

# Distraction osteogenesis of the femur using conventional monolateral external fixator

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## Abstract

**Introduction** The author has developed a new simple technique of distraction osteogenesis using conventional monolateral external fixator for femoral lengthening. The primary purpose of the present study was to evaluate the results of treatment with this new technique of femoral lengthening and also to evaluate the effect of preoperative and intraoperative variables on the outcome of distraction osteogenesis in general.

**Materials and methods** Fifty-one femora in 50 patients were lengthened. Limb-length discrepancy was the primary indication in all patients. The mean age of the patients at the time of the surgery was 21.9 years (range 5–48 years). The average follow-up period was 24.6 months after removal of the fixator (range 6–120 months). All lengthenings were performed using conventional AO/ASIF external fixator. Twenty-two femora had associated axial or rotational deformities. Gradual distraction was performed to increase length and to correct angular deformity in coronal plane. Acute closed wedge angular correction in sagittal plane or derotation was performed in 12 femora in this study.

**Results** The length of the 51 femora was increased by an average 4.4 cm (range 1–13 cm), or 12% (range 2.5–40.9%). The average healing index was 50.5 days/cm (range 22.5–110.6 days/cm). Average gradual angular correction in coronal plane in 14 femora was 20.4° (range 10–45°). Average acute correction in sagittal plane in five femora was 17° (range 10–20°). Average acute derotation in six

femora was 24.2° (range 10–60°). There were a total of 61 complications, including 26 problems, 18 obstacles, and 17 sequelae. The overall rate of complications was 1.2 per femur. Fifteen femora had delayed consolidation (healing index >54 days/cm). Three of 51 lengthening procedures did not lead to consolidation (nonunion). A significant negative parabolic relationship was noted between the healing index and the amount of length gained ( $R = -0.47$  and  $P = 0.004$ ). There was a significantly positive exponential relationship between age and healing index ( $R = 0.51$  and  $P < 0.001$ ). Acute deformity correction, level of osteotomy (submetaphysis versus diaphysis) had no significant effect on healing index. The greater amount of length gained was associated with complications.

**Conclusions** The newly presented technique of distraction osteogenesis is a useful and cost-effective method for femoral lengthening. Increased lengthenings produced a better healing index but might associate with complications. Younger age was associated with better bone healing but age had no effect on complication rate. Level of osteotomy, acute deformity correction had no effect on healing index and rate of complications.

**Keywords** Distraction osteogenesis · Femur · Conventional external fixator

## Introduction

To treat limb shortening with or without deformity by distraction osteogenesis, Ilizarov method has been rapidly gaining acceptance in developed countries, such as in North America and Europe. The Ilizarov ring fixator is so versatile that it can be used for fracture fixation, correction of bony and soft tissue deformity as well as limb lengthening

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[7]. However, this method needs sophisticated instruments, which are not always available in some developing countries in Asia and Africa. In addition, Ilizarov ring fixator has problems with patient tolerance, complicated post-operative management, and steep learning curve. The author has developed a new simple technique of distraction osteogenesis using conventional monolateral external fixator. This new technique made the simple unilateral fixator like AO/ASIF external fixator so versatile that it can be used for bone transport, limb lengthening, and deformity correction [16–18]. The author's technique consists of gradual distraction with the unique rate of 1 mm/48 h or 1 mm on the alternate day after subperiosteal osteotomy, using AO/ASIF conventional unilateral external fixator. No special equipments or distraction devices are used.

In the present study, a series of 51 femoral segments in 50 patients with leg-length discrepancy and deformity underwent gradual and/or acute deformity correction and subsequent distraction osteogenesis were reviewed. The primary purpose of the present study was to evaluate this new technique of femoral lengthening, and also to evaluate the effect of preoperative and intraoperative variables on the outcome of distraction osteogenesis in general.

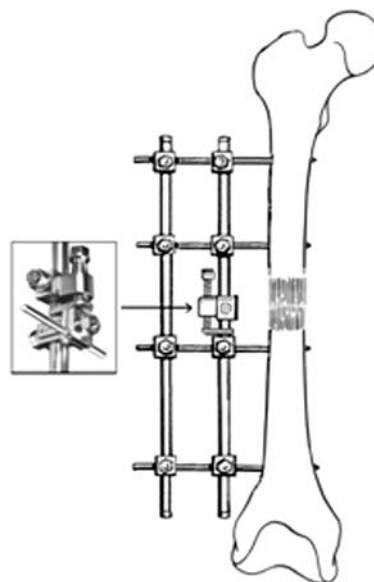
## Materials and methods

Between February 1994 and November 2005, 51 femora in 50 patients (15 female patients and 35 male patients) were lengthened. Limb-length discrepancy was the primary indication in all patients but one, who had disproportional short stature. Sixteen patients had simultaneous ipsilateral tibial lengthening. The mean age of the patients at the time of the surgery was 21.9 years (range 5–48 years). Eleven femora were in patients who were less than 14 years old (range 5–13-year old), and 40 in patients who were aged 14-years or more (range 14–48-year old). The average follow-up period was 24.6 months after removal of the fixator (range 6–120 months). Etiology of femoral shortening was physeal arrest secondary to growth-plate injury in three cases, physeal dysplasia in five, congenital shortening in six, post-poliomyelitis in nine, post-congenital hip dislocation in one, post-hip prosthesis in one, post-cerebral palsy in one, post-hip fusion in one, post-Perthes' disease in one, disproportional short stature in two, and post-traumatic in 21. All lengthenings were performed using conventional AO/ASIF external fixator, which is normally used for stabilization of the fracture, without distraction rod or special device. Twenty-two femora had associated axial or rotational deformities. Gradual distraction was performed to increase length and to correct angular deformity in coronal plane. Acute closed wedge osteotomy was done to correct angular deformity in sagittal plane and acute derotation for

malrotation. Acute correction was performed in 12 femora in this study.

