Femoral Lengthening over an Intramedullary Nail

A MATCHED-CASE COMPARISON WITH ILIZAROV FEMORAL LENGTHENING

BY DROR PALEY, M.D., F.R.C.S.C.T., JOHN E. HERZENBERG, M.D., F.R.C.S.C.T.,
GUY PAREMAIN, F.R.C.S.(ORTH), AND ANIL BHAVE, P.T.; BALTIMORE, MARYLAND

Investigation performed at the Maryland Center for Limb Lengthening and Reconstruction, Baltimore

ABSTRACT: Twenty-nine patients (thirty-two femora) had femoral lengthening over an intramedullary nail, with the nail and the external fixator applied concomitantly at the time of the femoral osteotomy. After gradual distraction at a rate of one millimeter per day, the nail was locked and the fixator was removed. The mean age was twenty-six years (range, ten to fifty-three years), and the mean amount of lengthening was 5.8 centimeters (range, two to thirteen centimeters). For comparison, thirty-one patients (thirty-two limbs) who had had standard Ilizarov femoral lengthening were matched with the group that had had lengthening over an intramedullary nail; the matching was performed on the basis of the amount of lengthening, the age of the patient, the etiology of the indication for lengthening, and the level of difficulty of the procedure.

Lengthening over an intramedullary nail reduced the average duration of external fixation by almost one-half. The radiographic consolidation index (the number of months needed for radiographic consolidation for each centimeter of lengthening) for the limbs that had had lengthening over an intramedullary nail was reduced significantly (p < 0.001) compared with that for the matched-case group. The range of motion of the knee returned to normal a mean of 2.2 times faster in the group that had had lengthening over an intramedullary nail. There were six refractures of the distraction bone in the matched-case group. In the group that had had lengthening over an intramedullary nail, one nail and one proximal locking screw failed. The over-all rate of complications was 1.4 per cent in the group that had had lengthening over an intramedullary nail compared with 1.9 per cent in the matched-case group. With the numbers of patients available for study, we could not detect a significant difference between the groups with respect to the operative time (p = 0.124); however, the cost of treatment and the estimated blood loss were higher in the group that had had lengthening over an intramedullary nail.

On the basis of clinical and radiographic criteria, there were twenty-three excellent, seven good, and two fair results in the group that had had lengthening over an intramedullary nail compared with twenty-six excellent, four good, and two fair results in the matched-case group (p = 0.37). The advantages of lengthening over an intramedullary nail include a decrease in the duration of external fixation, protection against refracture, and earlier rehabilitation.

Current techniques of femoral lengthening rely on gradual distraction with use of external fixation to form new bone in the distraction gap.6,14,20,23. These techniques of distraction osteogenesis have two distinct phases of treatment: distraction and consolidation. The distraction phase is the time during which the limb-lengthening occurs. The consolidation phase begins at the end of distraction and ends when the bone in the distraction gap has healed sufficiently to permit removal of the external fixator without fracture or deformation. The sum of the distraction and consolidation times is the external fixation time. The consolidation phase is usually twice as long as the distraction phase in children and three to four times longer in adults.8-3

The prolonged use of the external fixator is the most difficult aspect of femoral lengthening for the patient to tolerate. When the full extent of the lengthening has been achieved, the patient becomes eager to have the external fixator removed. Premature removal, however, may lead to fracture of the femur, resulting in deformity, shortening, or non-union, or all three.

To reduce the time during which the external fixator must be in place, we developed a method that allows us to remove the external fixator at the end of the distraction phase. With use of this method, an intramedullary nail is inserted concomitantly with the external fixator. At the end of the distraction phase, the nail is locked by inserting two screws distally and the external fixator is removed. The intramedullary nail protects the new bone from fracture during the consolidation phase. The purpose of the present study was to

*One or more of the authors have received or will receive benefits for personal or professional use from a commercial party related directly or indirectly to the subject of this article. In addition, benefits have been or will be directed to a research fund or foundation, educational institution, or other non-profit organization with which one or more of the authors are associated. No funds were received in support of this study.

1Maryland Center for Limb Lengthening and Reconstruction, The James Lawrence Kernan Hospital, 2200 Kernan Drive, Baltimore, Maryland 21207. The e-mail address for Dr. Paley is dpaley@mcll.ummc.ab.umaryland.edu.

62 The Street, Fetcham, Surrey KT22 9RF, England.
evaluate this new method of lengthening over an intramedullary nail and to compare it with the currently accepted Ilizarov method.

**Materials and Methods**

**Study Group (Lengthening over an Intramedullary Nail)**

We performed thirty-two femoral lengthenings over an intramedullary nail in twenty-nine patients (three patients had a bilateral procedure) between March 1990 and November 1993 (Table 1). The mean duration of follow-up was 2.8 years (range, two to five years). The mean age of the patients at the time of the operation was twenty-six years (range, ten to fifty-three years). Seventeen patients were female and twelve were male. Twenty-six patients had the lengthening because of a limb-length discrepancy, and three patients had it because of short stature. The limb-length discrepancy or
the short stature was classified as congenital (seven femora), post-traumatic (secondary to acute shortening due to a fracture or resection of a tumor; twelve femora), or developmental (for example, a limb-length discrepancy due to growth arrest as a result of a fracture, infection, radiation, Blount disease, or avascular necrosis), spina bifida, or Klippel-Trénaunay syndrome, or short stature [due to achondroplasia or growth-hormone deficiency]; thirteen femora). For limbs that had a malunion or a non-union of a fracture, the etiology was classified as post-traumatic. This should not be confused with post-traumatic growth arrest that gradually led to limb-length discrepancy; for those limbs, the etiology was classified as developmental. The Ilizarov external fixator (Smith and Nephew Orthopaedics, Memphis, Tennessee) was used in eleven femora, and the Orthofix external fixator (Orthofix S.R.L.; Bussolegno, Verona, Italy) was used in twenty-one. The Russell-Taylor Delta femoral ten-millimeter nail (Smith and Nephew Orthopaedics) was used in all femora. The osteotomy was subtrochanteric in twenty-four femora, mid-diaphyseal in seven, and at the distal third in one.

