Correction of Shortening and/or Angular Deformities by Distraction Osteogenesis Using AO-Tubular Fixator

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Abstract

Eighteen patients (20 bony segments) who had shortening and/or angular deformities were treated by distraction osteogenesis using AO-tubular external fixator. The mean angular correction was 18.9 degrees (range, 8-40 degrees). Of the group in whom shortening and angulation was corrected, the mean length gained was 4.2 cm (3-6 cm). The mean treatment time was 4.9 months (range, 2-13 months) and the mean follow-up was 12 months after removal of the fixator (range, 3-30 months). Delayed union with loosening of the fixator occurred in one patient which resulted in residual shortening of 1.5 cm. The author's technique of distraction osteogenesis using AO-tubular fixator with the new distraction rate of 1 mm/48 h (1 mm/step) could adequately correct shortening and/or angular deformities. No extra equipment was needed other than the readily-available AO-tubular fixation systems. No serious complications such as neurovascular injury were encountered.

Key word : Bone Lengthening, Distraction Osteogenesis, AO-External Fixator

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Ilizarov demonstrated that controlled distraction of a well-vascularised corticotomy produced bone in the distraction gap(1). In conjunction with the circular frame he developed, Ilizarov used this concept to provide an elegant method for correction of bony and soft tissue deformity as well as limb lengthening(2). De Bastiani et al developed a similar technique by distraction through callus (callotasis) using a monolateral lengthening device (Orthofix)® (3). Both of these lengthening devices can correct

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angulation by eccentric distraction and regain length by linear distraction using the distraction rate at 0.25 mm every 6 h[4,5]. Although the Ilizarov ring fixator and (Orthofix)® are available in Thailand, their costs remain high. To reduce the medical expenses the author sought a new lengthening technique, which was accidentally discovered. In April 1990 an 8-year-old-girl with 4-cm shortening of the left tibia secondary to congenital posteromedial bowing was treated in author's clinic. The tibia was lengthened with AO/ASIF unilateral external fixator because Wagner lengthening device for children was not available. Firstly, it had been planned to correct the shortening by Wagner' technique, that was daily lengthening of about 1 mm and an autologous iliac bone grafting after achieving the desired length. Because the patient had to go to her school, she was, therefore, managed on an outpatient basis, by distraction of about 1 mm on alternate days (every 48 hours). After the desired length had been gained, the author observed a new bone forming spontaneously in the distraction gap. The author hypothesized that with the distraction rate at 1 mm on alternate days or every 48 hours the new bone could have been formed in the distraction gap without neurovascular injury. One year later, a 32-year-old-policeman who had sustained an infected open fracture with bone loss of 6.5 cm was treated in the author's clinic by autogenous iliac bone graft and stabilized with an AO/ASIF external fixator. Unfortunately, the bone gap still remained because of inadequate bone grafts. Two surgical options were offered to the patient: allograft *versus* the author's own technique. The patient gave informed written consent that he preferred to have distraction osteogenesis, using the author's own technique. With this technique the healthy bone was osteotomized and transported with the distraction rate at 1 mm every 48 hours to fill the gap (Bone transportation). Finally, the author succeeded in closing the bone gap with his own technique in this patient and the patient resumed his work again as policeman. The result of this treatment has encouraged the author to continue its use and so far more than one hundred cases with limb deformity or length discrepancy have been treated with the author's own technique of distraction osteogenesis. To the best of the author's knowledge, there have been no reports describing the use of AO-conventional external fixator for correction of angulation and shortening. The purpose of the study was to evaluate the clinical results of treatment of shortening and/or angular deformity of lower limbs using the author's own technique of distraction osteogenesis.

PATIENTS AND METHOD

From February 1993 to September 1996, 20 procedures for correction of shortening and/or angular deformities were performed on 18 patients using the author's own technique (12 femur, 8 tibia). Five femur and six tibia had angular deformities. Seven femur and two tibia had both angulation and shortening (Table 1). The average age of the patients at the time of operation was 23 years (range, 6-45 years).