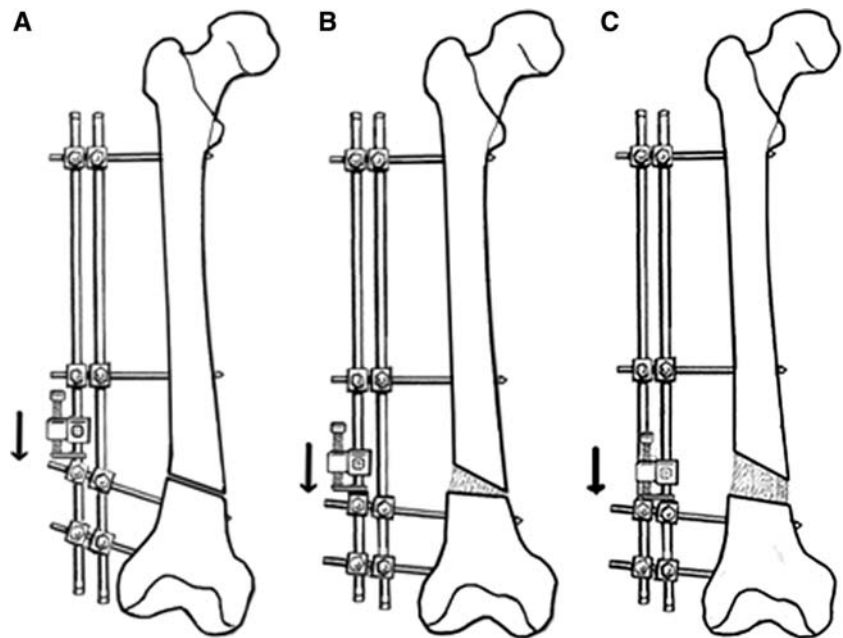
## Surgical technique and lengthening protocol

Corticotomy was performed using the technique described by Aldegheri and his associates [1]. Seventeen of the femoral osteotomies were performed in the submetaphyseal area (either subtrochanteric or supracondylar region), 34 in the diaphysis. The AO/ASIF external fixator lends itself for distraction, the fragment being pushed by the means of compression device [18]. For linear distraction to increase the length the compression device was placed on the near (to the bone) rod and the nuts on the four distal clamps locking the rods were loosened (Fig. 1). For eccentric distraction to correct angular deformity the compression device was placed on the far (from bone) rod and the nuts on the four distal clamps locking the rods and pins were loosened. As the compression device was placed on the far rod proximal to the pin, the force acting on the pin was greatest at the point directly pushed by the compressor (near the lateral end of pin) and gradually decreased toward the medial end of the pin. Therefore the pins of the distal bony fragment were rotated in the plane of the external fixator (coronal plane), bringing the distal bony fragment to rotate along. The medial end of distal fragment at the osteotomy site was not rotated because it abuts against the medial end of proximal fragment, resulting in the center of rotation. A laterally based open wedge was then created (Fig. 2). In the hospital the distraction was performed by the surgeon and after



**Fig. 1** For bone lengthening, linear distraction is achieved by using the compressor, pushing the clamp locking the pin of the distal segment, after the nuts on the four distal clamps locking the rods have been loosened. Note that the compressor mounted on the near (to bone) rod

**Fig. 2** **a** Correction of angular deformity in coronal plane is accomplished by eccentric distraction, which is performed by loosening the nuts on the four distal clamps locking the rods and pins. **b** The pins of the distal segment are rotated in the coronal plane or plane of the fixator by means of the compressor, mounted on the far (from bone) rod. **c** Subsequent lengthening is performed by linear distraction. The nuts on the four distal clamps locking the pins are tightened but locking the rods are loosened. The compression device pushing the pin of the distal segment is now placed on the near rod again. Finally angular correction and length gained can be achieved

