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The relationship between distraction length and treatment indices during distraction osteogenesis

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Abstract To evaluate the indices used to compare the results of limb lengthening with distraction osteogenesis, we analyzed the relationship between the lengthening and external fixation period in a series of 28 patients (30 limbs). The average lengthening was 4.6 cm (range, 2.0–8.9). The average age at operation was 16.6 years (range, 4–47). Limbs treated included 15 femurs and 15 tibias of 19 male and 9 female patients. The external fixation period and the maturation period had a direct linear relationship with length gain. There was a negative hyperbolic relationship between the external fixation index, maturation index, and length gain. Segments that were lengthened 0–3.0 cm had a maturation index of 38.3 days/cm and external fixation index of 57.6 days/cm, both of which were significantly higher than for those lengthened more than 3.0 cm. When comparing the maturation and external fixation indices between different patients or studies, the length of the distraction must be taken into consideration.

Key words Limb lengthening · Index · Distraction osteogenesis

Introduction

The healing index, which is obtained by dividing external fixation time by length gain, is used as a parameter when limb lengthening is performed. This value is considered by many investigators to be important to compare the results of distraction osteogenesis. However the medical term "healing" does not reflect adequately the process occurring during the external fixation period. Therefore, the frame index, the distraction–consolidation index, and the external fixation index have been recently developed to describe and evaluate the outcome with distraction osteogenesis.

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In the present study, we examined the relationship between the various indices and distraction length, the age at operation, specific bone (femur vs. tibia), external fixator (Ilizarov vs. Orthofix apparatus), or etiology of the limb shortening of bone.

Patients and methods

Between 1989 and 1999, 87 consecutive patients underwent 100 lower-extremity bone segment-lengthening procedures at Kanazawa University. External fixation was used in all cases. The inclusion criterion for this study was simple lengthening. This series included 28 patients with 30 treated lower limbs that were gradually lengthened without the need for any additional treatment for disease (deformity correction, chemotherapy, or combined intramedullary nailing) or complications (infection, malunion, fracture after device removal, or pes equinus).

Clinical and radiographic data included the patient's age at operation, the bone segment involved (femur, tibia), the amount of lengthening, and the external fixator (Ilizarov or Orthofix apparatus). Nineteen males and 9 females were studied. The etiologies of limb shortening were congenital in 11 patients, epiphyseal injury in 6, hemihypertrophy in 3, osteomyelitis in 3, fibrous dysplasia in 2, Ollier's disease in 1, hypochondroplasia in 1, and iatrogenic disease in 1 patient. Patients were subdivided into three groups based on etiology. There were 11 lengthenings in patients with congenital shortening (group a), 10 lengthenings in patients with acquired disease (group b; epiphyseal injury, osteomyelitis, iatrogenic), and 9 lengthenings in patients with other causes (group c).

Distraction at 0.5 mm twice daily was begun approximately 7–14 days after the operation. This level was later either reduced to 0 when callus formation was delayed or impaired or increased to 1.5 mm/day when

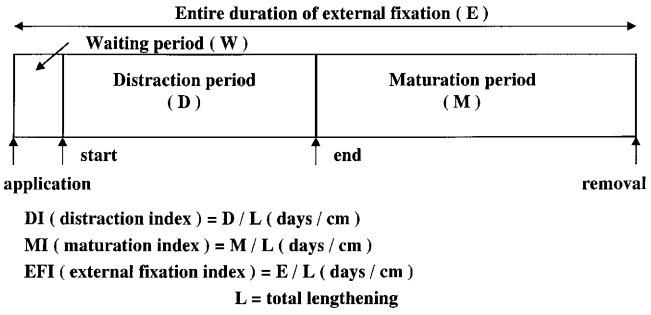

Fig. 1. Index definition. Each index was obtained by dividing the each period of lengthening by the length gained

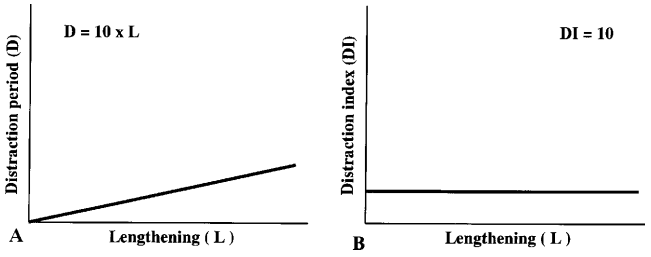

Fig. 2. Relationship between (**A**) lengthening and distraction period (*D*) and (**B**) lengthening (*L*) and distraction index (*DI*). The distraction index is constant

