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A Study of Bone Transport Using a New Callus Bone Distractor

Kamal Seyed-Forootan,[1] Hamid Karimi,[1,*] and Nazilla-Sadat Seyed-Forootan[2]

[1]Faculty of Medicine, Iran University of Medical Sciences, Tehran, IR Iran

[2]Iran University of Medical Sciences, Tehran, IR Iran

[*]*Corresponding author*: Hamid Karimi, Faculty of Medicine, Iran University of Medical Sciences, Tehran, IR Iran. Tel: +98-9123179089, Fax: +98-2188770048, E-mail: hamidkarimi1381@yahoo.comkarimihamid11@gmail.com

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Abstract

Background: This study was performed to evaluate the results of finger lengthening following traumatic amputation or congenitally short phalanges, metacarpal bones, or metatarsal bones using a new callus distraction device. The device is simple, light, cheap, reliable, and easy to use.

Methods: The study group consisted of 246 patients (108 females and 138 males) who had short bones in their hands or feet. The mean ($\pm$ SD) age of the patients was 23 $\pm$ 8 years (4 - 37 years). In the study group, 68.2% of the patients had previously undergone traumatic amputation of fingers or toes. The mean follow-up time of the patients was 7 $\pm$ 1.5 years.

Results: The mean metacarpal, phalangeal, and metatarsal length before surgery was 28 mm (19 - 35 mm). The mean lengthening after surgery was 18 mm (13 - 29 mm; more than 64% lengthening). The mean healing index ratio (HIR) was 3.88 mm/d. No bone grafts were required after bone lengthening. Complications included pin tract infection in 5 (2%) cases, scar formation in the dorsum of the finger in 19 (7.7%) cases, neuronal damage in 3 (1.2%) cases, reversible joint stiffness in 23 (9.3%) cases, and bone malalignment pain in 29 (11.7%) cases.

Conclusions: Callus distraction is an effective and reliable method for lengthening short phalangeal, metacarpal, and metatarsal bones. It also preserves periosteal tissue. Our distractor is reliable, cheap, lightweight, user friendly, and highly effective for callotasis.

Keywords: Distraction Osteogenesis, Small Bone, Hand, Callotasis, Lengthening

1. Background

Distraction osteogenesis is an accepted method that has been used for decades to lengthen the long bones of the extremities. In this method, an llizarov device, named after its inventor, a Russian doctor, is fitted to the extremity. The device consists of pins, screws, and rings. After osteotomy, with preservation of the medulla and periosteum, distraction of the bone, followed by new bone formation, occurs quickly, with lengthening of 1 mm each day. Although this method has been used to lengthen the small bones of the fingers, the application of the device, which is large and heavy, is very difficult, and it prevents normal daily hand or foot activity and function. In addition, it is not possible to preserve the periosteum and medulla in all cases (1-6). We designed a new, simple device, which is more practical and associated with fewer complications than current devices, and a new distraction technique. The device has no rings, complicated pins, or heavy parts and is easily assembled and used. The device was registered in the Iranian Patent Office in Tehran in 2006.

2. Objectives

Our objective was to compare the results obtained using our new device with those obtained using existing devices, and the bone lengthening achieved.

3. Methods

From March 1995 to March 2015, 246 patients who presented to our hospital underwent surgery using the distraction device. Most of the patients had suffered traumatic amputation of fingers, and some had congenital absence or shortness of digits or part of one digit or a bone in the hand or foot.

Demographic data and cause of the trauma or congenital abnormality, length of bones before and after distraction, and complications, such as infection, pain, bone deviation, neurovascular problems, and scarring in the operative site, were recorded. Photography, X-rays, and computerized tomographic (CT) scans were performed at various stages of the procedure.

All the patients returned for a follow-up visit each week after the surgery for one month and every two weeks thereafter. At the follow-up, they underwent an X-ray to evaluate the progression of the distraction. After removal of

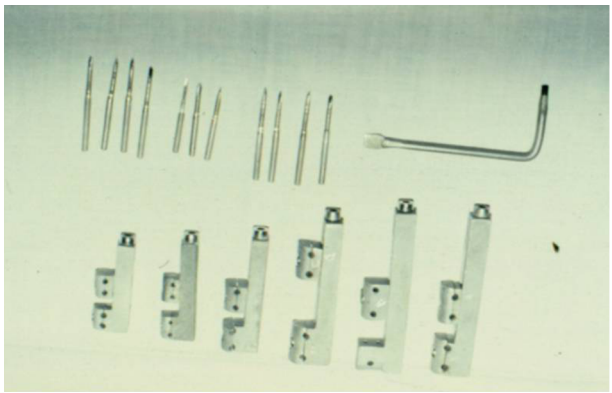

Figure 1. The Device, Showing the Different Sized Pins

the device, the patients were followed for 12 months. Photographs and X-rays were taken 6 and 12 months postoperatively. The mean follow up was 7 ± 1.5 years. In all cases, distraction occurred.