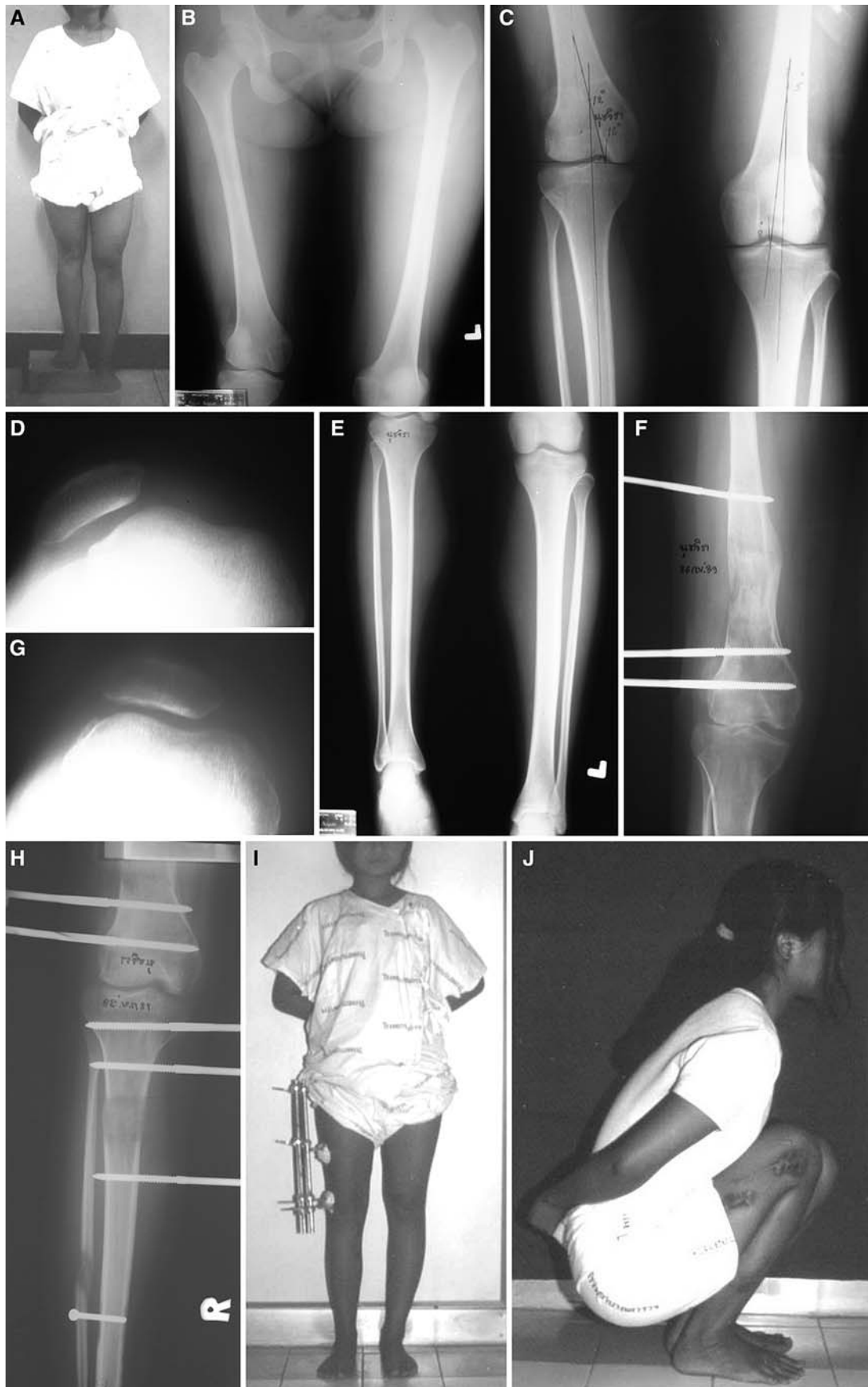


discharge this was done by the patient or his relative. In the case with combined angular deformity and shortening, angular correction was first accomplished gradually, followed by linear lengthening. Associated rotational deformities were corrected by acute derotation and axial deformities in sagittal plane by acute closed wedge osteotomy after corticotomy. Angular deformities in coronal plane were gradually corrected until the desired angle was achieved using distraction osteogenesis, followed by linear distraction to increase length (Fig. 3). The AO/ASIF external fixator was always applied to the lateral aspect of the femur. Two Schanz screws were placed in each bony segment. Later, in the present series, for osteotomy performed at the proximal third and distal third of the femur, three Schanz screws were placed in the proximal or distal bony segment to prevent axial deviation resulting from tension of abductor and hamstring muscles, respectively. Distraction was started between 5 and 7 days after corticotomy at a rate of 1 mm per 48 h or 1 mm on alternate day (1 mm/step). For eccentric distraction an open wedge with 1-mm base was aimed for each distraction, which was calculated from the X-ray film. Generally, when the pin moved from its starting point on the near rod about 1 cm, an opened wedge with 1-mm base was created. Post-operatively, patients were encouraged to walk with partial weight bearing throughout the lengthening period; the patients were also advised to keep the knee fully extended during the day and posterior splint at night to prevent flexion contractures. Range-of-motion exercise of hip, knee, and ankle was begun 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 regenerate bone

were monitored radiographically. Distraction was stopped when sufficient angular correction and gain of length had been achieved. The fixator was left in position for a further period to allow consolidation of the callus and removed when union was judged to be complete. The time to consolidation was calculated as the number of days required for complete healing of one centimeter of lengthened bone and was expressed as the healing index [1].

#### Statistical analysis

The effects of parameters on the healing index and rate of complications were examined, including the age at the time of the lengthening, the site of the osteotomy, the acute correction, and the amount of length gained. A curve estimation regression was used to determine the relationship between the amount of length gained (in centimeters and percentage), age and healing index. To study the effect of age at the time of osteotomy (<14 years vs.  $\geq 14$  years), the level of osteotomy (submetaphysis versus diaphysis), and the acute correction (acute versus gradual) on healing index, Mann–Whitney *U*-test was used to compare the healing index of each parameter. Binary logistic regression was performed to analyze the risk for delayed consolidation. The outcome measure of the healing index was binary-coded with 54 days or less/cm representing an acceptable outcome and more than 54 days/cm a delayed consolidation. Chi-square tests and Fischer's exact tests were used to compare the number of femora which had complications, in regard to age, level of osteotomy, and correction. A two-sided  $P < 0.05$  was considered to indicate statistical significance. All analyses were performed with SPSS for Windows software (Version 13.0).