Surgical technique

Only the standard elements of the AO/ASIF tubular system were used[6]. A special threaded rod designed by Alonso and Regazzni[7] was not used in this study. At the femur, where the lengthening and/or angular correction were performed, the fixator was always applied to the lateral aspect of the limb. For lengthening and/or angular correction of the tibia, the fixator was always applied to the medial side. A corticotomy or osteotomy was performed in the submetaphyseal area. In the femur this corresponded to the subtrochanteric region proximally and the level just above the supracondylar region distally, in the tibia to the level just distal to the insertion of the patellar tendon. When the lower limb was lengthened, an oblique fibulotomy was always done at the distal third together with tibiofibular transfixing screw (to keep the ankle mortise) before corticotomy was performed. Distraction was begun between 5 and 7 days later at a rate of 1 mm/48 h (1 mm/step). The AO/ASIF tubular fixator lent itself for distraction, the fragment being pushed by the means of compression device. If the space between the two clamps over the osteotomy site was not long enough to place the compression device on the tube, a bone-spreader was used. When angular deformity in coronal plane was associated with shortened extremity, eccentric distraction was first performed to correct angulation and, when alignment was satisfactory, linear distraction was substituted to regain length (Fig. 1). Linear distraction was carried out by pushing the clamp of the near rod (to the bone) after the nuts of the four distal clamps locking the rods had been loosened (Fig. 2). Eccentric distraction was carried out by pushing the clamp of the far rod (from the bone) with the com-

Table 1. Patients and method.

Cases	Age (yr)	Sex	Diagnosis	Procedure	Limb	Corrected angle (degrees)	New bone (cm)	% Length	Healing time (days)	Healing index (days/cm)	Follow-up (months)
Case 1	25	Male	Varus malunion	Angular correction	Tibia	15			101	-	14
Case 2	11	Female	Valgus malunion (physeal arrest)	Angular correction	Femur	40			64		9
Case 3	31	Male	Varus malunion	Angular correction	Femur	18			80		8
Case 4	11	Male	Varus malunion, shortening	Angular correction, lengthening	Femur	23	5.7	30	193	48.3	9
Case 5	38	Male	Varus malunion	Angular correction	Femur	15			153		6
Case 6	16	Male	Varus malunion	Angular correction	Tibia	20			74		6
Case 7	6	Female	Tibia vara	Angular correction	Tibia	28			78		6
Case 8	8	Male	Perthes' disease	Angular correction	Femur	32			67		16
Case 9	6	Female	Congenital shortening, genu valgum	Angular correction, lengthening	Femur	10	4	14.1	90	22.5	13
Case 10	38	Male	Disproportion short statue & genu varum	Angular correction, lengthening	Tibia	10	3.8	10.7	262	68.9	14
Case 11	22	Female	Congenital shortening, genu valgum	Angular correction, lengthening	Femur	8	3.4	8.4	113	33.2	8
Case 12	29	Male	Varus malunion & shortening	Angular correction, lengthening	Femur	11	5.2	12	381	73.3	14
Case 13	13	Female	Genu varum, shortening (physeal arrest)	Angular correction, lengthening	Tibia	26	3	9.4	134	44.7	17
Case 14	18	Female	Congenital shortening, genu valgum	Angular correction, lengthening	Femur	14	6.1	17.3	303	49.7	6
Case 15	39	Female	Genu valgum (physeal dysplasia)	Angular correction	Femur	22			113		16
Case 16	39	Female	Genu varum (physeal dysplasia)	Angular correction	Tibia	29			79		14
Case 17	39	Female	Genu valgum (physeal dysplasia)	Angular correction	Tibia	12			84		12
Case 18	30	Male	Valgus malunion	Angular correction, lengthening	Femur	20	4	9.7	165	41.3	18
Case 19	23	Male	Varus malunion, anterolateral bowing	Angular correction, lengthening	Femur	15	4.5	9	268	59.6	3
Case 20	54	Male	Valgus malunion	Angular correction	Tibia	13				174	30

(Case 15, 16, 17 belong to one patient. Please see Fig. 5). Follow-up = after removal of the fixator.

