Variables Affecting Time to Bone Healing During Limb Lengthening

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Radiographs and charts of 114 consecutive patients who underwent 140 lower-extremity bone-segment lengthening procedures using the Ilizarov external fixator were reviewed. Patient age, bone segment (femur, tibia), corticotomy level (metaphyseal, diaphyseal, double level), and distraction gap (DG) were recorded. Distraction-consolidation time (DCT) was defined as the interval in months from the date of the corticotomy until the DG was healed according to radiographic and manual testing criteria. Distraction-consolidation time had a direct linear relationship with the magnitude of the DG. Distraction-consolidation time versus DG was significantly less for femoral than tibial lengthening. Patients 20 years and older healed slower than patients younger than the age of 20 years. Patients 20 to 29 years old healed faster than patients older than 30 years and slower than patients younger than 20 years. Diaphyseal lengthening healed more slowly than metaphyseal lengthening. Double-level lengthening reduced the DCT when the DG was greater than 4 cm. Distraction-consolidation index—DCT divided by DG—was not a constant. Distraction-consolidation index decreased with increasing DG. To facilitate prediction of bone-healing time, graphs were developed demonstrating the average treatment time ± 2 SD expected for a specific amount of lengthening, considering the bone segment, the level of osteotomy, and the age of the patient.

Current methods of limb lengthening rely on bone healing without bone grafting. As with previous techniques,5,7 the external fixator serves as the limb distractor as well as the limb stabilizer, until complete bone consolidation is achieved.

To optimize the conditions for bone healing, Ilizarov8 has recommended stable fixation; a percutaneous osteotomy preserving the endosteum and periosteum rather than an open osteotomy resulting in damage to the endosteum and periosteum; a metaphyseal rather than a diaphyseal osteotomy; initial contact of the bone ends at the site of the osteotomy; a latency period before distraction begins; a rate of distraction of 1 mm per day; and a rhythm of distraction of at least four times per day.

Treatment time is divided into three consecutive periods: latency, distraction, and consolidation. The latency period is the time from the date of osteotomy until distraction begins, usually seven days.

During the distraction period, the apparatus is adjusted 1 mm per day at a rhythm of 0.25 mm four times a day. This produces a gradually elongating distraction gap (DG) between the bone ends. The distraction phase ends when either the lengthening is completed or the lengthening must be terminated because of complications or patient noncompliance.

The last, and longest, phase is the consolidation period. During this time, the newly formed bone in the DG is allowed to bridge
and corticalize. The apparatus is left in place until the new bone is judged to be strong enough to allow apparatus removal without shortening, bending, buckling, or fracturing the newly formed bone.

Plain radiographs remain the standard method for determining the time for frame removal. Other potentially objective methods to ascertain when bone consolidation is sufficient for apparatus removal are under investigation, including (1) quantitative computer tomography density scanning; (2) *in vivo* mechanical testing; and (3) ultrasound.

Factors that may affect the rate of healing include the patient’s age, the bone lengthened, and the level or levels of osteotomy. In a previous study, patients older than 20 years of age healed at one half the rate of patients younger than 20 years.

To assess and compare the rate of bone formation, the bone distraction-consolidation time has been indexed to the amount of lengthening. DeBastiani *et al.* and Aldegheri *et al.* termed this the “healing index,” calculated as the number of days of external fixation treatment per centimeter of DG. Paley expressed this index in months per centimeter and termed it the “lengthening index.” To calculate the external fixation treatment time, multiply the distraction amount planned by the distraction-consolidation index (DCI). If the index were one month/centimeter, the external fixation time should be three months for 3 cm, six months for 6 cm, and ten months for 10 cm.

In this report, the authors examine the relationship between the DCI and the age of the patient, specific bone (femur vs. tibia), magnitude of lengthening, osteotomy site (proximal vs. distal, metaphyseal vs. diaphyseal), and number of foci (mono- vs. bifocal).