Our device has two pairs of pins, which are placed at each side of the osteotomy site, and a median bar with an adjustable screw. The pins have a straight alignment, and they are all placed in the same line (Figure 1). The bar contains four holes, and two small screws are used to fix the pins to the bar.

The main screw and longitudinal screw gradually increase the distance between the pair of pins in the two sides of the cut bone. A complete turn (360 degrees) of the main screw increases the distance by 1 mm/d. Usually, a stepwise increase in the distance is performed twice a day (or 2 × 0.5 mm/d).

3.1 Operative Technique

After regional anesthesia and preparation of the hand with antiseptics, the skin was incised using a lazy S dorsal incision, and the tissue layers were dissected to the periosteum through the incision in the midline of the extensor tendon in the dorsum of the phalanges or the dorsum of the hand.

With the use of a periosteal elevator, the periosteum was elevated, and two pins were inserted in the proximal and distal sites using a hand drill (not an electrical drill). A complete, full-thickness osteotomy of the bone was then performed, without any effort to preserve the medulla. The skin was sutured and closed over the pins, and the longitudinal bar was fixed to the four pins. Antibiotic ointment was applied each day to prevent pin tract infection.

After five to seven days, when a callus was formed in the osteotomy site, distraction of 2 × 0.5 mm/d (or 1 mm/d) was started to distract the callus. Callotasis (i.e., distraction of the callus or movement of the callus) was confirmed by radiographic examination, in addition to a CT scan in some cases. The desired lengthening was achieved in all cases (Figures 2 - 5).

At the end of the treatment period, in cases where the lengthening of the bone was 18 mm or less, the device was left in place for about two times the lengthening time. In cases where the bone lengthening was more than 18 mm, the device was left in situ for about three to four times the lengthening time, until a complete firm callus had formed or bone ossification had occurred (Figure 4 - 7).

The lengthening of the callus was not apparent in the beginning on the X-ray examination, but it was clearly observed on the CT scans. After lengthening, bone tubules were observed on X-rays after six to nine weeks (Figures 6 and 7).

As the device works on the callus itself, it is a callus distractor, not an osteogenesis distractor. Earlier devices used traction from outside the bones on both bone ends to open

Figure 2. A Patient With Short Third and Fourth Fingers

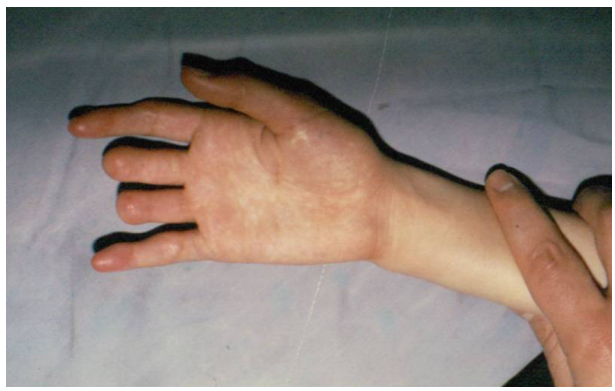

Figure 3. A Patient With Short Third and Fourth Fingers

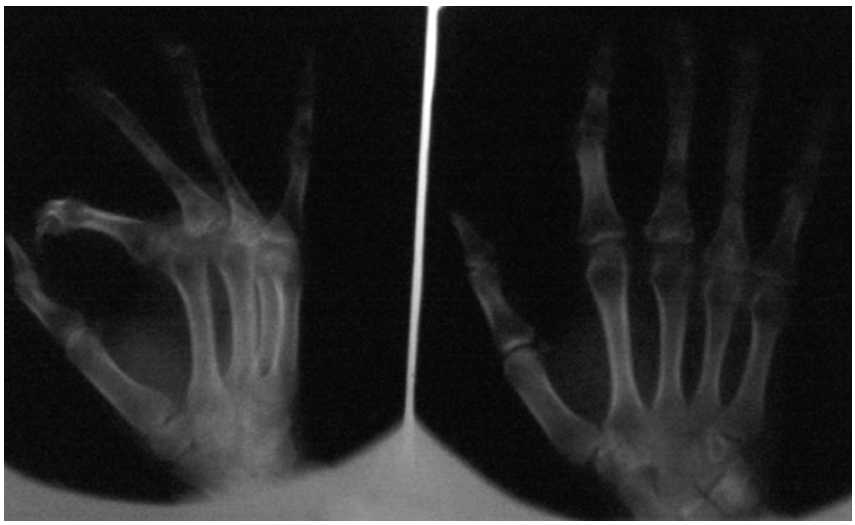

Figure 4. A Patient With Short Third and Fourth Fingers

the space between the bone. In contrast, our device used force from inside the two bone ends, inside to outside, to distract the distance. In this way, the callus moves gradually.