Fig. 1A. Shortening of 9 cm of the left lower extremity in a girl (case 13) aged 13 years. Pre-operative clinical appearance: Genu varum, 15 degrees of external malrotation, shortening of left femur and tibia of 4.5 cm and 3 cm respectively. (Only the tibia was included in the present study because there was both shortening and angulation. The femur was excluded because there was only shortening).

Fig. 1C. Pre-operative radiograph: varus angulation of 26 degrees of the left knee with shortening of the left femur and tibia secondary to physeal dysplasia around the knee.

Fig. 1B. Pre-operative radiograph. Coxa vara with short neck deformity, secondary to malunion of left femoral neck fracture at the age of nine years.

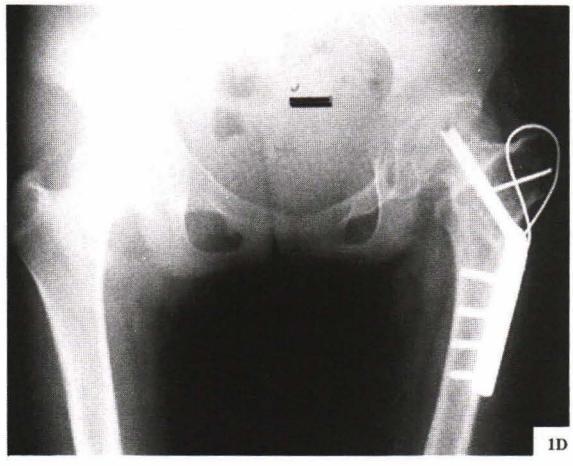

Fig. 1D. Radiograph eighteen months post-operatively revealing improved hip biomechanics after intertrochanteric valgus derotation osteotomy, inferolateral displacement of the femoral shaft and trochanteric lateralization. About 1 cm of length was regained.

Fig. 1E. **Eleven months post-operatively, after linear distraction of the femur and initial eccentric distraction of the proximal tibia (to correct angular deformity) followed by linear distraction. With these procedures lengthening of 4.5 cm and 3 cm were obtained at the femur and tibia, respectively.**

pression device after the nuts of the four clamps locking the rods and Schanz-screws had been loosened. With this manipulation, the two distal Schanz-screws were rotated in the plane of external fixator (coronal plane), resulting in opened wedge at the osteotomy site. A wedge with 1 mm-base was aimed for each distraction (Fig. 3). The distraction was performed by the surgeons. Correction of complex deformities or 3-plane deformities was accomplished with acute correction by derotation in the transverse plane, closed wedge osteotomy in the sagittal plane, and then gradually eccentric distraction in the coronal plane. (Fig. 4) Post-operatively, the patients were encouraged to bear partial weight, using crutches. Daily range of motion exercises of the hip, knee and ankle began on the fifth post-operative day. Pain management was accomplished with narcotics on the first post-operative day, followed by oral acetaminophen during the remaining course. The amount of length gained, the angular correction and the quality of the regenerated bone were monitored radiographically. Angular deformity in the sagittal plane that developed during lengthening was corrected by manipulation and adjustment of the pin under general anaesthesia. Distraction was stopped when sufficient angular correc-

Fig. 1F, G. **Clinical appearance at two-year follow-up. No limb length discrepancy, full range of motion of the left hip, knee and normal gait.**