**MATERIALS AND METHODS**

From December 1987 through December 1990, 114 consecutive patients underwent 140 lower-extremity bone segment lengthening procedures at the University of Maryland and James Lawrence Kernan Hospitals using the Ilizarov external fixator. Four physeal distractions and five lengthenings through nonunions or fractures were excluded from the study, leaving 131 lengthened limb segments. Medical records and radiographs of all patients were personally examined by one of the authors, independent of the senior author who personally treated all the patients.

Clinical and radiographic data included the patient’s age at time of application, the bone segment involved (femur, tibia), the length of the DG (mm), and the level(s) of corticotomy (diaphyseal, metaphyseal, combined proximal and distal metaphyseal). Metaphyseal lengthenings are performed at the metaphyseal-diaphyseal junction to allow enough room for external fixation pins in the metaphyseal-epiphysial end of the bone.

When angular deformity accompanied the shortened bone, the lengthening was performed at the deformity site, metaphyseal or diaphyseal. In an effort to decrease treatment time or when there was an indication for two-level deformity correction, combined proximal and distal metaphyseal lengthenings (double-level lengthening) were usually performed when the planned lengthening exceeded 4 cm.

Consolidation of the DG was considered sufficient for fixator removal when the DG was corticalized on three of four sides as seen on anteroposterior and lateral radiographs. The cortices had to be 2 mm or more in thickness and uninterrupted across the DG. Before fixator removal, all limbs were tested for structural integrity by partially disassembling the frame and manually stressing the bone. If the bone was believed to be mobile, the frame was reassembled and the bone was allowed to consolidate for an additional month before radiographs were reexamined and manual testing was again performed. Removal was carried out at the next visit if the removal criteria were met. For purposes of this study, the bone distraction-consolidation time (DCT) was defined as the interval in months from the date of the osteotomy until the DG was healed according to the previously described radiographic criteria. The DG was defined as the length in centimeters between the bone ends at the end of lengthening, measured from the radiograph at the end of the distraction phase, and compensating for magnification using a magnification marker. The bone DCI was defined as the DCT divided by the DG. The lengthening percentage was calculated as the DG divided by the pretlengthening bone segment length multiplied by 100%.

The patient’s ages ranged from four to 67 years. Patients were subdivided into age groups based on decades. There were 17 lengthenings in patients four to nine years old, 40 lengthenings in patients...
ten to 19 years old, 24 lengthenings in patients 20
to 29 years old, and 50 lengthenings in patients
aged 30 years and older. There were 97 tibial and
34 femoral lengthenings.

All osteotomies were performed percutaneously
and subperiosteally as previously described.13,14
There were 15 diaphyseal, 15 metaphyseal, and
four double-level lengthenings of the femur. There
were 19 diaphyseal, 57 metaphyseal, and 21 double-
level lengthenings of the tibia.

Distraction of the bone began approximately
seven days after the osteotomy. The rate of distrac-
tion was 1 mm per day, divided into four 0.25-mm
equal increments. The distraction rate was de-
creased if there was radiographic evidence of poor
bone formation or if the patient complained of
excessive pain. Conversely, the rate was increased
if radiographs showed accelerated consolidation of
the DG. Follow-up visits were scheduled every
other week during the distraction period and
monthly during the consolidation phase.

Thirty-five fixators were not removed at the
time of radiographic consolidation across the DG.
These fixators were retained for continuing treat-
ment at other sites in the same bone, such as defor-
mity, arthrodesis, and nonunion or an adjacent
joint contracture. (This apparatus is also used to
distact joint contractures.)

After fixator removal, most limbs were further
protected for four to six weeks in an external orth-
osis or cast. With the external fixator in place, par-
tial to full weight bearing was allowed as tolerated.
After removal, this was altered to gradually in-
creased partial weight bearing (maximum, 50% of
weight) during the first two weeks after fixator re-
moval. After this period, the patients were encour-
aged to progress to weight bearing as tolerated in
the orthosis.