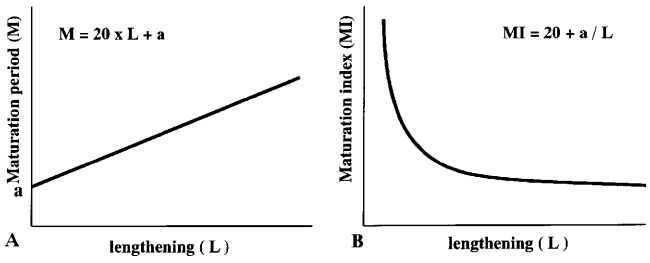

Fig. 3. Relationship between (**A**) lengthening and maturation period (*M*) and (**B**) lengthening and maturation index (*MI*). The maturation index demonstrates a hyperbolic curve

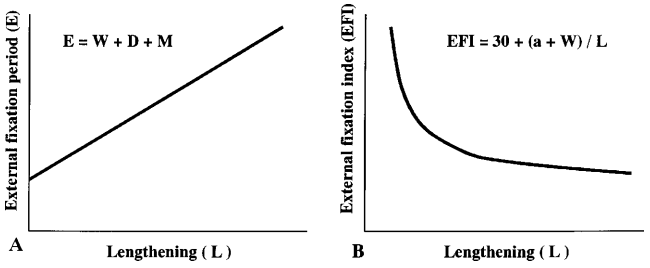

Fig. 4. Relationship between (**A**) lengthening and the external fixation period (*E*) and (**B**) lengthening and the external fixation index (*EFI*). The external fixation index demonstrates a hyperbolic curve

callus formation was likely to consolidate prematurely. The external fixation was removed when sufficient consolidation was obtained.

We defined three indices to evaluate the results. The distraction index was obtained by dividing the duration of lengthening by the length gained; the maturation index was calculated by dividing the duration of external fixation, measured from the completion of distraction to the removal of external fixation, by the length gained; and the external fixation index was the entire duration of the external fixation divided by the length gained (Fig. 1).[10–12]

The amount of lengthening and the duration of each period were measured to calculate the distraction, maturation, and external fixation indices. The limbs were grouped according to the length gained [0–3.0cm (n = 7), 3.1–4.0cm (n = 7), 4.1–5.0cm (n = 9), or >5.0cm (n = 7)].

Linear regression analysis was performed to show the relationship between the time period and amount of lengthening. Nonlinear regression analysis was carried out to compare the indices versus length and patient's age at operation. The period of lengthening, etiology, segment, and fixation were analyzed with the unpaired t test under the F test. A P value of less than 0.05 was considered significant.

Figure 2A shows the relationship between length gain and distraction period and the length gain and the distraction index produced. When distraction is carried out at a rate of 1mm/day, a direct linear correlation passing through point zero will be obtained between the distraction period (D) and length gain (L) (D days = 10 × L cm). The distraction index (DI) will be constant at 10 days/cm (DI = 10 days/cm) (Fig. 2B).

If the maturation period is twice as long as the distraction period, a direct linear correlation passing through point a will be obtained between the maturation period (M) and lengthening (M days = 20 × L cm + a days). Period "a" is the minimal consolidation time. The maturation index (MI) is calculated by dividing the maturation period by the amount of lengthening; a hyperbolic curve is produced when MI is plotted against lengthening (MI days/cm = 20 + a/L) (Fig. 3A,B).

The external fixation period (E) is equal to the sum of the waiting (W), distraction (D), and maturation periods (M) (E days = W days + D days + M days = W + 10 × L cm + 20 × L cm + a days). The external fixation index (EFI) is then calculated by dividing the external fixation period by lengthening so that all indices are represented on the same graph [EFI days/cm = 30 + (a + w)/L] (Fig. 4A,B).

