JB&JS Essential Surgical Techniques

SURGICAL TECHNIQUES

Lengthening of the Femur with a Remote-Controlled Magnetic Intramedullary Nail

Antegrade Technique

S. Robert Rozbruch, MD, Austin T. Fragomen, MD

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Introduction

Femoral lengthening with an intramedullary nail avoids the need for external fixation with its inherent challenges.

The remote-controlled magnetic intramedullary nail is a telescopic implant that contains a magnet that turns a gear box to induce controlled elongation of the nail. Femoral lengthening with this internal lengthening nail is performed through either an antegrade or a retrograde approach, each with its own indications, but the antegrade technique is our first choice for the approach, with the retrograde approach used for special occasions. In addition to gradual bone lengthening, angular and rotational deformity can be acutely corrected with the nail. The osteotomy is performed at the apex of the deformity. In our practice, the antegrade approach is principally done with a piriformis entry in adults and a trochanteric entry in adolescents. The retrograde approach is used when the apex of the deformity is in the distal part of the femur or when the antegrade approach is contraindicated.

Blocking screws are used mainly with the retrograde technique to assist with deformity correction and to prevent lengthening-induced deformity. The location of the magnet inside the intramedullary nail is marked on the patient's skin, and the remote control is applied to the thigh to induce distraction three or four times per day with a daily lengthening goal of approximately 1 mm (Video 1).

Video 1 Animation of antegrade femoral lengthening with the magnetic intramedullary nail. At ten days postoperatively, with the lengthening started on postoperative day 4, the total lengthening distance should be approximately 10 mm.

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Indications and Contraindications

Indications for Antegrade Approach

- Limb length discrepancy of >0.75 in (2 cm) that is causing symptoms.
- Age of twelve years or greater. In our practice, we use the piriformis approach for patients eighteen years of age and older and we use the trochanteric approach for patients twelve to seventeen years of age to protect the vascular supply of the femoral head. An open trochanteric apophysis is not a contraindication for a trochanteric approach. A trochanteric entry nail may be used for adults as well.
- Some or all of the limb length discrepancy originating from the femur.
- Diaphyseal angular deformity should be acutely corrected at the time of nail insertion. Distal femoral metaphyseal deformity can be corrected at the same time with a plate. However, we usually use a retrograde nail approach for that.
- Rotational deformity should be acutely corrected at the time of nail insertion.

Contraindications for Antegrade Approach

- A medullary canal that is not patent.
- The presence of a total hip replacement prosthesis.
- A previous hip fusion since this causes a problem with access.
- Infection.
- Excessive deformity that is not amenable to an acute correction.
- Poor bone quality with compromised regenerative potential.

Step 1: Preoperative Planning

Determine the location of the osteotomy, which should be at the apex of the deformity or at the natural anterior bow of the femur, as well as the length and type of nail, which must be ordered a few weeks in advance.

- Use preoperative planning to choose the level of the osteotomy, which should be at the apex of the deformity or at the natural anterior bow of the femur. Use calibrated radiographs to determine limb length discrepancy as well as the total femoral length and the distance from the proximal part of the femur to the planned osteotomy location (Figs. 1-A through 2-B).
- We prefer a piriformis entry approach and nail for adults eighteen years of age and older, although a trochanteric approach may be used for all patients. The reasons for our preference are that a straight nail leads to a straighter lengthening, the trochanteric nail results in mild varus with lengthening, and the rotation around the straight nail is smoother than the rotation around the trochanteric nail. We use a trochanteric entry approach and nail for adolescents between the ages of twelve and seventeen years to avoid damage to the femoral head blood supply.
- Issues of inventory require that the specific implant be ordered a few weeks in advance.
- When choosing the nail length, focus on the need for biomechanical stability of the lengthened femur with the telescopic nail expanded at the end of distraction. Keep in mind that, as the femoral lengthening progresses, the thick part of the nail is pulled out of the distal fragment and the goal is to have at least 50 mm of the thick part of the nail in the distal fragment at the end of distraction. Before any lengthening is started, the thin part of the nail extrudes from the thick part by 30 mm. As lengthening progresses, more of the thin part of the nail extrudes. Calculate the shortest nail length that should be used with the formula: shortest nail

length = distance of osteotomy from tip of trochanter + planned lengthening + 50 mm + 30 mm. The starting nail lengths available range from 170 to 365 mm, and the maximum amount of lengthening of the nail ranges from 30 to 80 mm, depending on the starting nail length.