All data were analyzed using Statistical Analysis
System, Version Five programs (SAS Institute,
Cary, North Carolina). Parametric data were ana-
lyzed using a chi-square test, or Fisher exact proba-
bility test for two-by-two tables. The effects of the
bone segment, osteotomy level, and age on the
DCT versus DG relationship and on DCI versus DG
relationship were analyzed using the Wil-
coxon rank sum test (also known as the Mann-
Whitney U Test).

RESULTS

The tibial DGs ranged from 1.5 cm to 15
cm (mean, 5.5 cm), which corresponded to a
5 to 77% increase in bone length. Femoral
DGs ranged from 2 cm to 11 cm (mean, 5
cm), which corresponded to a 4 to 65% in-
crease in bone length.

There was a direct linear relationship be-
tween the DG and DCT for all tibial (p <
0.0001) and femoral (p < 0.001) lengthenings
(Fig. 1A). This relationship remained signifi-
cant even when the tibial lengthenings were
subclassified with respect to age and level of
osteotomy. Femoral lengthenings healed
faster than tibial lengthenings (p < 0.01)
(Figs. 1A and 1B).

Among proximal tibial metaphyseal
lengthenings, three age groups (one to 19
years, 20–29 years, and older than 30 years)
demonstrated significantly different DCT
versus DG curves (Fig. 2). The slope of these
lines increased with increasing age group in-
dicating a slower healing rate. No difference

Figs. 1A and 1B. Graphic comparison between
all femoral and tibial lengthenings. The data are
presented as (A) DCT (distraction-consolidation
time) versus DG (distraction gap) and (B) DCI
(distraction consolidation index) versus DG. Fem-
oral lengthenings had a significantly lower DCI (p
< 0.01).
was detected between the one-to-nine-year and the ten-to-19-year age groups ($p > 0.05$).

The smaller number of femoral lengthenings could not be subdivided into different age groups. All femoral lengthenings demonstrated a linear relationship between DG and DCT ($p < 0.05$), especially distal femoral metaphyseal lengthenings ($p < 0.0001$) (Fig. 3). There was not a linear relationship for femoral diaphyseal lengthenings.

There was a significant difference in the DCI versus DG of diaphyseal and metaphyseal tibial lengthenings ($p < 0.001$). Figure 4 demonstrates that metaphyseal tibial lengthenings heal faster than diaphyseal lengthenings, especially for gaps less than 7 cm. More than 7 cm, the extrapolation of the lines suggests the opposite. Since there were few cases of diaphyseal lengthenings greater than 10 cm, this extrapolation may be invalid.

Combined proximal and distal metaphyseal lengthenings of the tibia (double-level lengthening) healed significantly faster per centimeter of lengthening ($p < 0.03$) than single-level tibial lengthenings in all age groups when the lengthening exceeded 4 cm.

There were four refractures of the new bone in four patients (3%) after fixator removal. Additional review of the radiographs in these cases reconfirmed the presence of three intact cortices before frame removal.

Two of these fractures occurred after proximal femoral lengthening for congenital short femurs. Both of these patients underwent ex-
extensive lengthening procedures (48% and 65% of the original bone length). In both cases, the new bone had developed an hourglass appearance. Fracture occurred despite complete corticalization of the distraction segment. The two other fractures occurred in patients who had marked osteoporosis; one had osteoporosis preoperatively in the tibia and the other developed it during the lengthening in the femur.

**DISCUSSION**

Current techniques of limb lengthening use external fixation for extended periods to achieve the lengthening desired and to allow the process of distraction osteogenesis to form and consolidate new bone. The longer the amount of desired lengthening, the longer the external fixation time. External fixators, while a means to an end, are an inconvenient form of treatment to the patient and are labor-intensive for the surgeon. Estimating the expected external fixator treatment time preoperatively aids in formulating a treatment strategy as well as in obtaining a well-informed consent for the procedure.

The effect of age on bone healing was previously reported by Paley,12 who compared the results of lengthening between 12 adult and 48 pediatric patients and reported a 50 to 100% increase in the lengthening index in adults versus children. DeBastiani et al.6 reported a difference in the index between the femur and tibia. Neither study considered variation of the index in relation to DG.