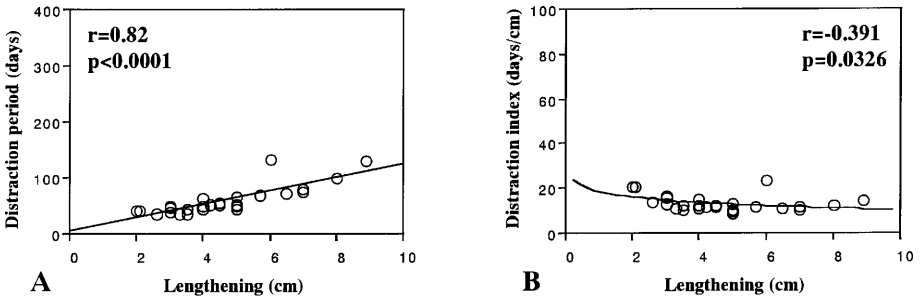

Fig. 5. A Lengthening versus distraction period. **B** Lengthening versus distraction index

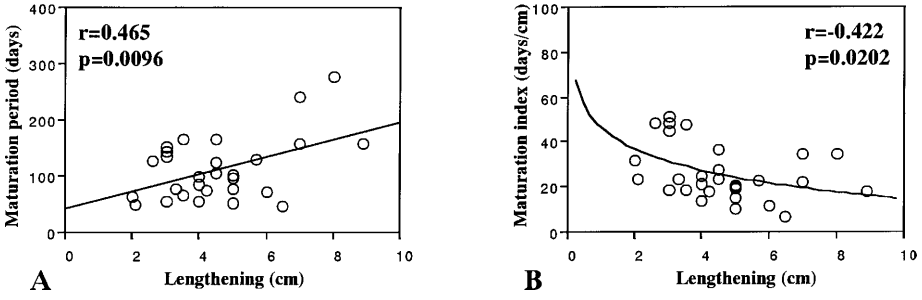

Fig. 6. A Lengthening versus maturation period. **B** Lengthening versus maturation index

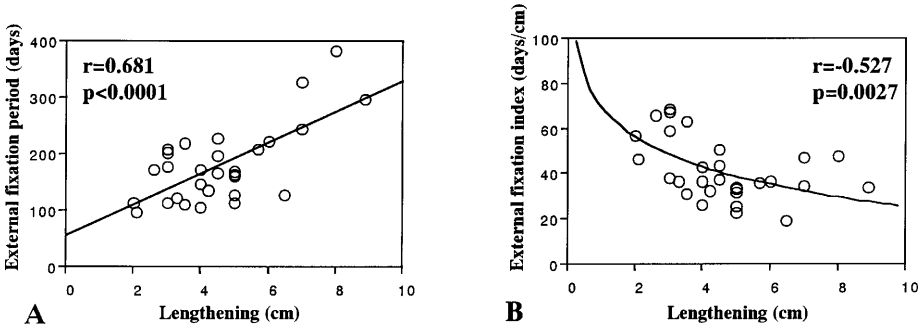

Fig. 7. A Lengthening versus external fixation period. **B** Lengthening versus external fixation index

Results

The average age at operation was 16.6 years (range, 4–47). Fifteen femurs and 15 tibias were lengthened. The average amount of lengthening was 4.6 cm (range, 2.0–8.9), the average distraction period was 60 days (range, 37–134), the average maturation period was 112 days (range, 47–277), and the average external fixation period was 180 days (range, 98–384).

A direct correlation between increase in distraction period and length gain was observed, resulting in a distraction index between 10 and 15 days per centimeter (Fig. 5A,B).

A direct correlation between the maturation period and length gain was also found. The maturation period increased with length gain, resulting in a negative hyperbolic relationship between the maturation index and length gain. A smaller amount of lengthening accompanied higher indices (Fig. 6A,B).

There was a linear relationship between the external fixation period and length gain and therefore a negative hyperbolic relationship between the external fixation index and length gain (Fig. 7A,B).

Segments that were lengthened 0–3.0 cm, 3.1–4.0 cm, 4.1–5.0 cm, and >5.0 cm showed distraction indices of 16.4, 12.2, 11.5, and 13.7 days/cm, respectively, but no statistically significant difference was found. These segments also showed maturation indices of 38.3, 25.2, 21.3, and 21.7 days/cm, and external fixation indices of 57.6, 39.6, 34.6, and 36.7 days/cm, respectively. Segments that were lengthened 0–3.0 cm showed both a significantly higher maturation index and external fixation index (Fig. 8A,B).