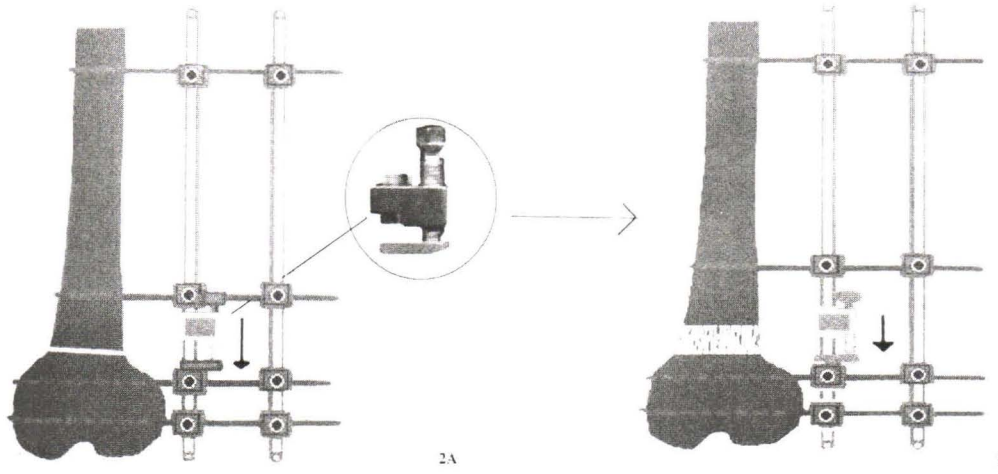

Fig. 2A. **For bone lengthening, linear distraction was achieved by using the compressor/distractor (circled), pushing the distal segment, after the nuts on the four distal clamps locking to the rods have been loosened. Note that the compressor is mounted on the near (to the bone) rod.**

Fig. 2B. **After linear distraction the new bone was created in the distraction gap.**

tion and gain of length had been achieved. Pin removal was performed when roentgenographic evidence of complete healing of the growth area was shown.

RESULTS

The patients were followed for a mean of 12 months after removal of the fixator (range, 3-30 months). All the lengthened segments united successfully without the need for bone grafting. Average time in the fixator (healing time) was 4.9 months (range, 2-13 months). In all instances except one, the desired amount of lengthening was achieved. Likewise, complete correction of angular deformities was obtained in all cases, except one. The length of new bone varied from 3 to 6 cm, with a mean of 4.2 cm. At the femur the mean was 4.5 cm (range, 3-6.1 cm) and at the tibia it was 3.4 cm (range, 3-3.8 cm). The percentage increase over the initial length varied from 8.4 per cent to 30 per cent with a mean of 13.4 per cent. At the femur the mean was 14.4 per cent (rane, 8.4-30%) and at the tibia it was 10.1 per cent (range, 9.4-10.7%). The mean correction of angular deformities was 19.1 degrees (range, 8-40 degrees). At the femur the mean was 19 degrees (range, 8-40 degrees) and at the tibia it was 19.1 degrees (range, 10-29 degrees). The mean Healing Index[8] (the number of days that external fixator was required to obtain 1 cm of discrepancy) in the lengthening group was 47.7 days/cm. In no case was the range of joint motion decreased compared with that before treatment.

Complications

Complications are reported as reported by Paley[9]. Problems represent minor complications that were treated non-operatively without resorting to general anaesthesia. Obstacles were complications that were resolved by operative means. Complications were residual permanent deficits at the end of the treatment period. (Table 2). Delayed union with breakage of Schanz-screws occurred in one patient resulting in collapse of the new bone. (case 19). In this case further distraction was discontinued because