◀ **Fig. 3** **a** A 19-year-old girl with congenital hypoplasia of the right lower limbs (case 15). She had 6 cm of femoral shortening and 2.5 cm of tibial shortening. **b** Radiograph showing hypotrophy of the right femur with shortening. **c** Radiograph revealing valgus alignment of the right knee with anatomic femorotibial angle of 12° valgus. **d** Merchant's view of the right knee showing lateral dislocation of the patella. **e** Radiograph also revealing hypotrophy of the right tibia with shortening. **f** Ten months after osteotomy radiographs shortly before removal of the fixator. The femoral lengthening of 6.1 cm and varus correction

of 10° were obtained. The healing index was 49.7 days/cm. The distraction phase and consolidation phase was 168 and 135 days, respectively. **g** After combined proximal and distal realignment of the extensor mechanism relocation of the patella was achieved. **h** The right tibia was also lengthened with bone regeneration of 2.7 cm. **i** Photograph shortly before removal of the femoral fixator showing limb-length equalization and normal limb alignment. The fixator of the tibia was removed. **j** Full range of motion of the right hip, knee after fixator removal

## Results

The average time from the corticotomy to the start of the distraction was 5.6 days (range 5–7 days). The increase in length was expressed in centimeters and as a percentage of the preoperative length of the femur. The length of the 51 femora increased an average 4.4 cm (range 1–13 cm), or 12% (range 2.5–40.9%). The average healing index was 50.5 days/cm (range 22.5–110.6 days/cm). Average gradual angular correction in coronal plane which was performed in 14 femora was 20.4° (range 10–45°). Acute angular correction in sagittal plane was performed in five femora: average angular correction was 17° (range 10–20°). Average acute derotation performed in six femora was 24.2° (range 10–60°) (Table 1). In the case in which 60°-derotation was done acutely, there was malunion of the proximal femur (case 33) and was reported elsewhere [16]. The mean time of distraction phase (duration of external fixation, measured from the corticotomy to complete of distraction) was 87.5 days (range 36–168 days). The mean time of consolidation or neutralization phase (duration of external fixation, measured from complete of distraction to the removal of the fixator) was 82.3 days (range 30–135 days). The consolidation phase was therefore 1.1-times lesser than the distraction phase. The case, whose healing index was >54 days/cm, was considered as delayed consolidation. This was based on the finding that, the healing index in the other series lay between 32 and 54 days/cm [1, 11, 13, 14]. Fifteen femora had delayed consolidation (healing index >54 days/cm) in which the average healing index was 75.9 days/cm (range 55.6–110.6 days/cm). Out of 51 lengthening procedures three did not lead to consolidation (nonunion), all of which osteotomy had been performed at the malunited site. The remaining 33 femora had an average healing index of 39.0 days/cm (range 22.5–51.7 days/cm).

Thirteen lengthenings (25.5%) were performed without any complication and 33 (74.5%) with complications. Complications are reported as reported by Paley [11]. *Problems* represent difficulties that arise during treatment that can be fully resolved nonoperatively without resorting to general anesthesia. *Obstacles* are difficulties that arise during treatment that can be fully resolved by operative means. *Sequelae* are temporary or permanent difficulties that remain after removal of the external fixator. There were a

total of 61 complications, including 26 problems, 18 obstacles, and 17 sequelae. The overall rate of complications was 1.2 per femur (Table 2). All of problems were superficial pin-track infections, which subsided after oral or intravenous antibiotics and local pin care. There were no neurovascular complications.

## Statistical analysis

### Healing index

*Length gained* The femur that gained more length had lower healing index. The amount of length gained in terms of percentage and centimeters were found to have a significant relationship to the healing index. A significant negative parabolic relationship was noted between the healing index and the amount of length gained (new bone in the distraction gap) ( $R = 0.47$  and  $P = 0.004$ ) (Fig. 4). Likewise, there was a significant parabolic relationship between the length gained in percentage and healing index ( $R = 0.48$  and  $P = 0.003$ ) (Fig. 5).

*Age* Age at surgery had significant effect on the healing index: the healing index was significantly higher in the femur of the older age. There was a significantly positive exponential relationship between age and healing index ( $R = 0.51$  and  $P < 0.001$ ) (Fig. 6). The mean healing index of patients who were aged less than 14 years (39 days/cm), was significantly different from those patients who were aged 14-years or more (75.9 days/cm) ( $P = 0.048$ ).

*Acute correction* Acute correction had no significant effect on the healing index. The mean healing index of the femora that had had acute correction (41.1 days/cm) was not significantly different from those of the femur that had gradual correction (52.7 days/cm) ( $P = 0.129$ ).

*Level of osteotomy* The level of osteotomy had also no significant effect on the healing index. The mean healing index of the femora that had had osteotomy at the submetaphysis (48.7 days/cm) was not significantly different from those of the femur that had osteotomy at the diaphysis (51.3 days/cm) ( $P = 0.768$ ).