The satisfaction of the patients and surgeon was classified as poor, fair, good, and excellent after the treatment. The results of the procedure were recorded, and complications associated with lengthening of 0.5 mm/d and 1 mm/d were compared (Figures 8 - 11).

4. Results

Over the course of more than 20 years, we treated 246 patients (138 males and 108 females). The mean ($\pm$ SD) age of the patients was 23 $\pm$ 8 years (4 - 37 years). Most of our patients (68.2%) had short fingers due to previous traumatic amputation, and the remainder (31.8%) had congenital defects. The mean follow-up time of the patients was 7 $\pm$ 1.5 years.

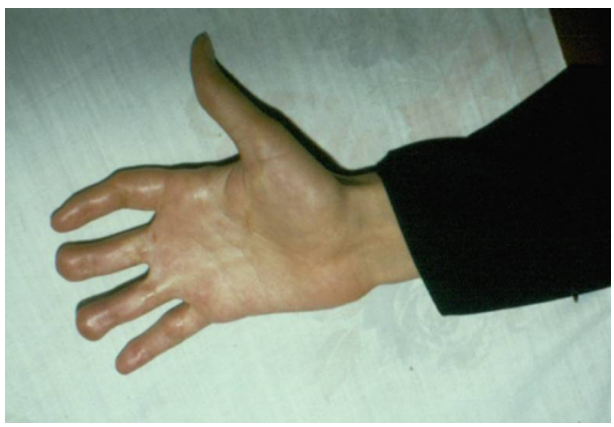

Figure 5. A Patient With Short Third and Fourth Fingers

The mean bone length before the procedure was 28 mm (19 - 35 mm). The mean bone lengthening was 18 mm (13 - 29 mm), resulting in more than a 64% increase in bone length.

Bone callus ossification occurred over 40 - 63 days. The healing index ratio (HIR), which was the total time of treatment divided by the total length of bone achieved after distraction, was about 38.8 mm/d (3.88 cm/d). The total duration of lengthening was 60 - 81 days. Four patients experienced bone lengthening of more than 29 mm, with no complications.

During the first five years of the study, in cases of more than 18 mm lengthening, some bowing in bones occurred due to the failure of sufficient soft tissue lengthening. To address this issue, in subsequent years, we used longer fixation and ossification periods. As a result, the outcomes were much better, with only minimal (if any) bowing. The most recent cases achieved lengthening of more than 27 mm, without any bowing in the bones.

Two of the four patients who achieved bone lengthening of more than 29 mm were aged four and seven years, respectively. Due to better soft tissue distraction in children, their results were much better than those of the other two patients. Bowing was also minimal in the pediatric patients.

Complications included pin tract infection in 5 (2%)

Figure 6. A Patient With Short Third and Fourth Fingers

cases, scar formation in the dorsum of the finger in 19 (7.7%) cases, neuronal (some sensory branches of the ulnar nerve) damage in 3 (1.2%) cases, reversible joint stiffness in 23 (9.3%) cases, and bone malalignment pain in 29 (11.7%) cases.

The first four female patients treated with the procedure had scars on the dorsum of their feet. These were repaired using scar revision surgery six months later. None of 24 patients subsequently treated with the device had scars on their feet.