There was a direct relationship between the indices and the age at operation, but the statistical significant difference was lower than that of length gained (Fig. 9A,B). Two age groups (1–19 years and older than 20 years) showed a different external fixation period and

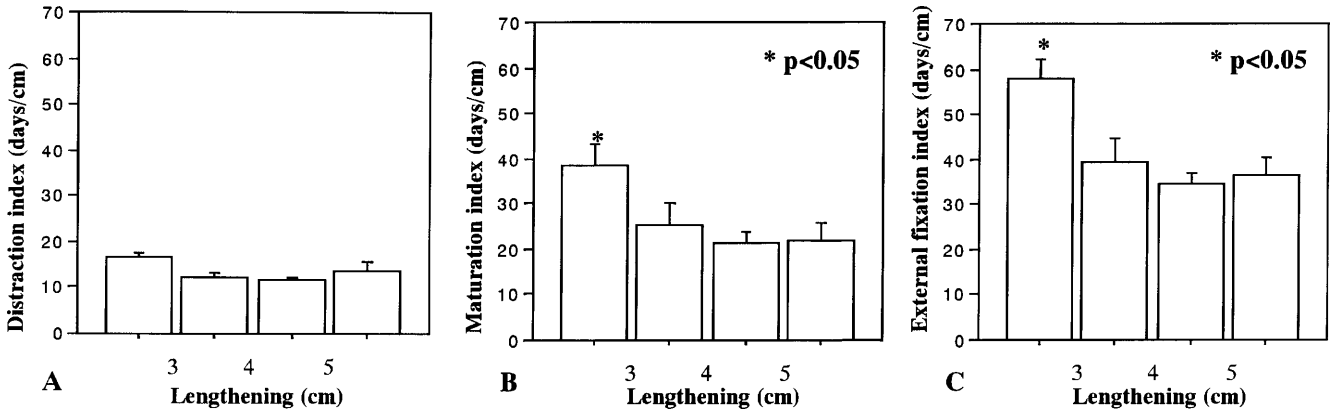

Fig. 8. Lengthening versus (**A**) distraction, (**B**) maturation, and (**C**) external fixation indices. Lengthened segments were subdivided by the amount of length gained: 0–3.0 cm, 3.1–4.0 cm, 4.1–5.0 cm, or >5.0 cm. The external fixation index and the maturation index for segments of 0–3.0 cm were significantly higher than for the other longer segments

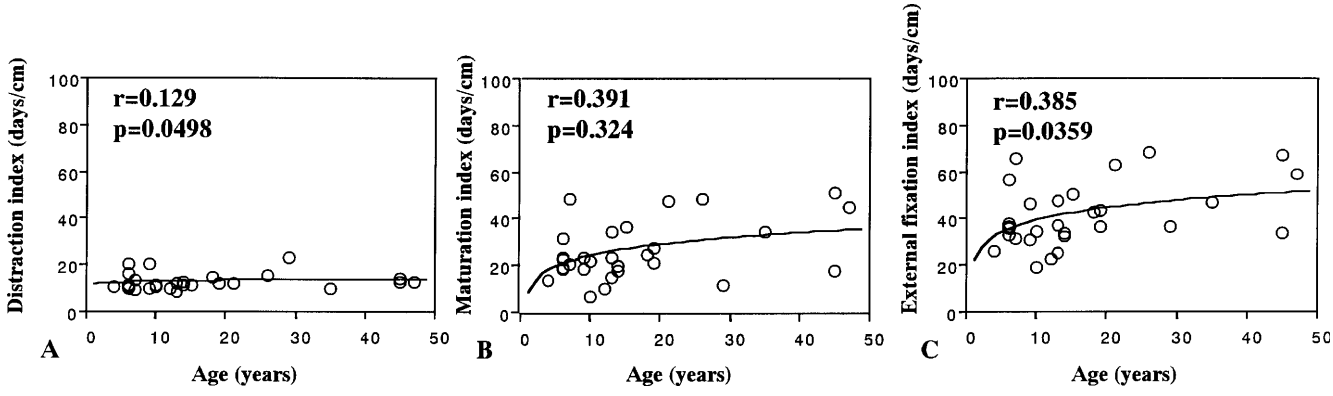

Fig. 9. **A** Age versus distraction index. **B** Age versus maturation index. **C** Age versus external fixation index