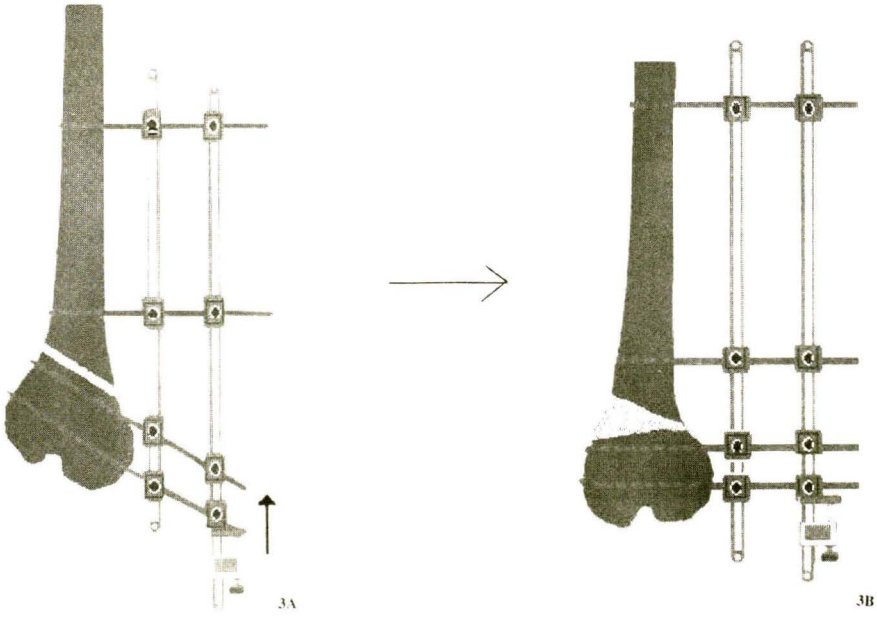

Fig. 3A. Correction of angular deformity was accomplished by eccentric distraction, which was performed by loosening the nuts on the four distal clamps locking the rods and pins.

Fig. 3B. The pins of the distal segment were rotated in the coronal plane or plane of the fixator by means of the compressor/distractor, mounted to the far (from bone) rod.

of the patient's desire. The fixator was removed and replaced with an AO/ASIF compression plate. Finally the bone healed and there was a limb-length discrepancy of 1.5 cm. Two fractures of new bone occurred after minor trauma following removal of the fixator. One of these two fractures was treated with casting (case 9). The other one was treated with an AO/ASIF compression plate (case 11). Six cases of superficial pin-tract infection and one case of deep pin-tract infection were encountered (total infection rate 35%). All cases of superficial pin-tract infection responded to oral antibiotics and release of tethered skin. In the case of deep pin-tract infection (case 15) which occurred at the condylar region of the distal femur, the infection spread to the knee joint. The fixator was removed and the knee-toilet was performed. The knee was immobilized in a plaster cast, to maintain correction. This complication did not compromise the successful outcome and the knee had a good range of motion (Fig. 5). Premature consolidation occurred in two patients. One of these two patients (case 4) was treated with osteoclasis and the other one (case 5) was treated with osteoclasis and osteotomy. Varus angulation of 20 degrees at the proximal femur was encountered in one patient (case 18). He declined the advised corrective osteotomy because he was satisfied with the result. In no case was there no neurovascular damage resulting from the treatment.

DISCUSSION

To correct axial limb deformities with associated length discrepancies, using distraction osteogenesis, the currently available lengthening devices in this country are Ilizarov's ring fixator and Orthofix (monolateral device). Although these devices provide stability and a predictable result, the cost factor precludes its use. Today's current technique is based on the observation by Ilizarov that a rate of 1 mm/day divided into four increments (4 x 0.25 mm) is necessary for regeneration of bone in the distraction gap[2]. Therefore, orthopaedic surgeons have to depend on these expensive, sophisticated instruments. 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 conven-

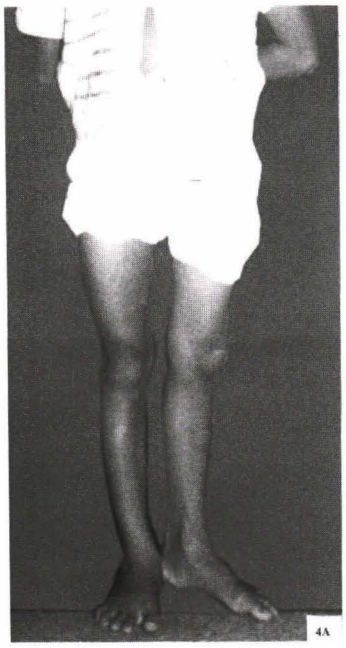

Fig. 4A. An eleven-year old boy (case 4) with malunion of a subtrochanteric fracture of the left femur. He had 6 cm of femoral shortening with 90 degrees external malrotation.