All the patients had callus formation and bone ossification, and none of the patients required a bone graft. During follow up, none of the patients had any complaints. There were also no complaints 89 months after the procedure. The patients rated their satisfaction with the

Figure 7. A Short Fourth Metatarsal Bone

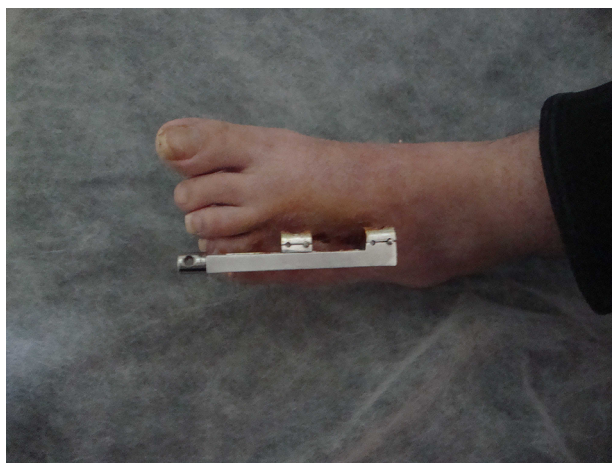

Figure 8. A Short Fourth Metatarsal Bone

Figure 9. A Short Fourth Metatarsal Bone

Figure 10. A Short Second Finger

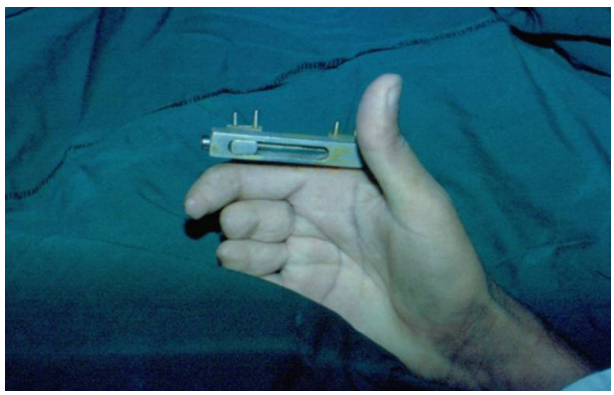

Figure 11. A Short Second Finger

bone lengthening as fair (7.4%), good (12.4%), and excellent (80.2%). The surgeon's satisfaction with the results of the bone lengthening was good in 10.4% of cases and excellent in 85.9% of cases.

In the comparison of the rate of distraction per day, there were no significant differences between the 0.5 mm/d and 1 mm/d rates (mean lengthening of 17 mm vs. 18 mm and patient satisfaction of 93% vs. 92.6%). Obviously, the total time for lengthening and the HIR doubled in the 0.5 mm/d group. There were also no differences in the rates of complications in the 0.5 mm/d and 1 mm/d groups, with an average rate of 7.1% and 6.9%, respectively.

5. Discussion

In 1921, bone elongation was introduced by Pattes, but it was abandoned later because of complications. Subsequently the Wagner method, which had fewer complications, was introduced. In 1950, Ilizarov introduced a device that had very few complications. Ilizarov's device involved the application of a special external fixator and gradual traction of bone, which had been transected earlier. Patients treated with this device were reported to feel some pain in the bones, muscles, tendons, and skin, in addition to neuropraxia, due to excessive traction of nerve bundles (1, 2, 5, 6).

To achieve satisfactory results, bone nutrition and collagen formation should be adequate. Two-thirds of bone nutrition is derived from cortical bone, and one-third is usually derived from the endosteal and periosteal blood supply. Thus, preservation of these two structures is essential. The Ilizarov device is very complex, and insertion of this device in small bones of the hand or foot is difficult and has a very high complication rate. Four to five days after the insertion of the device, distraction is started, with a velocity of 1 mm/d and a maximum velocity of 1.2 mm/d (6-8).

Although the Ilizarov device is useful for large bones, it is not suited for use with small bones, such as phalanges. Furthermore, it is not easy to preserve the periosteum using this device. In contrast, our delicate device is simple to use and very cost effective, especially when used for phalangeal, metacarpal, and metatarsal bones. The device weighs just 25 g. It is also very cheap (manufactured locally), has no sharp edges, and can be easily sterilized in an autoclave.

The device uses the same procedure as that described earlier for long bones. The incision is sutured, and the limb is immobilized for four to five days. The patient then undergoes an X-ray or CT scan to observe the callus formation. Gradual traction is then applied, with the traction applied every day. As shown by the results, bone lengthening of up

to 29 mm can be achieved. After a period of ossification, the device can be removed.

Our one-sided, straight-line four-pin device is simple, easy to use, and user friendly, and its results are comparable with those of other distractors. The desired bone length can be reached at a velocity of 1 mm/d. None of our patients had osteoporotic bones. In such cases, the velocity of lengthening should be slower to prevent fracture of the pins inside the bone.

Distraction lengthening is one of several surgical reconstructive methods used to increase the length of an amputated digit, improve the function of the hand, and enhance the esthetic appearance of the hand and fingers. Distraction osteogenesis is also helpful for digit lengthening in cases of congenital and post-traumatic deficits and for soft tissue stretching in cases of radial dysplasia (7).