We devised a scale based on twelve parameters that we believe increase the difficulty and risk of lengthening. The total score derived from this scale was defined as the level of difficulty of the individual lengthening procedure as assessed preoperatively (Fig. 1). The level of difficulty was classified as mild for sixteen femora, moderate for seven, and severe for nine. Five limbs had concomitant correction of femoral varus angulation or an external rotation deformity, or both, by means of the lengthening osteotomy. Seven limbs had concomitant tibial lengthening and correction of the deformity.

**Matched-Case Group**

The patients who had had lengthening over an intramedullary nail were compared with a group of matched patients in whom the Ilizarov external fixator had been used throughout both the distraction and the consolidation phase. These matched patients were selected from a prospectively followed group in which seventy Ilizarov femoral lengthenings had been performed by the same surgeons who had performed the lengthenings over an intramedullary nail and in the same center where those procedures had been done, between January 1988 and December 1992. The selection was made on the basis of the best match for the amount of lengthening (within 2.5 centimeters), age (within ten years), etiology (congenital, post-traumatic, or developmental), and level of difficulty of the procedure (mild, moderate, or severe). The matching was performed by making a table of these parameters for the seventy Ilizarov femoral lengthenings and the thirty-two lengthenings over an intramedullary nail. The patients were coded by number, without their name, the result, or the complications being known, in an attempt to avoid bias in the selection of a matched pair. Matching was prioritized according to four criteria, in the following order: amount of lengthening, age, etiology, and level of difficulty. Twenty-two femora were matched successfully for all four criteria, and ten were matched for three criteria.

The matched-case group consisted of thirty-one patients who had had thirty-two Ilizarov femoral lengthenings. The mean duration of follow-up was 3.7 years (range, two to six years). The mean age of the patients at the time of the operation was twenty-five years (range, nine to sixty-two years). Fourteen patients were female and seventeen were male. Thirty patients had the lengthening because of a limb-length discrepancy, and one had it because of short stature. The etiology was classified as congenital for six femora, post-traumatic for fifteen, and developmental for eleven. Of the eleven developmental etiologies, two were due to achondroplasia; one, to spina bifida; and eight, to growth arrest. Two of the eight growth arrests were secondary to radiation; five, to a fracture; and one, to an infection. The osteotomy was subtrochanteric in nine femora, mid-diaphyseal in nine, and at the distal third in fourteen. The level of difficulty was assessed preoperatively as mild for fifteen femora, moderate for seven, and severe for ten. Twenty-five limbs had concomitant correction of femoral angulation or a rotation deformity, or both, by means of the lengthening osteotomy. Thirteen limbs had concomitant tibial lengthening.

**Criteria for Evaluation**

We devised a scoring system for the outcome of the femoral lengthening procedure on the basis of the clinical and radiographic criteria (Table II). The scores were rated as excellent, good, fair, or poor and were calculated on the basis of the number of points that were assessed for six parameters: range of motion of the knee, amount of lengthening, gait, lateral distal femoral angle, pain, and ability to perform activities of daily living or to work. The range of motion of the knee was determined on the basis of the amount of fixed flexion deformity and the amount of flexion at the end of treatment or before treatment. Lengthening was assessed by comparing the actual amount of lengthening with the initial goal. Gait was evaluated according to the degree of limp (subjectively assessed on clinical examination) preoperatively compared with postoperatively. The lateral distal femoral angle was scored according to the number of degrees at the end of treatment. The amount of pain was assessed subjectively by the patient before and after treatment, as was the ability to perform activities of daily living and to work. Through the addition and subtraction of point values (Table II), the patient received a score that was excellent (95 to 100 points), good (75 to 94 points), fair (40 to 74 points), or poor (less than 40 points).

In addition to the outcome score for the range of motion of the knee at the latest follow-up evaluation,
FEMORAL LENGTHENING OVER AN INTRAMEDULLARY NAIL

<table>
<thead>
<tr>
<th>Planned femoral lengthening (each cm of lengthening = 1 point)</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0 Points</td>
</tr>
<tr>
<td><strong>Age (yrs.)</strong></td>
<td>5-19</td>
</tr>
<tr>
<td><strong>Complexity of correction of deformity at level of lengthening</strong></td>
<td>None</td>
</tr>
<tr>
<td><strong>Other levels of treatment in same bone</strong></td>
<td>None</td>
</tr>
<tr>
<td><strong>Associated tibial lengthening (cm)</strong></td>
<td>None</td>
</tr>
<tr>
<td><strong>Instability of joint</strong></td>
<td>None</td>
</tr>
<tr>
<td><strong>Fixed flexion deformity of knee (degrees)</strong></td>
<td>0</td>
</tr>
<tr>
<td><strong>Flexion of knee (degrees)</strong></td>
<td>&gt;120</td>
</tr>
<tr>
<td><strong>Osteoarthrosis of joint</strong></td>
<td>None</td>
</tr>
<tr>
<td><strong>Quality of bone</strong></td>
<td>Normal</td>
</tr>
<tr>
<td><strong>Quality of soft tissue</strong></td>
<td>Normal</td>
</tr>
<tr>
<td><strong>Medical problems and medications</strong></td>
<td>None</td>
</tr>
</tbody>
</table>

*Total*

*Mild = 0 to 6 points, moderate = 7 to 11 points, and severe = 12 points or more.

**FIG. 1**

Scale for classification of the level of difficulty of the lengthening procedure.

we also assessed the rate of recovery of the range of motion. The range of motion was measured by one of us (A. B.) preoperatively and at each postoperative visit with use of a goniometer. These measurements were compared, between the group that had had lengthening over an intramedullary nail and the matched-case group, at the end of the distraction and consolidation phases and at the time of maximum recovery. Operative times, estimated blood loss, and cost of treatment also were compared between the two groups.