**Table 1** Cumulative patient data

Femur	Sex	Age	Diagnosis	Level of osteotomy	Acute correction angle (degree) sagittal plane derotation	Length gained (cm)	Length gained (%)	Healing index (days/cm)
1	Male	23	Post-traumatic	Submetaphysis	15	4.5	10	Nonunion
2	Male	18	Post-poliomyelitis	Diaphysis		2.6	5.9	72.3
3	Female	22	CDH	Diaphysis		2.5	9	55.6
4	Female	10	Congenital shortening	Submetaphysis		3	9.5	87
5	Female	24	Post-poliomyelitis	Diaphysis		3	9	66.3
6	Female	48	Physeal dysplasia	Diaphysis		3	8.7	71.7
7	Female	21	Post-poliomyelitis	Diaphysis		1	2.5	80
8	Male	43	Post-poliomyelitis	Diaphysis		2.5	6	93.2
9	Male	17	Physeal arrest	Diaphysis		5	12.5	65.4
10	Male	38	Post-cranial palsy	Diaphysis		1.8	3.8	110.6
11	Male	21	Post-poliomyelitis	Diaphysis		3	9	45.3
12	Male	8	Physeal dysplasia	Diaphysis		2.8	7.8	40.4
13	Male	27	Physeal dysplasia	Diaphysis		4	9.1	42.8
14	Male	18	Post-hip prosthesis	Diaphysis		3.5	7.1	24.9
15	Female	19	Congenital shortening	Submetaphysis		6.1	17.3	49.7
16	Female	5	Physeal dysplasia	Submetaphysis		7.7	32.2	45.5
17	Male	5	Congenital shortening	Diaphysis		9.4	40.9	39.1
18	Female	12	Physeal arrest	Submetaphysis		7.8	22	32.4
19	Female	15	Congenital shortening	Submetaphysis		7.5	22.1	29.3
20	Male	16	Post-poliomyelitis	Diaphysis		2.5	5.4	28.4
21	Male	31	Post-hip fusion	Diaphysis		4.5	11.3	48.9
22	Male	18	Post-poliomyelitis	Diaphysis		5	10.9	48.4
23	Female	6	Congenital shortening	Submetaphysis		4	1.1	22.5
24	Female	29	Post-poliomyelitis	Diaphysis		3.5	8	36.9
25	Male	38	Short statue	Diaphysis		4.3	9.5	38.1
26	Male	39	Short statue	Diaphysis		4.7	10.6	40.9
27	Male	17	Post-poliomyelitis	Diaphysis		2.7	6.1	43
28	Female	22	Congenital shortening	Submetaphysis	10	3.4	8.4	33.2
29	Male	23	Physeal dysplasia	Diaphysis		4.8	12.5	51.7
30	Female	13	Physeal dysplasia	Submetaphysis		4.5	10.9	46
31	Male	21	Post-traumatic	Diaphysis		4	13	46
32	Male	14	Post-traumatic	Diaphysis	20	13	37	24
33	Male	11	Post-traumatic	Submetaphysis		6	30	48
34	Male	14	Post-traumatic	Diaphysis	20	6	16	36
35	Male	29	Post-traumatic	Submetaphysis		5	12	73
36	Male	38	Post-traumatic	Submetaphysis		2	4.8	73
37	Male	6	Post-traumatic	Diaphysis		4	14	23
38	Male	37	Post-traumatic	Diaphysis		4	10	64
39	Male	25	Post-traumatic	Submetaphysis		7	16	35
40	Male	20	Post-traumatic	Submetaphysis	20	5	10	66
41	Male	30	Post-traumatic	Submetaphysis		4	10	41
42	Male	32	Post-traumatic	Diaphysis		7	14	49
43	Male	34	Post-traumatic	Submetaphysis		5	10	Nonunion
44	Male	26	Post-traumatic	Diaphysis		3	6	80
45	Male	30	Post-traumatic	Submetaphysis		5	10	Nonunion
46	Female	19	Post-traumatic	Diaphysis		3	6	41

**Table 1** continued

Femur	Sex	Age	Diagnosis	Level of osteotomy	Acute correction angle (degree) sagittal plane derotation	Length gained (cm)	Length gained (%)	Healing index (days/cm)
47	Male	8	Post-traumatic	Diaphysis	15	3	8	30
48	Female	20	Post-traumatic	Diaphysis		4	8	40
49	Male	6	Post-traumatic	Diaphysis	15	2	7.2	40
50	Male	21	Post-traumatic	Diaphysis		4.3	11.3	45.6
51	Male	31	Post-Perthes	Diaphysis		2	5.3	81

### Risk for delayed consolidation

The femur that gained more length had lower risk for delayed consolidation. In contrast, the femur of the older age had higher risk for delayed consolidation. Binary logistic regression demonstrated significant association of the risk for delayed consolidation with the length gained (odds ratio = 0.403; 95% CI = 0.193–0.843 and  $P = 0.016$ ). Age at the time of surgery had higher risk for delayed consolidation (odds ratio = 1.098; 95% CI = 1.012–1.191 and  $P = 0.025$ ).

Percentage length gained ( $P = 0.837$ ), level of osteotomy (submetaphysis versus diaphysis) ( $P = 0.090$ ), and acute correction (acute versus gradual) ( $P = 0.574$ ) were not the risk factors associated with delayed consolidation.

### Complications

Greater amount of length gained was associated with complications. The average length gained (4.98 cm) of the femora which had obstacles or sequelae are greater than that (3.68 cm) of the femora which had no obstacles or sequelae ( $P = 0.012$ ). The age (<14 years vs.  $\geq 14$  years), level of osteotomy (submetaphysis versus diaphysis), and acute correction (acute versus gradual) had no effect on the complication rates. Seven out of eleven femora of the patients aged less than fourteen years, and 21 out of 40 femora of the patients aged 14-years or more had obstacles or sequelae ( $P = 0.734$ ). Thirteen out of seventeen femora with submetaphyseal osteotomy, and 15 of 34 femora with diaphyseal osteotomy had obstacles or sequelae ( $P = 0.059$ ). Twenty-one of forty femora with gradual correction, and 7 out of 11 femora with acute correction had obstacles or sequelae ( $P = 0.734$ ).