All the metacarpal and phalangeal bones achieved the target length, and all the patients were satisfied with the results and esthetic appearance of their fingers. The average length of the metacarpal distraction was 18 mm (range 13 - 29 mm). The average HIR was 3.88 mm/d (38.8 cm/d). Most of our patients (68.2%) had post-traumatic (amputation) deficits.

Some authors used the distractor device with intramedullary Kirschner wire to maintain the alignment of the osteotomized bone (9). However, this was not needed in the present study, as we placed the four pins in a straight line, and these four pins maintained the previous alignment of the bones.

In 2006, Baccari et al. reported 12 cases of digital distraction using a mini-orthofix device (10). They reported that the rate of callotasis was 0.25 - 0.5 mm/d and that the percentage of lengthening was the same for metacarpal and phalangeal bones (61% - 63%). They did not experience any spontaneous bone shortening after removal of the device. However, they reported frequent complications. In contrast, we did not experience major or frequent complications.

In 2004, Bosch et al. reported lengthening of the first metacarpals in patients with thumb amputations (11). They used a unilateral external fixator in 18 patients and reported good bone lengthening. In 2004, Akmaz et al. reported good results of late reconstruction of metacarpal shaft defects, but they used a bone graft, in addition to distraction (12). In 2013, Taghinia et al. used two-stage distraction for extensive lengthening of small bones (13). In our study, bone distraction and consolidation were sufficient, and no bone grafts were needed.

In 2004, Parmaksizoglu et al. reported lengthening of fingers following traumatic amputations using a complex unilateral dynamic external fixation (8). They reported that the mean lengthening of thumbs was more than the mean lengthening of the other fingers and that the mean healing index was the same for fingers and thumb (106 - 108 months/cm). They concluded that callotasis was an effective method for improving the function of the hands. In 2004, Heitmann et al. reported that distraction of the metacarpal bone of the thumb resulted in an effective functional improvement in the hands' pinch power (14). In their study, the two-point discrimination of the thumb was comparable with that of normal thumbs, and they reported no neuronal damage or major complications.

In 2004, Matsuno et al. reported a study of lengthening of 23 bones in patients with congenital hand defects (15). They reported that the lengthened bones grew continuously in children younger than 7 years and that distraction had no negative effects on bone growth. We did not evaluate this matter in our study. The functional outcome of callus distraction of the thumb was evaluated by Zimmerman et al. in 2003, and they reported that callus distraction was a suitable procedure for amputated thumbs, with good functional results (16). They also mentioned that bone healing also occurred in elderly patients. Thus, age does not seem to restrict the use of callus distraction.

In 2003, Sen et al. used Ilizarov-type semicircular external fixators for small bones in the hands and feet (17). Their results were good, but they reported a complication rate of 36%, which was much higher than the rate in the present study. Their device was also complex and heavy and uncomfortable for the patients.

In 2009, Das et al. described the use of monoaxial fixator histogenesis (18). The rate of distraction was 0.25 mm/d. They reported good results in the pinch test and few complications. The mean bone lengthening in their study was 24 mm. With our device, we experienced few complications, and the rate was distraction was four times faster. Thus, the length of the treatment was much shorter, and the results were the same.

A study performed in Japan in 2002 reported a distraction rate of 1 mm/d, which is the same as in our study (19). The same study reported a healing index of 37.2 cm/d, which was very similar to the HIR in the present study. In a 2001 report in the U.S., the authors compared the results of one- pin with two-pin distractors in the hands (20). They stated that the amount of distraction was the same but that more complications occurred using the one-pin device.

In our study, we compared the results of two different velocities for distraction of small bones. We could not find a similar study of small bones. We concluded that a velocity of 1 mm/d was safe and reliable for distraction callotasis of small bones. The results obtained were similar to those achieved using 0.5 mm/d distraction. Furthermore, as shown by our results, the rates of lengthening and com-

plications of the small bones of the hands and feet were similar. Most recent studies reported few complications and no major ones in this regard.

5.1. Conclusions

Our mono-directional distractor device is simple, cheap, user friendly, light, and easy to use compared with other distractor devices, and we strongly recommend its use, especially in short bones of the hands and feet. The mean lengthening of bones was 18 mm (13 - 29 mm). Thus, the device resulted in an increase in bone length of more than 64%. The HIR was about 38.8 mm/d (3.88 cm/d). The total duration of lengthening was 60 - 81 days. We conclude that distraction osteogenesis is a suitable method for lengthening of small bones, and has few complications.

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