Complications were classified according to a modification of the system proposed by one of us (D. P.)³³. With use of this system, grade 1 is defined as problems (difficulties that arise during treatment that can be fully resolved non-operatively); grade 2, as obstacles (difficulties that arise during treatment that can be fully resolved operatively); and grade 3, as sequelae (temporary or permanent difficulties that remain after removal of the external fixator). Grade-3 complications are subdivided into minor or major sequelae according to their clinical importance.

Radiographs were made for both groups monthly throughout the consolidation phase and at least every three to six months after consolidation had been completed. The consolidation phase began at the end of distraction (the limb-lengthening phase) and ended when the bone in the distraction gap had healed sufficiently (when three of four cortices were seen to be
**TABLE II**

**SCORING SYSTEM FOR OUTCOME OF FEMORAL LENGTHENING**

<table>
<thead>
<tr>
<th>Range of motion of knee</th>
<th>Additions (No. of Points to Be Added to Derive Total Score)</th>
<th>Subtractions (No. of Points to Be Subtracted from Total Score)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fixed flexion deformity = 0°, flexion &gt; 120°, or flexion &gt; 90% of prep. flexion</td>
<td>Excellent (25 points)</td>
<td>Excellent (0 Points)</td>
</tr>
<tr>
<td>Fixed flexion deformity = 5°, flexion = 101-120°, or flexion = 67-89% of prep. flexion</td>
<td>Good (20 Points)</td>
<td>Good (5 Points)</td>
</tr>
<tr>
<td>Fixed flexion deformity = 6-15°, flexion = 70-100°, or flexion = 50-66% of prep. flexion</td>
<td>Fair (10 Points)</td>
<td>Fair (20 Points)</td>
</tr>
<tr>
<td>Fixed flexion deformity = &gt;15°, flexion &lt;70°, or flexion &lt;50% of prep. flexion</td>
<td>Poor (0 Points)</td>
<td>Poor (30 Points)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Amount of lengthening</th>
<th>Within 1 cm of goal</th>
<th>0.1 to 0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gait (prep. to postop.)</td>
<td>Within 1.1-3 cm of goal</td>
<td>1.2 to 1</td>
</tr>
<tr>
<td>Lateral distal femoral angle (degree)</td>
<td>85-90</td>
<td>79-81 or 94-96</td>
</tr>
<tr>
<td>Pain (prep. to postop.)</td>
<td>82-84 or 91-93</td>
<td>&lt;79 or &gt;96</td>
</tr>
<tr>
<td>Ability to perform activities of daily living or to work (prep. to postop.)</td>
<td>0.1, 2 to 0</td>
<td>0.2, 3 to 1</td>
</tr>
</tbody>
</table>

*Excellent = 95 to 100 points, good = 75 to 94 points, fair = 49 to 74 points, and poor = less than 40 points.

†0 points = no limp, 1 point = slight limp, and 2 points = moderate limp.

‡0 points = no pain, 1 point = slight pain, 2 points = moderate pain, and 3 points = severe pain.

§0 points = full activity and full-time work, 1 point = reduced activity and reduced work, and 2 points = no activity or no work.

intact on anteroposterior and lateral radiographs [the radiographic consolidation end point]. The time to radiographic consolidation for both groups of patients was the time from the osteotomy to the radiographic consolidation end point, and it included both the distraction and the consolidation phase. The presence of a nail did not interfere with this evaluation. The time to radiographic consolidation in the matched-case group was the same as the duration of external fixation, as the date of removal was based on the radiographic criterion of consolidation. The radiographic consolidation index (time to radiographic consolidation per centimeter of distraction gap) was calculated for both groups and compared. The external fixation index (duration of external fixation, in months, for each centimeter of lengthening) was also calculated for both groups. As the bone had not healed at the time of removal of the external fixator in the group that had had lengthening over an intramedullary nail, the time to radiographic consolidation was measured by one of us (G. P.).

With use of the Ilizarov fixator, lengthening occurs along the mechanical axis of the femur, whereas lengthening over an intramedullary nail occurs along the anatomical axis (Fig. 2). Theoretically, lengthening along the anatomical axis places the center of the knee joint in a more medial position; thus, the mechanical axis is in a lateral position, resulting in a valgus deformity of the knee. To clarify whether lengthening over an intramedullary nail caused notable malalignment, one of us (G. P.) measured the displacement of the mechanical axis (the distance of the mechanical axis line of the lower limb from the center of the knee joint) and the lateral distal femoral angle (the lateral angle measured between the mechanical axis of the femur and the knee-joint line) on preoperative and latest follow-up 130-centimeter radiographs.

Statistical significance was evaluated with use of a paired Student t test in which all matched variables except cost were compared for the two groups. The data for cost were compared with use of an unpaired t test only for patients who had had a unilateral lengthening procedure. A p value of less than 0.01 was considered significant. Factorial analysis of variance was used to assess the effect of lengthening on mechanical alignment. A p value of less than 0.01 was also considered significant for this analysis. (We chose 0.01 as opposed to 0.05, as the matching criteria were not within one year or within one centimeter but rather were ten years and 2.5 centimeters.)

**Operative Technique for Lengthening over an Intramedullary Nail**

**Step 1: Insertion of the Intramedullary Nail and Osteotomy (Figs. 3-A and 3-B)**

The patient is placed supine on a fracture table with the limbs in a scissors position and the uninvolved limb down. The canal is vented through a stab wound, with insertion of a 3.8 or 4.8-millimeter cannulated drill-bit over a two-millimeter Kirschner wire through one cortex at the junction of the middle and distal thirds of the femur. Venting of the distal aspect of the femur diminishes the pressure in the canal, thereby reducing the risk.
of fat embolism\textsuperscript{7}, during reaming of the intact femur. When the Kirschner wire is removed, the cannulated drill-bit, which is left in place, serves as a decompression tube during reaming. The standard approach to the piriformis fossa is used. The femoral canal is reamed over a guide-wire to a diameter 1.5 millimeters larger than that of the nail. The proximal aspect of the femur is overreamed to accommodate the proximal flare of the nail.