- Plan the diameter of the nail on the basis of a measurement of the medullary canal on a calibrated radiograph. Nails are available in 8.5, 10.7, and 12.5-mm diameters.


Fig. 1-A


Fig. 1-B

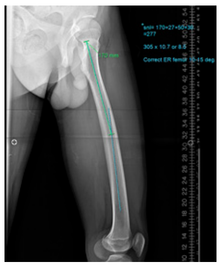
Fig. 2-A


Fig. 2-B

Fig. 1-A Standing radiograph of a sixteen-year-old boy with congenital limb-length discrepancy, showing a femoral discrepancy of 22 mm. Also, with a 25-mm block under the left leg, the left hip was still 2 mm lower than the right hip, yielding a lower-extremity length discrepancy of 27 mm with the left side short. (The remaining 5 mm of discrepancy comes from the tibia and foot.) The lengthening goal was 27 mm.

Fig. 1-B Clinical photograph of the boy, who had fibular hemimelia as well as congenital shortening of the femur and had undergone a previous lengthening of the tibia and fibula with external fixation.

Fig. 2-A Lateral radiograph showing the apex of the anterior bow of the normal femur to be 170 mm distal to the tip of the greater trochanter, which determines the location of the osteotomy site. The shortest nail length (snl) to be used is 277 mm (170 + 27 + 50 + 30 mm). ER = external rotation.

Fig. 2-B Anteroposterior radiograph of the femur showing a plan for a 305-mm nail and the level of the osteotomy at 170 mm. The medullary canal diameter is 9 mm, so the surgeon should prepare 8.5-mm and 10.7-mm-diameter nails. An external rotation deformity that was noted on physical examination and confirmed on a computed tomography scan will be corrected acutely.

Step 2: Operating Room Setup

Position the patient supine on a flat radiolucent table; the goal is access for antegrade canal reaming and nail insertion.

- Position the patient on a flat radiolucent operating room table, with C-arm fluoroscopy coming from the opposite side. Fluoroscopic visualization of the entire femur in two orthogonal planes is needed.
- Position a bump (e.g., rolled towels or blankets) under the ipsilateral buttock, tilting the pelvis about 20° from the horizontal.
- Adduct the ipsilateral arm across the chest and secure it with tape.
- Drape the entire lower extremity and buttock into the field with split sheets.

Step 3: Part 1 of the Osteotomy: Multiple Percutaneous Drill-Holes (Fig. 3)

Begin the osteotomy by making multiple percutaneous drill-holes, thereby avoiding the soft-tissue stripping and heat necrosis associated with the use of a power saw.

- Measure the distance of the planned osteotomy level from the tip of the trochanter.
- Use a 1.8-mm Kirschner wire to feel (sound) the bone percutaneously.
- Make a 1-cm incision and spread the soft tissue to the bone.
- With a new (unused) 4.8-mm drill-bit and a drill-sleeve, make multiple drill-holes in a transverse fashion while altering the axial plane angle. Clean the drill-flutes frequently to keep the drill sharp and avoid heat necrosis of the bone. Make the drill-holes with the limb adducted, as this will be the limb position when the osteotomy is completed later and thus will allow you to avoid shifting the soft tissues, as would otherwise occur. This detail will help to maintain the percutaneous track directly through to the soft tissue to the bone.
- The multiple drill-holes will also serve to vent the canal during intramedullary reaming.
- The bone remains intact at the end of this step.

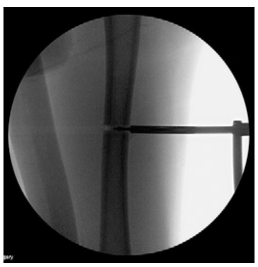

Fig. 3

Fig. 3 Percutaneously, multiple drill-holes are made as part 1 of the osteotomy.