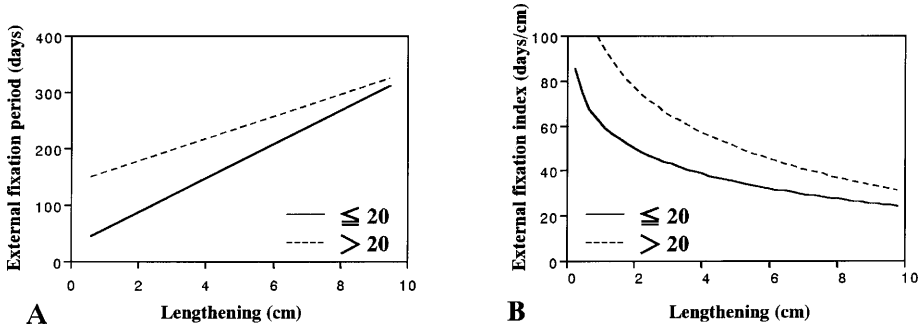

Fig. 10. **A** Relationship between lengthening and external fixation time among age groups. **B** Lengthening versus external fixation index

EFI versus length gained curves. The slope of these lines increased with increasing age, indicating a slower healing rate (Fig. 10A,B).

There was a direct linear relationship between the length gained and the external fixation period for femoral and tibial lengthening. Femoral lengthening tended to heal faster than tibial lengthening as length gained increased (Fig. 11A,B).

We used 9 Ilizarov and 21 Orthofix apparatuses. Almost the same curves were obtained between the length gained and the external fixation period or EFI with both types (Fig. 12A,B).

No statistical differences in indices were noted between the three diagnosis groups. However, DI, MI, and EFI for group a (congenital shortening) tended to be lower than those for group b or c (Fig. 13A,B).

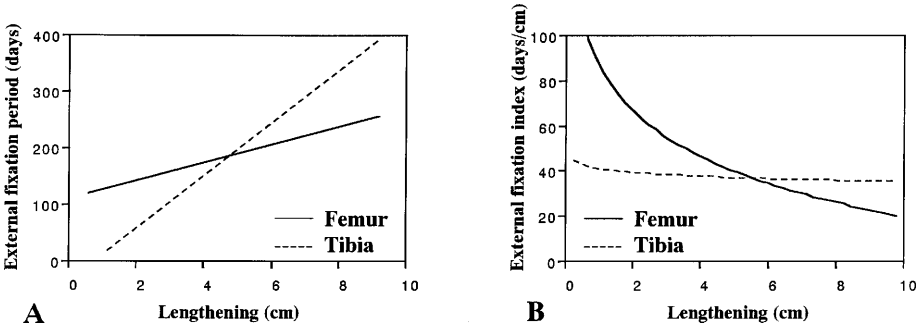

Fig. 11. Graphic comparison between femoral and tibial lengthenings. **A** Lengthening versus external fixation time. **B** Lengthening versus external fixation index