On the radiograph, the level of the osteotomy is chosen to ensure that at least eight centimeters of the nail is on the distal side of the distraction gap at the end of lengthening. The level of the osteotomy depends on the amount of lengthening that is planned and on the initial length of the femur. For shorter lengthenings, the osteotomy may be more mid-diaphyseal. For longer lengthenings and for shorter femora, the osteotomy should be more proximal in order to maximize the length of the nail in the distal segment at the end of lengthening. The guide-wire is withdrawn proximal to the level of the planned osteotomy. Percutaneous drill-holes are made in the femur, and the osteotomy is completed with an osteotome. We do not use an intramedullary saw as it necessitates reaming of the canal to at least thirteen millimeters. The use of percutaneous drill-holes is simpler, quicker, and less traumatic, necessitating reaming of the femur to only 11.5 millimeters when a ten-millimeter nail is used. The guide-wire is readvanced into the distal segment so that the length of the nail can be measured; the nail should be as long as possible so that the distal locking screws are as distal as possible at the end of the lengthening. The nail is inserted and locked proximally, and the incision is closed over a suction drain.

Step 2: Application of the External Fixator
(Figs. 4-A, 4-B, and 4-C)

With the nail in place, an external fixator is applied for lengthening. All external fixation pins and wires are inserted without their coming into contact with the intramedullary nail. There should be approximately one millimeter or more of space between the external fixation pin and the nail.

Use of the Ilizarov Fixator
(Figs. 5-A through 5-F)

A frame consisting of one or two femoral arches and two rings is preconstructed. The rings should be sized to allow two fingerbreadths of clearance circumferentially around the distal aspect of the thigh. After the nail has been inserted, an image intensifier is used to assess the space available for external fixation pins anterior or posterior to the nail in the proximal and distal metaphyseal regions of the femur. A

![Anatomical Axis](image1)

**Fig. 2**

Drawings showing lengthening along the anatomical compared with the mechanical axis. The left femur (right side of figure) is lengthened with an external fixator parallel to the mechanical axis of the lower extremity. Lengthening along the mechanical axis creates a slight zigzag in the femoral shaft but does not change the displacement of the axis. The right femur (left side of figure) is lengthened with an external fixator parallel to the anatomical axis. Lengthening along the anatomical axis displaces the knee medially and therefore displaces the mechanical axis laterally. The displacement theoretically should increase with more extensive lengthenings. MAD = mechanical axis displacement.
**Fig. 3-A**

(i) 

(ii) 

(iii) 

**Fig. 3-B**

Figs. 3-A and 3-B: Drawings showing the cannulated drill-bit technique for insertion of half-pins around an intramedullary nail. The proximal (Fig. 3-A) and distal (Fig. 3-B) ends of the femur are visualized (insets) with an image intensifier. There should be adequate space available for the half-pin anterior or posterior to the nail so that the pin does not come into contact with the nail. A 1.8-millimeter wire is drilled perpendicular to the nail centered in the radiographic available space. The wire should be visualized with the image intensifier to ensure that it has adequate clearance for overdripping with a 4.5-millimeter cannulated drill-bit (i). If the wire is too close to the nail, it should be reinserted in a more central location as determined with the image intensifier. After the wire is in a satisfactory position, it should be overdripped with a 4.8-millimeter cannulated drill-bit (ii). The drill-bit and the wire then are removed, and a six-millimeter stainless-steel half-pin is inserted. There should still be a radiographic clear space between the nail and the pin (iii).
1.8-millimeter bayonet-tipped Kirschner wire is inserted perpendicular to the nail into the predetermined space. The position of the wire is checked with the image intensifier to ensure that the wire does not touch the nail. Two wires (drilled laterally to medially) are used in the frontal plane of the distal aspect of the femur. The proximal aspect of the femur requires more clearance from the nail to allow the wire to be overdrilled for insertion of the half-pins. The wire is overdrilled with a 4.8-millimeter cannulated drill-bit, and a six-millimeter half-pin is inserted into the hole. The position of the pin is checked with the image intensifier to ensure that it is not in contact with the nail. The two half-pins and the two wires are tensioned to 130 kilograms with graduated wire-tensioners and are connected to the preconstructed frame.

The Ilizarov apparatus may be easier to use than the Orthofix fixator when lengthening is performed over a nail because less accuracy is needed to place the pins relative to each other, because only the proximal pins are half-pins, and because wires instead of pins are used distally. The Ilizarov apparatus also may be preferable in patients who have a congenital disorder as it can be extended across to the tibia with hinges, permitting motion of the knee while preventing subluxation.

**Use of the Orthofix Fixator**
(Figs. 6-A through 6-G)

A long slide lengthener (Orthofix S. R. L. limb-reconstruction system) that will allow adequate excursion (usually 400 millimeters) for lengthening is inserted. The most proximal and distal six-millimeter half-pins are inserted parallel to each other and perpendicular to the nail with use of the cannulated drill-bit technique. The levels of the second proximal and second distal half-pins are chosen on the basis of the space available and the spacing of the Orthofix pin clamp. The cannulated drill-bit technique also is used to insert these two middle pins.