Step 4: Entry Into the Proximal Part of the Medullary Canal

Use a minimal incision approach to the proximal part of the medullary canal (Figs. 4-A and 4-B).

- Adduct the hip about 20° without internally rotating the femur.
- Insert a 2.4-mm Steinmann pin percutaneously into the tip of the piriformis fossa or the tip of the greater trochanter and confirm the optimal position with biplanar fluoroscopy.
- Insert the Steinmann pin into the medullary canal. Confirm the direction and entry into the canal with radiographs.
- Make a 2-cm incision around the pin and spread the soft tissue. A soft-tissue protector may be used.
- Use an 11-mm anterior cruciate ligament (acorn-type) or other cannulated reamer to create a path through the soft tissue and enter the medullary canal. Then remove the reamer. Protect the soft tissues.

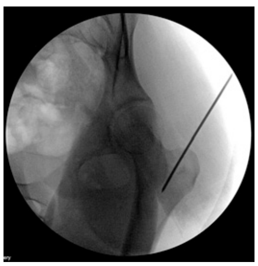

Fig. 4-A

Fig. 4-B

Figs. 4-A and 4-B Anteroposterior (**Fig. 4-A**) and lateral (**Fig. 4-B**) fluoroscopic views showing percutaneous insertion of a 2.4-mm pin into the medullary canal through the tip of the greater trochanter.

Step 5: Preparation of the Medullary Canal and Insertion of Rotational Markers

Ream the medullary canal of the intact bone over a guidewire; mark the rotation before the osteotomy is complete (Figs. 5-A and 5-B).

- Insert a ball-tipped flexible guidewire into the medullary canal in an antegrade direction to the distal part of the femur.
- Ream the canal with cannulated flexible reamers to the intended distance of the nail length.
- The drill-holes for the osteotomy will vent the canal and decrease intramedullary pressure even though an intact bone is being reamed. In addition, bone fragments created by the reaming will extrude from the vent holes and serve as bone graft.
- The resistance and cortical chatter perceived during reaming will help to determine the optimal nail diameter that should be used. Ream the canal about 2 mm greater than the nail diameter to allow enough room for the nail to glide during the distraction. As the lengthening nail is currently available in diameters of 8.5, 10.7, and 12.5 mm, the canal must be reamed to 10.5, 12.5, and 14.5 mm, respectively.
- Use sharp reamers and start with a sufficiently small diameter based on a measurement of the radiograph. Start with a 6-mm pediatric flexible reamer in small-diameter bones.
- While the bone is intact, mark the original rotational alignment by inserting Steinmann pins into the proximal and distal segments—i.e., proximal and distal to the osteotomy.
- Insert the proximal pin into the posterior aspect of the proximal part of the femur at the level of the lesser trochanter and posterior to the track of the intramedullary nail. Insert the distal pin into the distal part of the femur beyond the anticipated tip of the nail. These two pins should be placed either parallel in the same rotational alignment or with a divergence equal to the intended rotational deformity correction.

Fig. 5-A

Fig. 5-B

Fig. 5-A A cannulated reamer is used to open the medullary canal. The transverse Kirschner wire is a rotational marker placed posteriorly, out of the path of the nail.

Fig. 5-B A flexible guidewire is inserted and the canal is reamed with flexible reamers. In this case, there was substantial cortical chatter with the 10.5-mm reamer. The surgeon discontinued the reaming, and an 8.5-mm nail was chosen for insertion.

Step 6: Insertion of the Nail, and Part 2 of the Osteotomy

Insert the internal lengthening nail in an antegrade direction up to the osteotomy location, complete the osteotomy, and pass the nail across the osteotomy site (Figs. 6-A through 6-F).