### Discussion

The history of development of this technique was delineated elsewhere [16]. The author has succeeded in performing distraction osteogenesis using his own technique to treat a variety of disease [16–18]. Comparison of the present method of

limb lengthening with those by Ilizarov, De Bastiani, or other techniques are difficult because groups of patients selected for lengthening are not always comparable. The bone regeneration was somewhat affected by the age, length gained, level of osteotomy, and underlying pathologic condition. However, the healing index in this study (50.5 days/cm) remains within the range reported by other studies (32–54 days/cm) [1, 2, 11, 13, 14]. In the present series the distraction was 1 mm/48 h, the healing index would have been greater than that of other series with distraction rate of 1 mm/24 h. But the healing index in the present series remained the same as in the other series. Generally, with the distraction rate of 1 mm/24 h the duration of the consolidation phase was longer than that of the distraction phase. Sakurakichi et al. have reported that the mean maturation index (duration of external fixation measured from the completion of distraction to the removal of the fixator divided by length gained) was 38.3 days/cm and the mean external fixation index (duration of external fixation divided by the length gained) was 57.6 days/cm [15]. This means that the duration of the consolidation phase was approximately two times longer than that of the distraction phase. On the contrary, in the present series the average duration of consolidation phase was approximately that of the distraction phase (distraction phase/consolidation phase = 1.1), as a result the healing index remained the same as those of other series with distraction rate of 1mm/24 h.

Likewise, the overall rate of complications (1.2 per femur) was the same as those of other reports (1–1.9 per femur) [9, 12]. There were three cases of nonunion in the present study. All of these nonunion occurred in the femora, in which osteotomy had been performed at the malunited site. These could be attributed to the poor osteogenesis property of the previously injured zone. Therefore, to ensure the optimal osteogenesis the corticotomy should be performed in the normal bone.

The unilateral fixator, constructed with two half pins in each segment is adequately stable for partial weight bearing. The stability of the fixator depends not only on number of pins in each bony segment, but also on its configuration. That means the rod should lie near the bone and the two pins in each bony segment should be maximally spread.

**Table 2** Complications

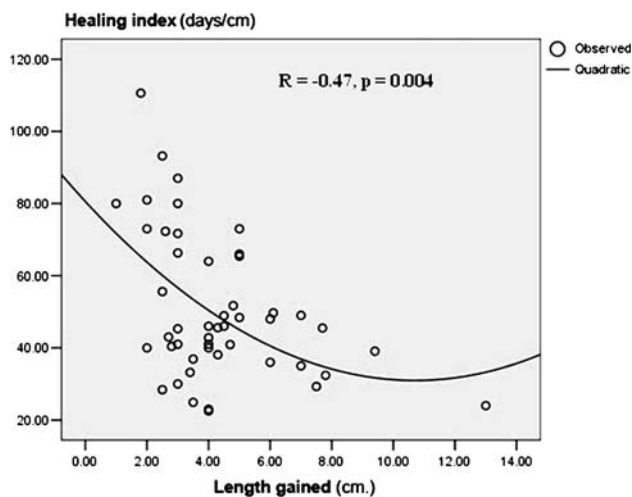
Femur	Length gained (cm)	Problems	Obstacles	Associated procedures	Sequelae	Associated procedures
1	4.5		Broken pin	Pin exchange	Nonunion	Compression plate
2	2.6	SPTI				
3	2.5	SPTI				
4	3		Premature consolidation	Osteoclasis	Anterolateral bowing	
			Tight soft tissue	Manipulation		
6	3		Bending of regenerate bone	Pin adjustment	Anterior bowing	
7	1	SPTI				
8	2.5	SPTI	Bending of regenerate bone	Pin adjustment		
9	5		Bending of regenerate bone	Pin adjustment	Anterior bowing	
11	3	SPTI				
14	3.5					
15	6.1	SPTI	Bending of regenerate bone	Pin adjustment		
16	7.7	SPTI	Stiff knee	Manipulation	Fracture after fixator removal	Corrective
			Hip flexion contracture	Physical therapy	valgus deformity	Osteotomy planned
17	9.4	SPTI			Fracture after fixator removal	Compression plate
19	7.5				Stiff knee	Physical therapy
20	2.5				Anterior bowing	
21	4.5	SPTI				
22	5				Decreased knee ROM	Physical therapy
23	4	SPTI			Fracture after fixator removal	Re-external fixation
25	4.3	SPTI	Bending of regenerate bone	Pin adjustment		
26	4.7	SPTI			Bending after fixator removal	Re-external fixation
30	4.5	SPTI				
31	4	SPTI				
32	13	SPTI			Varus angulation	Corrective osteotomy
33	6	SPTI				
35	5				Stiff knee	Physical therapy
36	2		Bending of regenerate bone	Pin adjustment	Residual shortening (2.4 cm)	
37	4	SPTI	Bending of regenerate bone	Pin adjustment		
38	4	SPTI	Bending of regenerate bone	Pin adjustment		
40	5	SPTI			Stiff knee	Physical therapy
41	4	SPTI			Varus angulation	
42	7	SPTI	Bending of regenerate bone	Pin adjustment		
			Premature consolidation	Osteoclasis		
43	5					Nonunion
44	3	SPTI	Bending of regenerate bone	Pin adjustment		
45	5	SPTI				Nonunion
46	3	SPTI				
47	3	SPTI	Premature consolidation	Osteoclasis		
50	4.3	SPTI	Premature consolidation		Fracture after fixator removal	Re-external fixation