**Postoperative Care**

Distraction is begun at a rate of 0.25 millimeter four times a day seven days postoperatively. Daily physical therapy to maintain the range of motion of the hip and the knee is begun one to two days after the operation. In addition to one hour of therapy a day with a...
During lengthening, an anteroposterior radiograph of the femur is made every two weeks to monitor distraction. During visits to the clinic, it is important to debride any necrotic tissue from around the pin sites. Gauze wraps are used daily to decrease motion at the pin-skin interface in an effort to prevent pin-track infection. The patient is instructed to look for redness, tenderness, and increased drainage around the pin sites. All patients are given a prescription for an antibiotic to be taken orally. Cefazolin (500 milligrams four times per day for adults and fifty milligrams per kilogram of body weight per day for children) usually is prescribed. Adults who are allergic to penicillin are given ciprofloxacin. If the patient suspects a pin-track infection, the antibiotic therapy should be started immediately. The patient is instructed to call the physician if the signs or symptoms do not begin to resolve within twenty-four hours. Specimens for culture are obtained only if the infection does not resolve with use of the antibiotic. Early treatment prevents deeper infection.

After the desired limb length has been achieved, the patient is returned to the operating room for insertion of the distal locking screws and removal of the external fixator. To prevent loss of length, it is important to insert the locking screws before removing the fixator. With the Orthofix fixator, if the distal locking holes are near the level of the distal external fixation pins then the nail is locked from the medial side to avoid contamination of the incision. If the locking site is three centimeters or more proximal or distal to the external

Fig. 5-C: The preconstructed Ilizarov apparatus is fixed to the pins so that the lengthening rods are parallel to the nail in both the frontal and the sagittal plane.

Fig. 5-D: With gradual lengthening at a rate of one millimeter per day, the distal end of the femur slides distally over the nail for the same distance as the distraction gap.

Fig. 5-E: At the end of distraction, the two distal locking screws are inserted from the lateral side as the nail is proximal to the external fixation pins.

Fig. 5-F: After the nail has been locked, the external fixator is removed and the newly formed bone consolidates under the protection of the intramedullary nail.
Figs. 6-A through 6-G: Drawings showing the method when the Orthofix fixator is used.

Fig. 6-A: The canal is overreamed by 1.5 millimeters. A cannulated drill-bit is used to rent the medullary canal during reaming.

Fig. 6-B: The guide-wire is withdrawn proximal to the level of the osteotomy. After multiple drill-holes have been made percutaneously from the lateral side (inset), an osteotome is used to complete the osteotomy. (The osteotomy is mid-diaphyseal because the planned lengthening is short.)

Fig. 6-C: The intramedullary nail is inserted and is locked proximally.

Fig. 6-D: The external fixator is applied to four half-pins that were inserted with the cannulated drill-bit technique. The pins should be perpendicular to the nail, and the body of the fixator should be parallel to the nail.

Fig. 6-E: During distraction, the femur slides over the distal end of the nail.

Fig. 6-F: At the end of lengthening, the two distal locking screws are inserted. Because the tip of the nail is at the level of the external fixation pins, the locking is performed from the medial side to avoid contamination.

Fig. 6-G: After the nail has been locked, the external fixator is removed and the newly formed bone consolidates.

Fixation pins, the nail can be locked from the lateral side. This usually is done in the central one-third of the femur because medial locking would endanger the femoral vessels. The patient must continue partial weight-bearing with use of two crutches until the newly formed bone has bridged two cortices as seen on radiographs.
After one cortex has bridged completely, patients who had a unilateral procedure may bear full weight while using crutches and those who had a bilateral procedure may bear half of their weight while using crutches or a walker. After two intact cortices have been seen on the radiographs, full weight-bearing without crutches is permitted for all patients.

When we began performing lengthening over an intramedullary nail, we used the Ilizarov external fixator and then we gradually developed the method for use of the Orthofix external fixator. The indications are the same for both fixators. We have used an Orthofix articulated distractor for such patients, but its use is more difficult.

**Results**

The mean amount of femoral lengthening over an intramedullary nail was 5.8 centimeters (range, two to thirteen centimeters) compared with 5.2 centimeters (range, two to thirteen centimeters) in the matched-case group; no significant difference could be detected between the groups (p = 0.03), with the numbers available. The mean age for the group that had had lengthening over an intramedullary nail was twenty-six years (range, ten to fifty-three years) whereas that for the matched-case group was twenty-five years (range, nine to sixty-two years); again, there was no significant difference between the two groups (p = 0.95). We also could not detect a significant difference with respect to the level of difficulty of the procedure between the two groups (p = 0.87).

The mean duration (and standard deviation) of external fixation was 4 ± 2.5 months (range, 1.0 to 13.6 months) for the limbs that had had lengthening over an intramedullary nail compared with 7.5 ± 4.3 months (range, 3.3 to 19.5 months) for the matched-case group. The mean external fixation index was 0.7 ± 0.4 month per centimeter (range, 0.3 to 2.1 months per centimeter) for the limbs that had had lengthening over an intramedullary nail compared with 1.7 ± 1.0 months per centimeter (range, 0.7 to 4.5 months per centimeter) for the matched-case group; this difference was found to be significant (p < 0.001). Four limbs that had had lengthening over an intramedullary nail were not treated with immediate removal of the external fixator at the end of the distraction phase. In three of these four limbs, the fixator was left in place after locking to provide additional temporary support for the long distraction gap as only a short length of nail extended distal to the distraction gap (Figs. 7-A, 7-B, and 7-C). In the fourth limb, the fixator was left in place to be used for correcting a flexion contracture of the knee that was present preoperatively. The data for these four limbs markedly increased the mean values for the duration of external fixation and the external fixation index. When these data are excluded, the mean external fixation index for the limbs that had had lengthening over an intramedullary nail decreases to 0.5 month per centimeter (range, 0.3 to 0.8 month per centimeter) and the range of variability in the external fixation index is markedly reduced (to ±0.18). This recalculation of external fixation index is more representative of the duration of external fixation that is expected for most limbs that have lengthening over an intramedullary nail.