- Remove the flexible guidewire (as the nail is solid), and insert the intramedullary nail in an antegrade direction up to the osteotomy location.
- With the tip of the nail about 1 cm proximal to the osteotomy drill-holes, complete the osteotomy using a 7-mm sharp osteotome with a hexagonal handle that can be rotated with a 13-mm wrench. With multiple multiplanar passes and rotation of the osteotome, try to achieve a transverse osteotomy without propagation in an oblique direction. Also try to avoid displacing the osteotomy.
- Pass the nail tip across the osteotomy site. The typical deformity that occurs through the osteotomy is varus and flexion, so counter this by lifting the leg and producing a valgus force.
- Advance the nail into the distal fragment and until the proximal part of the nail is just flush or buried by a few millimeters in relation to the proximal end of the bone.
- Rotate the cut bone around the nail to confirm that the osteotomy is complete.
- Align the rotational wire markers, as planned according to their insertion, to avoid unwanted rotational deformity or to correct preoperative deformity.
- With passage of the nail, the diaphyseal deformity and/or the natural anterior bow of the femur will be straightened. The internal lengthening nail is straight, without the anterior bow that is typical of standard intramedullary nails.

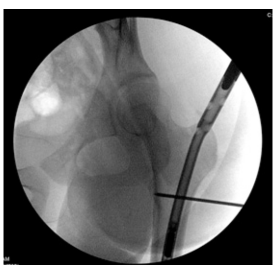
Fig. 6-A

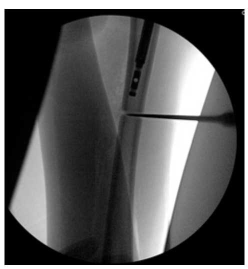
Fig. 6-B

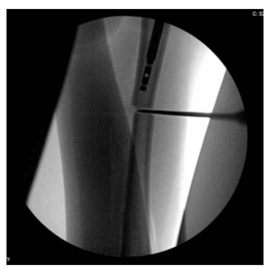
Fig. 6-C

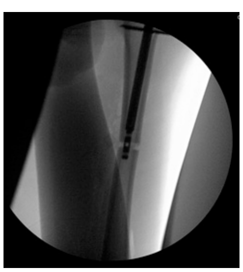
Fig. 6-D

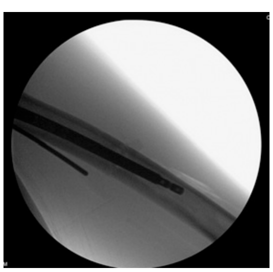
Fig. 6-E

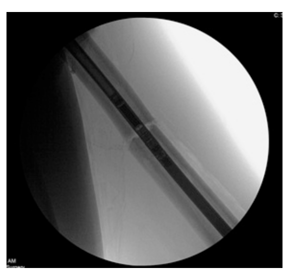
Fig. 6-F

Fig. 6-A The rotational markers are inserted out of the path of the nail. The proximal marker is posterior in the femur, at the level of the lesser trochanter. The nail is then inserted.

Fig. 6-B Anteroposterior view: the nail is inserted up to the osteotomy site, and then a 7-mm osteotome is used to complete the osteotomy, as seen on this.

Fig. 6-C Anteroposterior view: the osteotomy is completed with an effort to avoid much displacement.

Fig. 6-D Anteroposterior view: the tip of the solid nail is passed across the osteotomy site into the distal fragment

Fig. 6-E Lateral view: the procurvatum requires correction by lifting the leg.

Fig. 6-F Lateral view: the anterior bow is straightened by the nail.

Step 7: Insertion of Locking Screws

Insert proximal and distal interlocking screws (Figs. 7-A, 7-B, and 7-C).

- Insert the proximal interlocking screws using the jig as a guide, and insert the distal interlocking screws using a freehand technique.
- Although the order of insertion of the proximal and distal screws is according to surgeon preference, we prefer to insert the distal interlocking screws first. This allows rotation of the nail by the proximal handle to assist in obtaining perfect circles.
- Make sure that rotation of the segments is correct by checking the position of the rotational markers.
- Proximal interlocking screws are easily inserted with the assistance of the jig while making sure to avoid unwanted rotational deformity.