Fig. 4C. At the time of osteotomy, acute derotation was done. An AO/ASIF external fixator applied for gradual correction. Eccentric distraction was performed first to correct angular deformity, followed by linear distraction to increase length.

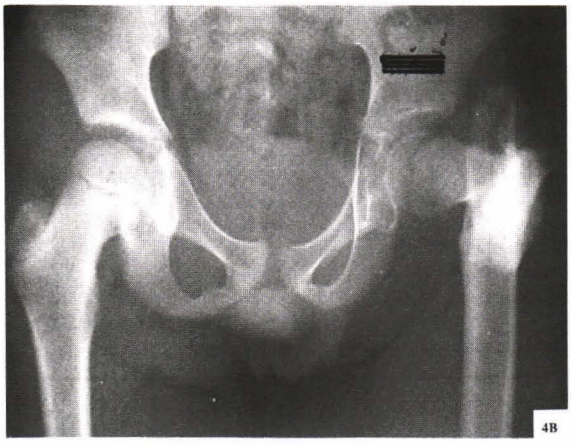

Fig. 4B. Radiograph showing severe coxa vara and proximal migration of the femoral shaft.

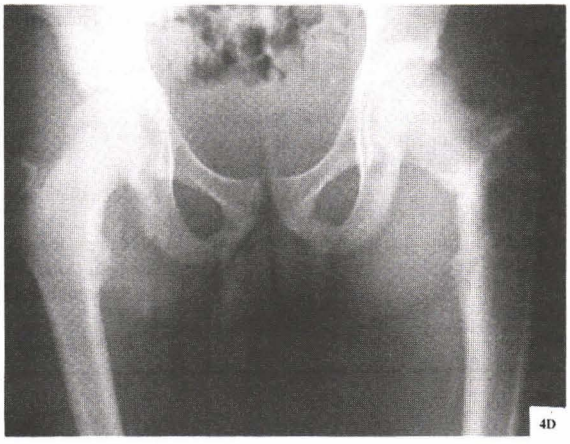

Fig. 4D. Three years and four months after surgery. Radiograph showing abundantly new bone formation and adequate correction of the deformity. The shaft-neck-angle of 115 degrees and the femoral shaft lengthening of 5.5 cm was achieved.

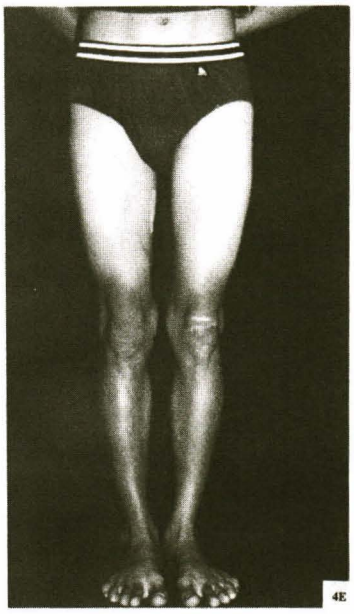

Fig. 4E, F. Photograph showing limb length equalization, no rotational deformity and full range of motion of the left lower extremity.

Table 2. Complications.

	Problems	Obstackes	Complications
Case 2	Superficial pin-tract infection	-	-
Case 4	Superficial pin-tract infection	2 X Osteoclasis 1 X Manipulation & adjustment of pin-site	-
Case 5	-	2 X Osteoclasis 1 X Manipulation & adjustment of pin- site 1 X Osteotomy	-
Case 7	Superficial pin-tract infection	-	-
Case 8	Superficial pin-tract infection	-	-
Case 9	Superficial pin-tract infection	-	Fracture of new bone
Case 10	-	2 X Manipulation & adjustment of pin–site	-
Case 11	-	-	Fracture of new bone
Case 14	Superficial pin-tract infection	1 X Manipulation & adjustment of pin-site	-
Case 15	-	1 X Manipulation & adjustment of pin-site Knee joint toilet (septic arthritis)	-
Case 18	-	-	Varus angulation 20 degrees (proximal femur)
Case 19	-	Delayed union & broken pin-site	Rest shortening (1.5 cm)