To determine the stage at which the new bone had healed, the time to radiographic consolidation was determined from serial radiographs made, after removal of the fixator, of twenty-six patients (twenty-eight femora) who had had lengthening over an intramedullary nail. An insufficient number of radiographs were available to make this determination for the remaining three patients (four femora). The mean radiographic consolidation index was 1.4 months per centimeter (range, 0.5 to 4.5 months per centimeter) for the femora that had had lengthening over an intramedullary nail compared with 1.7 months per centimeter (range, 0.7 to 4.5 months per centimeter) for the matched-case group. The femora that had been lengthened over an intramedullary nail needed less time per centimeter to reach radiographic consolidation than did the femora in the matched-case group (p < 0.001).

To assess malalignment due to lengthening along the anatomical axis, we determined whether lengthening over an intramedullary nail had caused a detectable difference between the preoperative and postoperative displacement of the mechanical axis. We considered only the twenty-five limbs that had been lengthened over a nail without concomitant tibial lengthening or correction of a femoral or tibial deformity as these additional procedures can affect the change in displacement of the mechanical axis. Theoretically, greater lengthening and a greater preoperative femoral anatomical-mechanical angle (the angle between the anatomical and mechanical axes of the femur) should produce greater lateral displacement of the mechanical axis. However, the greater lengthening did not cause any more change in the displacement of the mechanical axis than did the shorter lengthenings. To test this, we used factorial analysis of variance. A change in the displacement of the mechanical axis was compared with the magnitude of the preoperative femoral anatomical-mechanical angle and the amount of lengthening. We could not detect a significant relationship, with the numbers available, between the femoral anatomical-mechanical angle and the amount of lengthening with the change in the displacement of the mechanical axis (p = 0.17).

We also studied the effect of the amount of lengthening on the lateral distal femoral angle for the limbs that had had lengthening over an intramedullary nail. The mean difference between the preoperative and postoperative lateral distal femoral angles was 2.5 ± 2.7 degrees. We could not detect a significant relationship, with the numbers available, between the change in the lateral distal femoral angle and the amount of lengthen-
ing (p = 0.89). We also could not identify any consistent pattern of change in the displacement of the mechanical axis associated with lengthening over an intramedullary nail.

The preoperative displacement of the mechanical axis was outside of the normal range in twelve of the thirty-two limbs that had had lengthening over an intramedullary nail. Of these twelve, five still had abnormal displacement of the mechanical axis after lengthening; however, two of the five had an improvement compared with the preoperative displacement. Three limbs had had normal alignment preoperatively, but displacement outside of the normal range developed after lengthening. The amount of residual displacement of the mechanical axis was clinically important (greater than two centimeters laterally) in only one limb. Greater than one centimeter of displacement outside of the normal range is considered clinically important. The theoretical lateral shift of the mechanical axis did not occur or was clinically unimportant in all but this one limb.

In the matched-case group, twenty-one of the thirty-two limbs had had preoperative displacement of the mechanical axis that was outside of the normal range. Seven limbs also had a deformity in the sagittal plane. In nineteen limbs, the displacement of the mechanical axis was corrected to within the normal range during the lengthening. At the latest follow-up evaluation, seven limbs had displacement of the mechanical axis that was outside of the normal range; five of these limbs had more than one centimeter of displacement. In four of these limbs, the displacement was secondary to bending of the distraction gap after removal of the external fixator. The fifth was in varus angulation secondary to axial deviation during lengthening.

There were twenty-three excellent, seven good, and two fair results in the group that had had lengthening over an intramedullary nail compared with twenty-six excellent, four good, and two fair results in the matched-case group. There were no poor results in either group. We could detect no significant difference, with the num-
<table>
<thead>
<tr>
<th>Case</th>
<th>Complication</th>
<th>Study Group Treatment</th>
<th>Complication</th>
<th>Matched-Case Group Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>2</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>3</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>4</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>5</td>
<td>Non-separation</td>
<td>Osteoclastis, exchange of Orthofix fixator for Ilizarov fixator</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>6*</td>
<td>Fixed flexion deform. of L knee</td>
<td>Phys. ther.</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>7*</td>
<td>Premature consol.</td>
<td>Repeat osteot.</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>8*</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>9*</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>10</td>
<td>Non-separation, premature consol., delayed union</td>
<td>Osteoclastis, repeat osteot., removal of locking screws</td>
<td>Broken pin, premature consol.</td>
<td>Replacement of pin, repeat osteot.</td>
</tr>
<tr>
<td>11</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>65° loss of flex. of knee</td>
</tr>
<tr>
<td>12</td>
<td>Bending of prox. pins, subluxat. of hip</td>
<td>Addition of pin, closed reduct. and adductor tenot.</td>
<td>Peroneal nerve dysesthesia, varus axial deviation, bending of regenerated bone during lengthening, delayed union</td>
<td>Slowing of distract., manip. under general anesth.</td>
</tr>
<tr>
<td>13</td>
<td>Delayed union, broken locking screws 1.0 cm of shortening</td>
<td>None</td>
<td>Fract. and bending after removal of fixator</td>
<td>None</td>
</tr>
<tr>
<td>14</td>
<td>Broken wire, peroneal nerve palsy, premature consol.</td>
<td>Replacement of wire, decompression, spontaneous refract.</td>
<td>Varus axial deviation during lengthening, delayed union</td>
<td>Correction with hinges</td>
</tr>
<tr>
<td>15</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>16</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>17</td>
<td>Premature consol., heterotopic bone around distal pins</td>
<td>Repeat osteot. for premature consol., no treatment for heterotopic bone</td>
<td>Peroneal nerve palsy, broken pin, premature consol.</td>
<td>Distract. of femur and tibia discontinued and Ilizarov apparatus backed up, both at 2 wks; recovery, repeat osteot., insertion of new pins</td>
</tr>
<tr>
<td>18</td>
<td>Fract. of distal aspect of femur due to fall during lengthening</td>
<td>Extension of fixator distal to fract.</td>
<td>Peroneal nerve palsy, broken pin, premature consol.</td>
<td>Distract. of femur and tibia discontinued and Ilizarov apparatus backed up, both at 2 wks; recovery, repeat osteot., insertion of new pins</td>
</tr>
<tr>
<td>19*</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>20*</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>21</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>22</td>
<td>45° loss of flex. of knee</td>
<td>Unresolved despite phys. ther.</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>23</td>
<td>Broken nail, undisplaced</td>
<td>Repeat nailing</td>
<td>Deep pin-track infect.</td>
<td>Replacement of pins</td>
</tr>
<tr>
<td>24</td>
<td>Premature consol., late deep infect.</td>
<td>Repeat osteot., removal of nail</td>
<td>Bending of regenerated bone after removal of fixator</td>
<td>Application of cast</td>
</tr>
<tr>
<td>25</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>Application of spica cast</td>
</tr>
<tr>
<td>26</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>Application of spica cast</td>
</tr>
<tr>
<td>27</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>28</td>
<td>Premature consol., pin-track infect., varus deviation of prox. aspect of femur</td>
<td>Repeat osteot., removal of pin, correction during subsequent lengthening</td>
<td>Premature consol., fract. of regenerated bone, 3 cm of shortening, varus deform.</td>
<td>Repeat osteot., application of spica cast</td>
</tr>
<tr>
<td>29</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>Repeat osteot.</td>
</tr>
<tr>
<td>30</td>
<td>Prominent locking screw</td>
<td>Removal of screw</td>
<td>Mild subluxat. of knee</td>
<td>Traction at night</td>
</tr>
<tr>
<td>31</td>
<td>Prominent locking screw</td>
<td>Exchange of screw</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>32</td>
<td>Non-separation, premature consol.</td>
<td>Osteoclastis, repeat osteot.</td>
<td>45° loss of flexion of knee</td>
<td>Unresolved despite phys. ther.</td>
</tr>
</tbody>
</table>