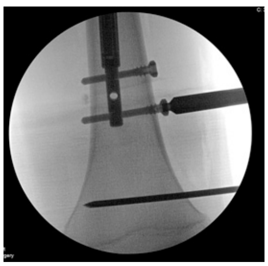

Fig. 7-A

Fig. 7-B

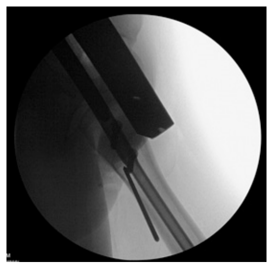

Fig. 7-C

Fig. 7-A Anterorposterior view: insertion of distal interlocking screws. Note the rotational marker in the distal part of the femur.
Fig. 7-B Anteroposterior view: insertion of proximal interlocking screws. Note the rotational marker in the posterior part of the femur, at the level of the lesser trochanter.
Fig. 7-C The rotational marker is posterior to the intramedullary nail. The lateral view confirms proper location of the locking screws through the intramedullary nail.

Step 8: Release of the Iliotibial Band

To prevent knee stiffness, release the iliotibial band through a 3-cm lateral incision, which is usually made by connecting the two stab wounds created for the distal interlocking screws.

- Expose the iliotibial band by dissecting the superficial soft tissue.
- Make a 1-cm transverse incision.
- Use curved Mayo scissors to transversely incise the iliotibial band in an anterior direction as it becomes confluent with the anterior fascia of the thigh.
- Then incise the iliotibial band transversely in a posterior direction until the lateral intermuscular septum is reached.
- Observe the foot for involuntary movement to make sure that there is no unwanted pressure or contact with the peroneal nerve.

Step 9: Marking the Magnet Location

Mark the magnet location in the implant on the skin to enable use of the remote control (Figs. 8-A and 8-B).

- Using a magnified anteroposterior C-arm image centered over the magnet in the nail, identify the center of the magnet with a long wire and mark it on the anterior aspect of the thigh.
- Also mark the orientation of the nail on the skin as a line pointing to the knee.
- The remote control device is a rotating magnet with a footprint of 13 × 9 cm. Mark this footprint on the anterior thigh skin, around the magnet point in the implant.
- Use a permanent (Sharpie) marker to maintain these important landmarks and reinforce the mark at every office visit. The skin position relative to the femoral target will not change substantially over time.

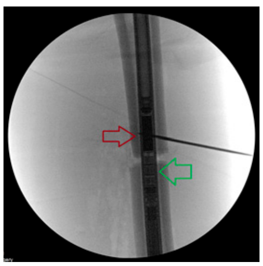

Fig. 8-A

Fig. 8-B

Fig. 8-A The location of the magnet (red arrow) is determined with a Kirschner wire and marked on the skin with a permanent (Sharpie) marker. Distal to the magnet is the gear box (green arrow).
Fig. 8-B The remote control is placed on the footprint drawn on the anterior aspect of the thigh and is pointed toward the knee (smiley face).

Step 10: Postoperative Care

Postoperative management entails limited weight-bearing, distraction, and range-of-motion exercises (Figs. 9-A through 10-D).

- Maximum weight-bearing, which is determined by the nail diameter, is limited to 30 lb (13.6 kg) for an 8.5-mm nail, 50 lb (22.7 kg) for a 10.7-mm nail, and 70 lb (31.8 kg) for a 12.5-mm nail until three of the four cortices have consolidated.
- On postoperative day four, distraction is started with the remote control, which is programmed for antegrade lengthening at the desired rate. The lengthening rate is 0.33 mm four times per day for four days, after which it is decreased to 0.33 mm three times per day. The distraction is done by the patient at home.
- The remote control is positioned in the footprint drawn on the anterior aspect of the thigh, pointed toward the knee, and is turned on. It takes two minutes and twenty seconds to achieve 0.33 mm of lengthening, after which the lengthening automatically stops (Fig. 8-B). The small amount of lengthening is not painful to the patient.
- Physical therapy is directed toward restoring the range of motion of the knee and hip. Active and passive motion and stretching exercises are used daily. The most important exercises focus on maintaining knee flexion and hip extension.