SPTI superficial pin-tract infection

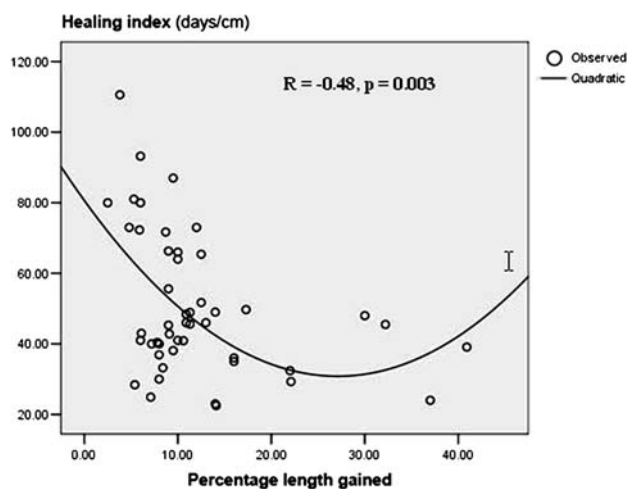
Less bending stability stimulates more callus than rigid construct. In author's experience, for mid-diaphyseal osteotomy two pins in each segment was adequate for stability promoting callus and remodeling. A histologic examination

of the new bone in the distraction gap was performed in some cases on the occasion of reosteotomy to treat premature consolidation. The finding was intramembranous ossification, the same finding found in the bone lengthened by



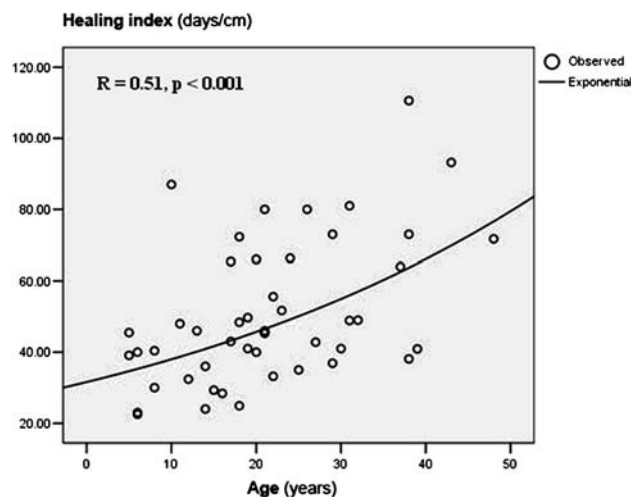


**Fig. 4** Healing index versus length gained in centimeters. The negative  $R$ -value ( $R = 0.47$ ) demonstrates a moderately strong negative parabolic relationship between healing index and length gained ( $P = 0.004$ )



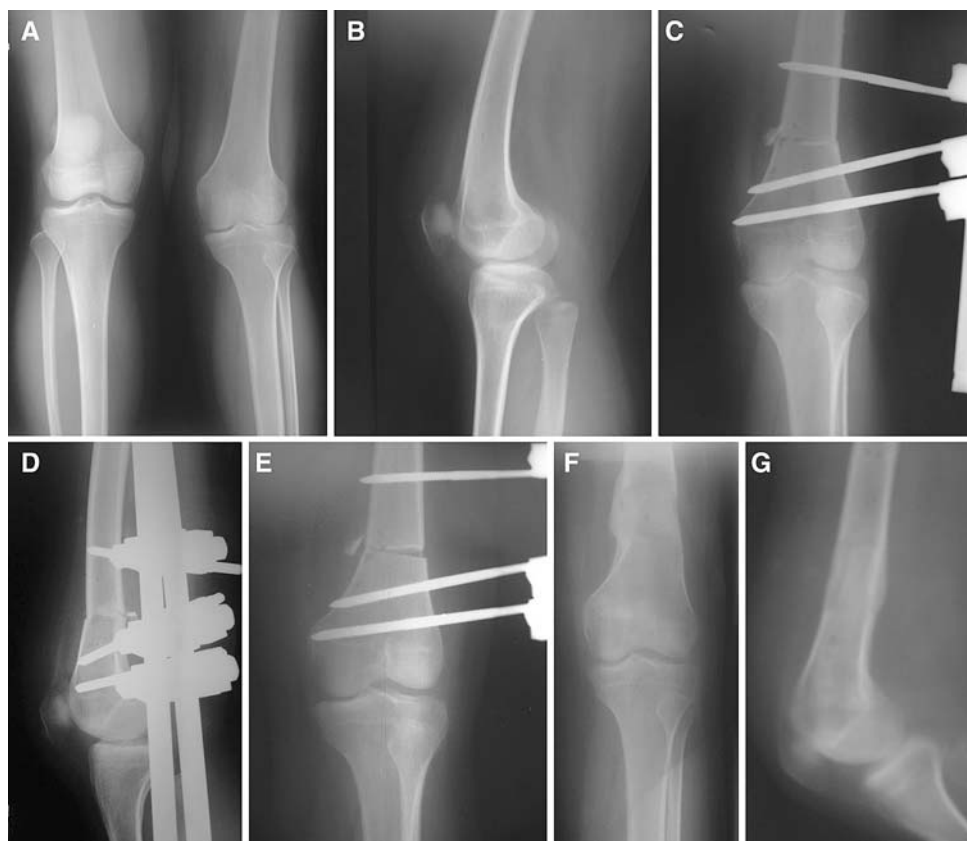
**Fig. 5** Healing index versus percentage length gained. The negative  $R$ -value ( $R = 0.48$ ) demonstrates a moderately strong negative parabolic relationship between healing index and percentage length gained ( $P = 0.003$ )

Ilizarov technique. Three pins in each segment are necessary for proximal or distal osteotomy to resist large deforming force of abductor and hamstring muscles, respectively. In the present series, after distraction had been stopped there was no loss of alignment in the consolidation phase. In the present series varus angulation secondary to abduction force of gluteal muscles was found in two cases (cases 32 and 41) and anterior bowing secondary to bending force of hamstring muscles in three cases (cases 4, 9, and 20) with two pins in each bony segment. But there was no angular deformity in two cases with three Schanz-screws in each segment, when the osteotomy was done in the proximal and distal femur. (Case 6: osteotomy at the proximal femur, and case 18: at the distal femur.)