tional external fixator. Ilizarov showed, in his study that using a canine tibial model, that a distraction rate of 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(2). However, clinically Wagner demonstrated that the bone could be lengthened at a rate of 1.5 mm/day in one step without nerurologic damage. In addition, in children, spontaneous regeneration of the bone may occur in the distraction site (10). In rabbit experiments Alho et al had found that gradual distraction of the tibiofibular bone at the rate of 1 mm/week stimulated endosteal and periosteal callus formation which resulted in filling of the distraction gap(11). Similarly, Delloye et al created bone regeneration in the distraction gap of osteotomized limbs of dogs with an average distraction rate of 0.8

Fig. 5A. **A 40 year-old-woman (case 15) with "wind-swept deformity", secondary to multiple physeal dysplasia. She could not stand upright and could only limp with support in her room for about 20 years. Notice that in this figure she has to lean against the wall to support her self while standing.**

Fig. 5B. **Radiograph revealing severe valgus deformity of the left knee and varus deformity of the right knee. In addition to severe ligamentous laxity of the left knee, the lateral tibial plateau is also depressed.**

cm every 36 hours[12]. From these experiments the author interpreted that if the osteotomized bone was distracted at the rate of 0.8 or 1 mm each time, the bone and soft tissue, including neurovascular structures might have at least 36 h for adaptation, to create the bone in the distraction gap without neurovascular damage. Based on this interpretation and the results of the present series the author's hypothesis has proved that the distraction rate of 1 mm/48 h in one step could create new bone in the distraction gap without neurovascular damage. The AO/ASIF external fixator is a unilateral fixator which is simpler to apply and is better tolerated by patients compared with the Ilizarov ring fixator. In the femur, the unilateral fixator has proved to be superior to the Ilizarov ring system, which in this anatomical region is very uncomfortable for the patient and risky to apply[13]. Comparing the Orthofix® fixator with the AO/ASIF fixator, the former is more expensive and less versatile than the latter. The Orthofix® limb lengthener cannot correct angular deformities associated with shortening, it requires an articulated body and a T-Clamp[4,13]. According to Grill's experience, the ball joint of the articulated body is unstable, resulted in loss of correction, even being locked with bone cement[13]. In contrast to this, the AO-ASIF conventional fixator can be used for correction of angular deformities and limb lengthening of the tibia without the need of any accessory and is stable to maintain the corrected axial angle during lengthening. In the author's study, once the correction was achieved, there was roentgenographically no loss of correction, as long as the fixator was mounted. With regard to the distraction rate, the distraction rate of 1 mm/48 h (1 mm/step) was more comfortable for the patient than the distraction rate of 0.25 mm every 6 h. With the latter, the patients cannot sleep for more than 6 h, and have to wake up for distraction. Although in the present series the distraction was performed by a surgeon, it was not a burden because the distraction was done once a day, on alternate days. Although during limb lengthening, the unilateral fixator did not allow as much gradual correction of

Fig. 5C. Eccentric distraction was performed at both the left proximal tibia and distal femur, and tightening of the medial collateral ligament by proximal advancement of its insertion at the left femoral epicondyle (left). The depressed lateral tibial plateau was elevated with bone graft and stabilized with tension band wiring after consolidation of the distraction gap (right).

Fig. 5D. Seventeen months after corticotomy. Radiograph showing the end-result of correction after posterior cruciate ligament reconstruction, using bone-patellar-tendon-bone graft.