*Cases 6 and 7, 8 and 9, and 19 and 20 in the study group represent the same patients, each of whom had a bilateral procedure.
bers available, with respect to the results between the two groups (p = 0.37).

The mean operative time for lengthening over an intramedullary nail was 5.8 hours (range, three to fifteen hours) compared with 7.2 hours (range, three to twelve hours) for the matched-case group; we could detect no significant difference, with the numbers available, between the two groups (p = 0.124). These prolonged times were secondary to simultaneous tibial or bilateral procedures in eight patients (eleven limbs). When the data for the limbs that had simultaneous tibial lengthening or a bilateral procedure are excluded from both groups, the mean operative time was 4.2 hours for lengthening over an intramedullary nail compared with 4.8 hours for the matched-case group. We could detect no significant difference, with the numbers available, between the mean operative times for the two groups after exclusion of these data (p = 0.09).

The mean blood loss recorded in the anesthesia record was 460 milliliters (range, 100 to 1000 milliliters) in the group that had lengthening over an intramedullary nail. Patients who were scheduled to have lengthening over an intramedullary nail were asked to donate blood before the procedure, and the Cell Saver (Haemonetics, Braintree, Massachusetts) was used in the operating room. Three patients required an autologous or a donor-directed blood transfusion postoperatively. In the matched-case group, the mean blood loss was sixty milliliters (range, fifty to 1800 milliliters). Two patients lost more than 1000 milliliters of blood intraoperatively because of resection of an area of nonunion. The blood loss associated with lengthening over an intramedullary nail was significantly greater than that in the matched-case group (p < 0.01).

The cost of treatment, including fees for the index procedure, the procedure for removal of the external fixator, and hospital charges, was compared between the two groups of patients. The cost of postoperative physical therapy was not included. Patients who had a bilateral lengthening or a combined tibial-femoral procedure were excluded from this analysis. The mean cost for unilateral femoral lengthening over an intramedullary nail was $23,885 (range, $17,883 to $27,893) compared with $18,857 (range, $17,849 to $28,974) for unilateral Ilizarov femoral lengthening.

Lengthening over an intramedullary nail was associated with a total of forty-five complications, including seventeen problems, nineteen obstacles, and nine sequelae. Seven sequelae resolved spontaneously or after an additional operation, and two (loss of flexion of the knee and loss of one centimeter of length) were permanent. The matched-case group had a total of sixty-one complications, including thirty-four problems, eighteen obstacles, and nine sequelae. One sequela resolved after an additional operation, and eight (loss of flexion of three knees and five varus deformities) were permanent (Table III). The over-all rate of complications was 1.4 per cent in the group that had had lengthening over an intramedullary nail compared with 1.9 per cent in the matched-case group. Excluding superficial pin-track infections, the rate of complications was 0.9 per cent in the group that had had lengthening over an intramedullary nail compared with 1.0 per cent for the matched-case group.

Most of the complications were similar between the two groups with respect to type, prevalence, and severity. However, there was an important difference with respect to the number of refractures. There were five refractures in the matched-case group. All five fractures were bent, and one also shortened. The frame was removed when the bone is considered sufficiently strong to resist physiological forces. This determination is made radiographically. Osteoporosis, a narrow diameter of the new bone, and residual muscle tension all play a role in bending and breaking. A new bone fracture also can occur through a pin-hole, although there was no instance of this in the current study. The five fractures in the matched-case group were believed to be related to the narrow diameter of the new bone in one limb, to osteoporosis in one limb, and to residual muscle tension in three limbs. Pin-track infection was twice as common in the matched-case group, reflecting the larger number of pins needed by these patients. (Most patients in the matched-case group needed eight pins compared with four pins in the patients who had had lengthening over an intramedullary nail.)