The present study found a linear relationship between DCT and DG. Extrapolation of this line to the zero distraction point (ostectomy with no distraction) verified that bone as expected has a minimal consolidation time that may vary with age and location.

The DCI was calculated as the DCT divided by DG which produces a hyperbolic curve when plotted against DG. The index rises exponentially as the DG approaches zero. As the DG increases, the index tends toward a plateau.

These findings show that the DCI is not a constant. For large DGs, the DCI approximates a constant. For smaller gaps, the minimal consolidation time becomes the more significant factor.

Use of the classic healing or lengthening index to predict the external fixation time is inaccurate except when DGs are greater than

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**FIG. 3.** The graph shows the relationship between DG and DCT for patients of all ages with distal femoral metaphyseal distraction.

**FIG. 4.** All tibial distractions in patients older than the age of 19 years were subdivided by ostectomy level (metaphyseal, diaphyseal, and double level). Metaphyseal lengthenings healed faster than diaphyseal lengthenings, especially for DGs less than 7 cm (p < 0.001). Double-level lengthening healed faster per total distraction length than metaphyseal or diaphyseal lengthenings.
8 cm. A more accurate prediction of the external fixation time required for a given DG can be obtained by referring to the graphs of DCT versus DG (Figs. 2 and 3) which show the mean and two standard deviations from the mean.

Age has a significant effect on the DCI; children heal faster than adults, as confirmed by this study. Three distinct DCIs related to age group were identified: one to 19 years, 20 to 29 years, and older than 30 years of age. It is interesting to note that young adults aged 20 to 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. It is possible that there are other age-related differences. The numbers of patients per decade age group was too small to subdivide patients older than the age of 30 years. Patient age groups one to nine years and ten to 19 years were not found to be significantly different from each other in bone-healing rate.

Metaphyseal lengthening is usually preferred to diaphyseal lengthening since metaphyseal bone is expected to heal faster than diaphyseal bone. Monticelli and Spinelli\(^\text{10}\) claim that the metaphysis has a much greater osteogenesis potential than the diaphysis and therefore heals faster after distraction. Steen and Fjeld\(^\text{16}\) found a significant difference between the healing times of diaphyseal and metaphyseal lengthenings in sheep. They hypothesized that the increased osteogenic response of the metaphysis was offset by the decreased mechanical stability of fixation in metaphyseal versus diaphyseal lengthenings. In this study, a significant difference was found between metaphyseal and diaphyseal lengthenings. Metaphyseal lengthenings healed faster (a lower DCI) than diaphyseal lengthenings. Figure 4 suggests that this effect is greatest for small lengthenings. With larger lengthenings, there appears to be little difference. This may again reflect the minimum bone consolidation time that is higher (four to five months) for diaphyseal lengthenings than for metaphyseal lengthenings (two to three months). Double-level lengthenings, as expected, decrease the total DCT since they represent the simultaneous healing of two smaller DGs. The overall DCT is almost halved. Figure 4 demonstrates that DCT is not significantly reduced until a distraction of 4 cm or more.

This study is based on a radiographic method for assessing the end point of bone consolidation. This method is the most common one in current clinical use. The 3% re-fracture rate demonstrates that in the majority of cases, the bone was sufficiently consolidated to prevent bending or breakage of the new bone.

The radiographic criteria for evaluating bone consolidation in patients with long DGs or osteoporosis may underestimate the bone strength. Unfortunately, more objective diagnostic tests are not yet readily available. Recently, Aronson\(^\text{3,4}\) described a method of DG assessment using quantitative computed tomography. Richardson et al.\(^\text{15}\) reported on the use of an electronic goniometer to assess the stiffness of the DG bone. Lowet et al.\(^\text{9}\) used ultrasound acoustic monitoring to evaluate the healing of lengthening gaps. Future similar studies may use these or other more objective methods to determine the “end point” of bone consolidation.

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