increased to 3/4 turn (0.53 mm) daily. On October 10, (three months postoperative) the external fixator was removed due to resistance of turning and adequate length achieved. Final growth measured 2.3 cm. (Figure 6, 7)

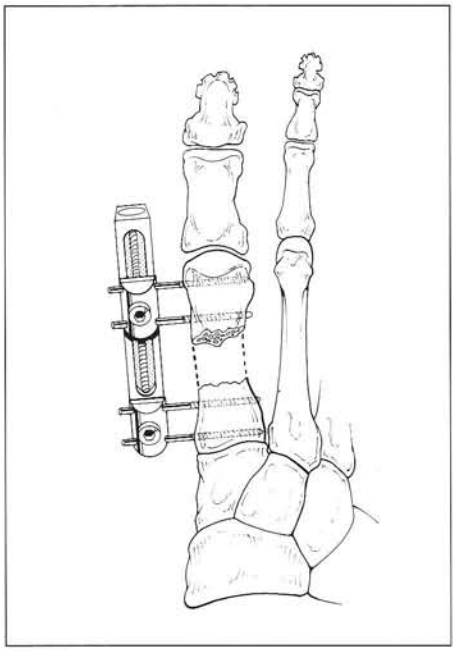

Figure 7. Slow distraction is carried out at a controlled rate.

Figure 8. Preoperative radiograph showing significant iatrogenic shortening of the first metatarsal secondary to multiple salvage procedures.

CASE 2

A 45 year-old female presented with a history of bilateral bunion surgery. In the postoperative period, she injured her right foot and was re-operated on with resultant aseptic necrosis of the first metatarsal head. Salvage procedures were later performed. The patient continued to complain of lesser metatarsalgia of her right foot secondary to significant iatrogenic shortening of the first metatarsal.

Radiographically, the first metatarsal was significantly shortened. (Figure 8) The patient was given several treatment alternatives of which distraction osteogenesis was the preferred alternative for restoration of the length of the medial column.

On October 29, 1992, the application of an Orthofix M-100 lengthening device was performed along with the metatarsal osteotomy. (Figure 9) The patient was placed in a modified Jones splint postoperatively and instructed to be fully non-weight bearing. On November 11, 1992, she was instructed to begin distraction by turning the screw 1/4 turn clockwise (0.175 mm) per day for one week, then 1/2 (0.35 mm) turn per day thereafter. She will be closely followed. Thus far, there are no complications noted.

Figure 9. The application of the Orthofix M-100 lengthening device with an osteotomy in the proximal diaphysis.

CONCLUSION

Distraction osteogenesis can be a valuable option for correction of brachymetatarsia as evidenced in the two cases presented. The technique is ideally suited for lengthening brachymetatarsia found in the younger patient population. It is not without complications such as pin tract infection, pin loosening, bending of the screw, medial or lateral translation of the osteotomy, soft tissue contracture, nerve or vessel injury, decreased muscular strength, osteolysis or angulation and pain.[9]

Considering the screw size, pin tract infection is very uncommon and occurs most commonly with loosening of the screw. Other innovative techniques utilizing the EBI mini external fixator include slow distraction of the epiphysis studied by DeBastiani and gradual soft tissue lengthening as performed by Kalish.[12]

The principal of continuous distraction has been shown to result in controlled lengthening of bone structures and has resulted in reliable adaptation of associated soft tissue structures in response to slow stretching. This technique of bone lengthening is an alternative to bone grafting and lends itself well to controlled distraction performed on an out-patient basis.

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