Fig. 9-A


Fig. 9-B

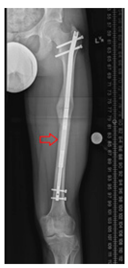
Fig. 10-A

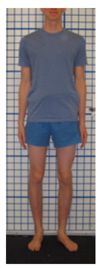
Fig. 10-B


Fig. 10-C


Fig. 10-D

Figs. 9-A and 9-B Standing radiograph and clinical photograph of a seventeen-year-old boy with a limb-length discrepancy of 45 mm.

Fig. 10-A Anteroposterior radiograph showing a well-healed femur with 45 mm of lengthening. Note the distraction of the nail (red arrow) and the 25-mm magnification marker (round ball just lateral to the thigh).

Fig. 10-B Photograph showing equalization of limb lengths.

Figs. 10-C and 10-D Anteroposterior (**Fig. 10-C**) and lateral (**Fig. 10-D**) radiographs of the femur after removal of the lengthening nail.

Results

Femoral lengthening with the remote-controlled magnetic intramedullary nail has had excellent clinical efficacy[1]. At the time of writing, we had performed seventy-five femoral lengthening procedures. We reported our experience with our first twenty-four patients[2], in whom the lengthening averaged 35 mm (range, 14 to 65 mm). The accuracy of the lengthening, determined by comparing the distraction performed with the remote control device with the bone lengthening measured on radiographs, was 96%. Correction of angular and rotational deformity was successful, and unwanted change in bone alignment during lengthening was minimal. A temporary loss of 1° (range, 0° to 5°) of knee extension and 8° (range, 5° to 30°) of knee flexion was observed during femoral lengthening. This resolved, with physical therapy, within a few months in all patients, who then had a normal range of motion. The lengthening goal was achieved for all patients. There was one implant failure, caused by a nonfunctional distraction mechanism, that required implant removal and insertion of a new nail. There was one premature consolidation that required a repeat osteotomy. There were no cases of nonunion.

Pitfalls and Challenges

- Avoid propagation of the osteotomy, as that could compromise the ability of the nail to provide adequate support and could lead to unwanted deformity.
- If the nail does not fill the diameter of the bone at the osteotomy site, there will be a tendency for bone deformation during lengthening. In the femur, this deformity is typically varus and procurvatum (angulation apex anterior), which can be prevented with blocking screws placed in the concavity of the anticipated deformity. While this is not usually an issue with the antegrade technique, since the osteotomy is typically diaphyseal, it is very relevant to the retrograde technique.
- Avoid displacement of the osteotomy site prior to passage of the nail. With a solid nail, a guidewire cannot be used.
- Avoid incomplete osteotomy. Rotation of the bone around the nail prior to locking is a good way to finish the osteotomy and confirm that the osteotomy is complete. However, if the osteotomy is not advanced far enough, rotation around the nail can propagate the osteotomy.
- Avoid rotational deformity by using rotational markers.
- Avoid heat necrosis by using sharp drills and reamers and by not overreaming the bone more than necessary.
- Overream the bone by 2 mm to avoid impingement of the nail.
- Avoid premature consolidation by beginning distraction on postoperative day four at a rate of 1.33 mm/day for four days and then slowing the rate to 1 mm/day.
- Avoid nonunion and premature consolidation by checking radiographs every two weeks and adjusting the rate of distraction on the basis of the bone formation. For example, hypertrophic bone formation in a young person may be addressed by increasing the rate of distraction. Atrophic bone formation in an older patient may be addressed by slowing the rate of distraction.
- Avoid an unstable construct by using the largest-diameter nail needed to fill the medullary canal and by making sure that at least 5 cm of the thick part of the nail has been placed in the distal (moving) fragment at the end of distraction.
- Avoid excessive intramedullary reaming when inserting an oversized nail as this may impair bone healing.

S. Robert Rozbruch, MD
Austin T. Fragomen, MD
Limb Lengthening and Complex Reconstruction Service, Hospital for Special Surgery, New York, NY

E-mail address for S.R. Rozbruch: RozbruchSR@hss.edu

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