Serial data for flexion of the knee were available for twenty-nine of the thirty-two limbs that had had lengthening over an intramedullary nail. The mean preoperative flexion for these limbs was 125 degrees. On the average, 77 per cent of the preoperative flexion was regained by four weeks after removal of the fixator. Flexion continued to improve postoperatively, to a mean of 118 degrees at the latest follow-up evaluation. The mean preoperative flexion in the matched-case group was 114 degrees compared with 106 degrees at the latest follow-up evaluation. We could detect no significant difference, with the numbers available, with respect to the amount of flexion at the latest follow-up evaluation between the two groups (p = 0.12). One limb that had had lengthening over an intramedullary nail lost clinically important motion compared with three limbs in the matched-case group. These results were similar to those that we reported in a previous study.

At the end of the distraction phase, the mean flexion of the knee in the group that had had lengthening over an intramedullary nail was 58 degrees compared with 47 degrees in the matched-case group. At the end of the consolidation phase, the mean flexion was 88 degrees in the group that had had lengthening over an intramedullary nail compared with 56 degrees in the matched-case group. The difference in these values, both at the end of distraction and at the end of consolidation, was signifi-
This finding demonstrates faster rehabilitation in the group that had had lengthening over an intramedullary nail (Fig. 8).

Discussion

To maintain length as well as alignment with interlocking intramedullary nailing. In addition to reducing the time needed for external fixation and protecting against fracture of the newly formed bone, the intramedullary nail helps to neutralize the forces on the femur during lengthening. A marked varus deformity occurred in five of the nine limbs that had had proximal femoral lengthening in the matched-case group. Although there was a tendency for varus deformity to develop when a subtrochanteric osteotomy had been performed with lengthening over an intramedullary nail, the total amount of varus angulation was limited by the nail and the nail probably compensated for the varus angulation that theoretically occurs in association with lengthening along the anatomical axis of the femur.

The radiographic results in our study provided no consistent evidence of a trend toward valgus deformity when lengthening over an intramedullary nail had been performed. This is an important finding as the valgus deformity that theoretically occurs in association with lengthening over an intramedullary nail is the basis for one argument against the use of this technique. However, when axial deviation does occur with use of this method it cannot be corrected as readily with the external fixator as axial deviation that occurs with standard Ilizarov femoral lengthening. Fortunately, that was not a major problem in our series.

One nail and one proximal locking screw failed in the group that had had lengthening over an intramedullary nail. In comparison, in the matched-case group there were six fractures of the distraction bone, four of which were associated with loss of length. The risk of fracture of the nail is theoretically higher after a more extensive lengthening. This complication did not occur more often in the current study because of the extra precautions that were taken with some of the more extensive lengthenings. These precautions consisted of leaving the fixator in place after the end of the distraction phase until the immature bone had shown early evidence of bridging as well as limiting weight-bearing after removal of the fixator until one or two cortices were seen.

Premature consolidation of the immature bone necessitating repeat osteotomy occurred at similar rates in the two groups. The high rate of premature consolidation and non-separation associated with lengthening over an intramedullary nail (Figs. 9-A, 9-B, and 9-C) may have been due to the fact that reaming was not used in the first fifteen limbs that were treated with the procedure. (When we began to use this technique, we were concerned that new bone might not form after reaming.) In the remaining seventeen limbs, we overreamed the femur and allowed only touch-down weight-bearing. In addition, to prevent non-separation we test-distracted the site of the osteotomy to separation during the operation and then reversed it.

Ilizarov emphasized the importance of preservation of the endosteal blood supply in distraction osteogenesis. Reaming of the endosteme in our study did not prolong the time until consolidation of the newly formed bone. Abundant new bone was produced consistently in all but one limb that had had lengthening over an intramedullary nail despite reaming of the medullary canal. This suggests that any slowing of new-bone formation due to damage to the medullary circulation may be compensated for by the effect of revascularization after reaming, the better stability provided by the nail fixation, and earlier functional loading.

The potential disadvantages of combined external and internal fixation for femoral lengthening include
the increased risk of blood loss, intramedullary infection, and fat embolism as well as problems with the retained hardware. The most worrisome problem is pin-track infection leading to deep intramedullary infection during lengthening, a concern that is due to the trauma of nailing after external fixation. The one deep infection in our series occurred almost one year after interlocking nailing, long after the bone had healed. Proximity of the external fixation pins during lateral locking was considered to be the cause of the infection in this patient, and removal of the nail resolved the problem. Locking from the medial side when the end of the nail is near the external fixation pins is important to avoid contamination. Furthermore, care must be taken to ensure that there is no contact between the nail and the external fixation pins.

Concerns regarding lengthening over an intramedullary nail in children include the risk of avascular necrosis, recently described as a complication of femoral nailing, and the potential for growth arrest of the greater trochanteric epiphysis with secondary valgus deformity of the femoral neck. We cannot readily compare our results with those reported in the literature, which has focused primarily on lengthening in children, as all but four patients in the study group in the current series were skeletally mature. In comparing the method of lengthening over an intramedullary nail with the standard Ilizarov method of limb-lengthening, we tried to reduce the variability between the two groups by matching them for factors that are commonly believed to affect
the results and the risk of complications. While a prospective, randomized, controlled trial would have eliminated the variable of patient selection for each group, a matched-case study of two prospectively followed groups is the next-best comparison. It was not possible to control for all potentially important variables, such as associated tibial lengthening, femoral deformity, and the level of the osteotomy. Nevertheless, our study is the first, to our knowledge, in which two closely matched groups controlled by variables were compared.

Although the combination of intramedullary nailing and external fixation is technically more demanding than the Ilizarov method, it has the advantages of a reduction in the duration of external fixation, protection against refracture, and earlier rehabilitation. We believe that these advantages offset the disadvantages of increased cost and increased blood loss. The difference in the cost of acute care may be offset by the lower cost due to a shorter rehabilitation time after lengthening over an intramedullary nail. However, this variable was not assessed and warrants additional study. In conclusion, we believe that our findings demonstrate that femoral lengthening over an intramedullary nail is safe and reliable and offers some advantages compared with the standard method of Ilizarov femoral lengthening.

Note: The authors are grateful to James A. Goletti, M.D., for assistance in managing some of the patients.

References