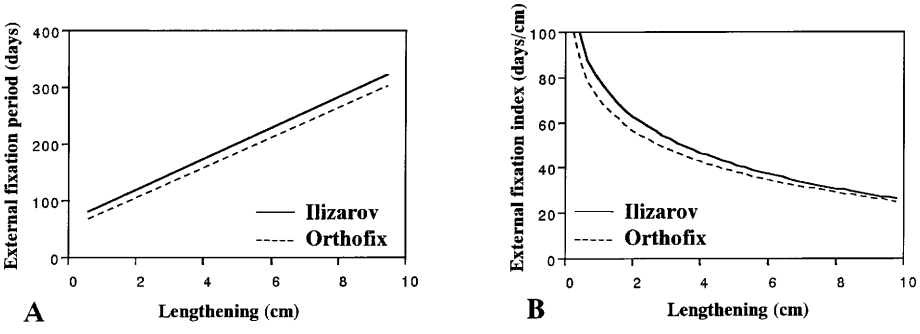

Fig. 12A,B. Graphic comparison between Ilizarov and Orthofix apparatus

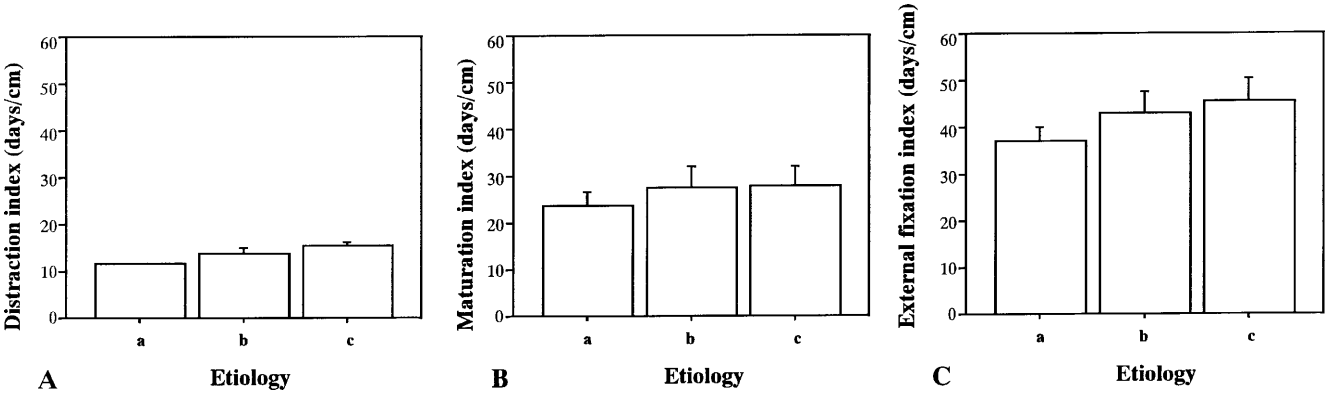

Fig. 13. Data presented as etiology versus (**A**) distraction index, (**B**) maturation index, and (**C**) external fixation index. Group *a* was congenital shortening, group *b* was acquired disease (epiphyseal injury, osteomyelitis, iatrogenic), and group *c* was other causes

Discussion

Although it is essential to compare our outcome with those published in the literature, it is impossible to compare the quality of bone produced in different studies as each uses different radiographic methods to assess bone regeneration. Therefore, indices represent the only feasible way to compare results of routine distraction osteogenesis reported by different centers.

The healing index, used to evaluate osteogenesis of bone lengthening, is obtained by dividing the entire duration of lengthening by the amount of length gained.[2] The term healing, however, is not appropriate to describe the relationship between the external fixation period and its index because the healing time is longer and implies the entire period from frame on to cast off.

Each period (waiting, lengthening, maturation, and total period) should also be evaluated separately because the external fixation index does not adequately represent all these stages during distraction osteogenesis.[10–12] In fact, whether the length gained is long or short, the distraction index is almost constant, but the

maturation and external fixation indices tend to decrease with length gain.

Fischgrund et al.[3] reported that the distraction–consolidation index, calculated as the distraction consolidation time divided by lengthening, produces a hyperbolic curve when plotted against lengthening. A nonlinear relationship exists between the distraction–consolidation index and the length gained. This index rises exponentially as the lengthening approaches zero whereas it tends toward a plateau as the lengthening increases. The distraction–consolidation index must decrease with lengthening as the number of days is divided by a large number.[3,6,7,13] For smaller bone gaps, the minimal consolidation time becomes the more significant factor.

The effect of age on bone healing was previously reported.[3,6] Bone formation of children is faster than that of adults. Fischgrund et al.[3] reported that young adults aged 20–29 years had a significantly faster healing rate than adults older than the age of 30 years but a significantly slower healing rate than an individual younger than 20 years. In this study, there was a nonlinear relationship between indices and age at operation but the indices showed an almost fixed value. Adults older than the age of 20 years had a lower healing rate than those younger than 20 years.

Some authors have reported a difference in the index between the femur and tibia.[2,3,7] Femoral lengthening healed faster than tibial lengthening. The external fixation period of tibial lengthening was longer than that of femoral lengthening as length increased.

The external fixation index has been reported to be 30–60 days/cm, and varies according to disorder, age, location of osteotomy, whether the limbs underwent previous surgery, and the use of dynamization. Most of these reports did not consider the effect of the amount of lengthening.[1,4,5,8,9] In this study, a significant difference in the maturation index and the external fixation index was seen between two groups of limbs: those that gained 3 cm or less in length and those that gained more than 3 cm in length. The distraction index, on the other hand, was constant regardless of the length gained.

The relationship between index and lengthening depends on, age, etiology of shortening, osteotomy site, and the amount of bone lengthening. Each case has its own curve. In conclusion, when comparing the maturation and external fixation indices for different patients or studies, the length of distraction must be taken into consideration.

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