Fig. 5E, F. Clinical appearance after correction of the deformities. Although during the treatment period, she developed deep pin-tract infection and septic arthritis of the left knee this complication did not compromise a successful outcome. She can stand independently and walk with a cane.

multiplanar deformity as the ring fixator[14], distraction osteogenesis by the unilateral frame was possible after acute angular or rotational correction had been done, as seen in the present study. In animal experiments, Kojimoto et al proved that even with osteotomy there was no effect on bone regeneration, when the periosteum was preserved[15]. From clinical experience it was found that acute correction of the deformity did not interfere with bone formation in children and adolescents[13,16]. The time needed for bone formation per 1 cm or healing index in the present series was not different from that reported in other series. The healing or lengthening index in the other series lay between 32-51 days/cm[9,16,17] and in the present series it was 47.7 days/cm. Last but not least, the cost of AO/ASIF is much lower than that of Ilizarov ring fixator and Orthofix® (1,000 *vs* 2,500 *vs* 2,000 US. dollars for an implant respectively).

SUMMARY

The author has developed a new technique for distraction osteogenesis, using an AO/ASIF conventional external fixator for correction of limb shortening and/or angular deformities. With the new distraction rate of 1 mm/48 h (1 mm/step), the new bone could be formed in the distraction gap without neurovascular damage. The technique is simple, safe, well tolerated and cost-effective. Moreover, AO/ASIF external fixators are readily available in most orthopedic clinics.

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การรักษากระดูกขาสั้นและหรือผิดรูปโดยการยืดกระดูกด้วยเครื่องมือยืดตรึงกระดูกแบบภายนอก

*ชาญชิต แสงแก้ว, พบ**

ได้ทำการศึกษาผู้ป่วย 18 คน (20 bony segments) ที่มีกระดูกขาสั้นและหรือผิดรูปซึ่งได้รับการรักษาด้วยวิธีการยืดกระดูก (distraction osteogenesis) โดยใช้อุปกรณ์ยืดตรึงกระดูกแบบภายนอกที่ปกติใช้ในการรักษากระดูกหัก (AO/ASIF external fixator) มาใช้แทนเครื่องมือยืดกระดูกที่มีราคาแพงโดยได้ดัดแปลงเทคนิคในการยืดกระดูกใหม่ กล่าวคือทำการยืดกระดูกด้วยอัตราการยืด 1 มม ทุก ๆ 2 วันแทนการยืดกระดูกแบบเดิมที่ยืดด้วยอัตรา 0.25 มม ทุก 6 ชม มุมของกระดูกที่ได้รับการแก้ไขมีค่าเฉลี่ย 18.9 องศา (ช่วง 8–40 องศา) ในกลุ่มผู้ป่วยที่มีขาสั้นร่วมด้วยได้รับการยืดกระดูกให้ยาวขึ้นเฉลี่ย 4.2 ซม (ช่วง 3–6 ซม) ระยะเวลาที่ใส่เครื่องยืดตรึงกระดูกไว้มีค่าเฉลี่ย 4.9 เดือน (ช่วง 2–13 เดือน) และระยะเวลาเฉลี่ยในการติดตามผลการรักษา 12 เดือนหลังจากถอดเครื่องยืดตรึงกระดูกออก (ช่วง 3–30 เดือน) กระดูกติดช้าและทำให้เครื่องยืดตรึงกระดูกหลวมพบในผู้ป่วย 1 รายเป็นผลให้กระดูกขาสั้นกว่าขาอีกข้างหนึ่ง 1.5 ซม โดยสรุปก็คือ อุปกรณ์ยืดตรึงกระดูกแบบภายนอกสามารถนำมาใช้ในการยืดกระดูกขาที่สั้นและหรือผิดรูปได้ดีให้ผลเป็นที่น่าพอใจโดยไม่ต้องใช้อุปกรณ์เสริมใด ๆ เลย และไม่พบผลแทรกซ้อนที่รุนแรง เช่นการบาดเจ็บของเส้นประสาทและหลอดเลือด

คำสำคัญ : การยืดกระดูก, เครื่องมือยืดตรึงกระดูกแบบภายนอก

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