**Fig. 6** Healing index versus age. Graph reveals a significantly positive exponential relationship between age and healing index ( $R = 0.51$  and  $P < 0.001$ )

Regarding the effect of variables on the outcome, our results were in good agreement with the previous studies on limb lengthening. *Length gained*: longer lengthenings produced a better healing index. In the present study, a significant negative parabolic relationship was noted between the healing index and the amount of length gained in centimeters and in percentage. Noonan et al. and Sakurakichi et al., demonstrated a strong negative parabolic relationship between healing index and length gained in centimeters [9, 15]. Noonan et al. also found the negative parabolic relationship between healing index and length gained in percentage [9]. Although in the present study the length gained was not a risk factor for delayed consolidation, the greater amount of length gained was associated with complications. *Age*: age did play an important role in outcome. Femur of the older age had higher healing index than that of the younger age. In this study, there was a significantly positive exponential relationship between age and healing index. The patients aged less than 14 years had a significantly faster healing rate than patients aged 14 years or more. In addition, age at the time of surgery had higher risk for delayed consolidation. Noonan et al. found a positive relationship of increasing healing index with increased age at surgery [10]. Noonan et al. also demonstrated that femoral healing index was significantly higher in the patients who were 14-years old or more, than in those who were aged less than <14-years [9]. This effect of age on healing index could be explained by the study of Sakurakichi and his associates, who found that maturation index was increased with the increased age at surgery [15]. Although Noonan and his colleagues [9] reported that the complication rate associated with femoral lengthening in patients who were 14-years old or more was significantly higher than that associated with lengthening in patients who were



**Fig. 7** **a** A 22-year-old woman with congenital shortening of left femur (case 28). She had 3.5 cm of femoral shortening and axial deformity of left knee. Radiographs showing anatomic femorotibial angle of  $16^\circ$  valgus. **b** Radiographs revealing  $10^\circ$  of anterior bowing of the distal femur. **c** and **d** Radiograph immediate postsurgery: acute extension closed wedge osteotomy. **e** Gradual correction of valgus deformity by eccentric distraction. Radiographs showing an open wedge is created while the two distal pins are rotated clockwise around

the medial end of the osteotomy. Note, that there is no translation of distal fragment. **f** and **g** Linear distraction was performed to increase length after gradual correction of valgus alignment had been achieved. Radiographs taken 3 months after fixator removal: axial malalignment (coronal and sagittal) and shortening has been corrected; 3.4 cm of new bone in the distraction gap; distraction phase 60 days and consolidation phase 53 days, Healing index 32 days/cm)

<14-years old, the author has found no difference in complication rate between these two age groups. The rate of complications associated with the distraction osteogenesis depends not only on age but also on the nature of the disease. In the present series, almost half of the femora (21/51) were post-traumatic. However, if the post-traumatic cases were excluded, leaving the remaining 30 cases for analysis, the outcome was the same, confirming that age had no effect on the complication rate. Six out of seven femora of the patients aged less than <14-years, and 15 out of 23 femora of the patients aged 14 years or more, had obstacles or sequelae ( $P = 0.39$ ). It is noteworthy that the distraction in the present series was quite different from that of the current technique. It might be possible that with distraction of 1 mm every 48 h the soft tissues have more time for recovery and accommodation after distraction, comparing with those of 0.25 mm every 6 h. Therefore, even in adults the soft-tissues could adapt themselves to the distraction of 1 mm every 48 h better than to the distraction of 1 mm every 6 h, making their complications not different from the

children. *Acute correction*: from the results of this study there was no significant different of healing index between the femora that had acute deformity correction and those that had no. Acute correction and lengthening, with the monolateral fixator, have traditionally been avoided since it was thought that disruption of medullary circulation at the osteotomy site, particularly diaphysis, could lead to a poor or defective bony regeneration. However, in animal studies, Delloye et al. [3] and Kojimoto et al. [8] proved that even with osteotomy there was no effect on bone regeneration, when periosteum was preserved. Clinically, it was found that acute correction of the deformity did not interfere with bone formation in children and adolescents [6, 13]. Donnan et al. found a dose response between increasing angular correction and poor healing index. In their study open wedge correction needed translation to restore the mechanical axis had decreased the contact area between the divided bone ends [4]. In contrast, in the present study the degree of maximum acute correction had an unlikely effect on the healing index, because closed wedge osteotomy had been

performed. With closed wedge osteotomy the periosteal blood supply could be preserved because the bone was dissected subperiosteally (not to be stripped off). With this technique the bone was shortened, the periosteal sleeve could therefore be reapproximated (Fig. 7). *Level of osteotomy*: in the present study the osteotomy was performed at the submetaphyseal region to avoid encroachment of the most distal pin of the fixator into the knee joint. The level of osteotomy (submetaphysis versus diaphysis) had no significant effect on the healing index. This finding is contrary to the study of Fischgrund and his associates, which confirmed the empirically accepted idea that diaphyseal lengthening heals more slowly than metaphyseal lengthening [5]. However, the animal study of Steen and Fjeld suggested that metaphyseal healing might not be superior to diaphyseal healing. They explained that any biologic difference in osteogenic potential between the metaphysis and diaphysis was nullified by different mechanical conditions at the two bone regions [19].

## Conclusion

The newly presented technique of distraction osteogenesis is a useful and cost-effective method for femoral lengthening. In addition, this present technique is simple because only conventional monolateral external fixator is used. Longer lengthenings produced a better healing index but might associate with complications. Younger aged afforded a better bone healing, but age had no effect on complication rate. Level of osteotomy, acute deformity correction had no effect on healing index and rate of complications.

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