

SURGICAL TECHNIQUES

LENGTHENING OF THE FEMUR WITH
A REMOTE-CONTROLLED MAGNETIC
INTRAMEDULLARY NAIL:
RETROGRADE TECHNIQUE

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

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Introduction

Femoral lengthening with an intramedullary nail inserted through a retrograde approach offers the unique benefit of accurate deformity correction and distraction osteogenesis without the need for external fixation with its inherent challenges.

Femoral lengthening using the internal lengthening nail is performed with either an antegrade or retrograde approach. We believe that the preferred technique for internal femoral lengthening is with an antegrade approach utilizing either a piriformis fossa or greater trochanteric starting point, which we described in an earlier article¹. However, in the setting of a distal femoral deformity, the retrograde technique provides a great deal of flexibility for deformity correction and lengthening. The retrograde approach allows for an accurate and stable acute correction of any existing distal femoral deformity when the osteotomy is done at the time of nail insertion. This technique is appropriate for patients with closed growth plates.

After the femoral alignment is corrected, the retrograde nail is locked statically into the distal fragment both with locking screws and with additional blocking screws, ensuring that the newly corrected distal alignment does not change during the lengthening process. The lengthening then occurs as the nail slides through the proximal femoral segment. The accuracy of nail placement into the distal fragment and the control of the fragment during distraction achieved with a retrograde nail would be hard to reproduce with an antegrade nail. The nail is removed once the regenerate bone has healed fully (Video 1).

Video 1 Animation of the retrograde nailing technique.

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Indications & Contraindications

Indications

- A skeletally mature patient.
- A distal femoral deformity that requires correction. When an osteotomy is planned distal to the isthmus of the femur, then a retrograde approach provides great control of the distal femoral fragment. A distal femoral deformity is particularly well suited to osteotomy near the apex of the deformity and retrograde nailing.
- Avoiding an obstacle in the proximal part of the femur is another good reason for “going retrograde.” (This obstacle could be proximal hardware or a hip prosthesis [which could be retained in situ by using a short, retrograde lengthening nail], an implanted nerve stimulator or bladder stimulator that could be affected by the external magnet, excessive buttock fat in some obese patients, or a proximal femoral deformity that would make antegrade nail insertion excessively difficult or impossible.)

Contraindications

- A skeletally immature patient with an open distal femoral physis.
- Femoral osteomyelitis.
- A narrow femoral canal.
- A poor surgical host.
- A total knee prosthesis on the ipsilateral side.
- A long-stemmed total hip prosthesis.
- Osteoporosis or metabolic bone disease that will not allow for adequate locking screw purchase in the bone.
- Distal femoral hardware that the surgeon does not want to remove.
- Distal femoral deformity or canal blockage that the surgeon does not want to correct.
- Use of a proximal tibial ring fixator is *not* a contraindication. (Specifically, the use of a circular external fixator on the ipsilateral tibia with aluminum rings placed just distal to the knee has had no effect on the mechanics of a magnetic lengthening retrograde nail.)
- A previous lengthening with external fixation may be a relative contraindication. Anecdotal evidence indicating that previous external fixation causes deep infection during subsequent internal lengthening is surfacing. The surgeon should consider a preoperative magnetic resonance imaging (MRI) scan and serum infection marker analysis before proceeding with internal lengthening surgery.

Step 1: Planning the Deformity Correction and Nail Insertion

The key to a successful deformity correction and proper nail placement is preoperative planning.

- Find the apex and magnitude of the deformity on a preoperative standing (51-in; 130-cm) radiograph (Figs. 1 through 6). A magnification marker needs to be used for accurate planning.
- Consider a computed tomographic (CT) version study of the lower extremity if a rotational deformity is suspected.
- Choose a level for the osteotomy and measure the distance to the joint line.
- Template the path of an intramedullary nail that will achieve the desired correction (Fig. 7).
- Make a 36-in (91-cm) lateral radiograph of the femur to assess the sagittal bowing and to help in determining the optimal length of the straight lengthening nail as it will not pass through the curved section of the femur. Decide between a curved or a straight distal nail shape based on surgeon preference (Fig. 8).
- Measure the canal diameter on anteroposterior and lateral radiographs to select the width of the nail, keeping in mind that the canal will need to be overreamed by at least 2 mm. How much to ream has been debated. The consensus is that 5 mm of cortex needs to be maintained circumferentially after reaming. The diameter of the nail to be used is therefore calculated by measuring the outer diameter of the bone and subtracting 10 mm (5 mm for each cortex). An additional 2 mm must be subtracted for the intended overreaming; thus, the outer diameter minus 12 mm equals the nail diameter. A thinner nail can be used as well. Alternatively, the inner diameter of the bone can be measured and the closest larger nail size can be used, provided that it leaves 5 mm of cortex circumferentially. Therefore, if the inner diameter of the canal measures 10 mm, a 10.7-mm nail can be used safely. A 12.5-mm-diameter nail could also be used if the outer diameter of the bone is 24.5 mm ($12.5 + 12$ mm). The larger nail would require reaming the 10-mm canal to 14.5 mm; the appropriate amount of reaming is the surgeon's choice.
- Select a length for the nail (Figs. 9 and 10). We use a formula to calculate the minimum length that the nail needs to be. This includes adding the length of the tip of the nail (3 cm), the length of the thicker part of the nail that needs to be in the proximal fragment at the completion of lengthening (5 cm), and the amount of lengthening planned (in centimeters). The sum of these numbers equals the length of the nail needed proximal to the osteotomy site for a retrograde nail. The distance from the osteotomy site to the nail insertion site at the knee is then added to render the minimum total nail length. A longer nail can be used, but one must realize that the proximal femoral sagittal bow can be an obstacle. A retrograde nail that ends distal to this bow is recommended. Most of the nails allow for 8 cm of lengthening. However, the newer short nails only have 3 to 5 cm of length available. This needs to be checked prior to surgery.
- Template the position of the blocking screws to ensure proper nail orientation in the distal end of the femur. The blocking screw needs to be placed in the concavity of the deformity. It should not be closer than 1 cm to the osteotomy site. The further away it lies from the osteotomy site, the less powerfully it controls alignment. The screw must allow enough room for the intramedullary nail to pass between the screw and the cortex. The position of the screw is measured on the radiograph and is then reproduced in the operating room under fluoroscopy. Typically, a blocking screw is used in the distal fragment since it is more challenging to control. However, the proximal fragment can also require a blocking screw. The need for a proximal blocking screw requires a judgment call from the surgeon. If there is enough space in the proximal fragment to lose the correction during lengthening, then the additional blocking screw should be used (Video 2).
- Order the magnetic lengthening nail from the company. It is advisable to have other possible sizes available in the operating room in the event that the planning is not as accurate as anticipated.
- A similar alternative planning technique for retrograde intramedullary nailing with deformity correction and lengthening has been described by Baumgart².

- A proper operating-room setup will ensure a smooth operation. A flat Jackson table is best for this procedure. The patient is placed supine. A bump should be placed under the ipsilateral buttock to ensure the ability to obtain a lateral fluoroscopic image of the proximal part of the femur.
- In addition to the nail set, the surgeon will need Steinmann pins (>4 mm) or half-pins (5 to 6 mm), titanium 5-mm blocking screws, flexible reamers (or rigid reamers), a femoral distractor (or standard pin-to-bar external fixator set), a sterile goniometer and ruler, a large bump or radiolucent triangle, a large C-arm fluoroscopy unit, and a preoperative plan visible in the operating room. A tourniquet is optional.

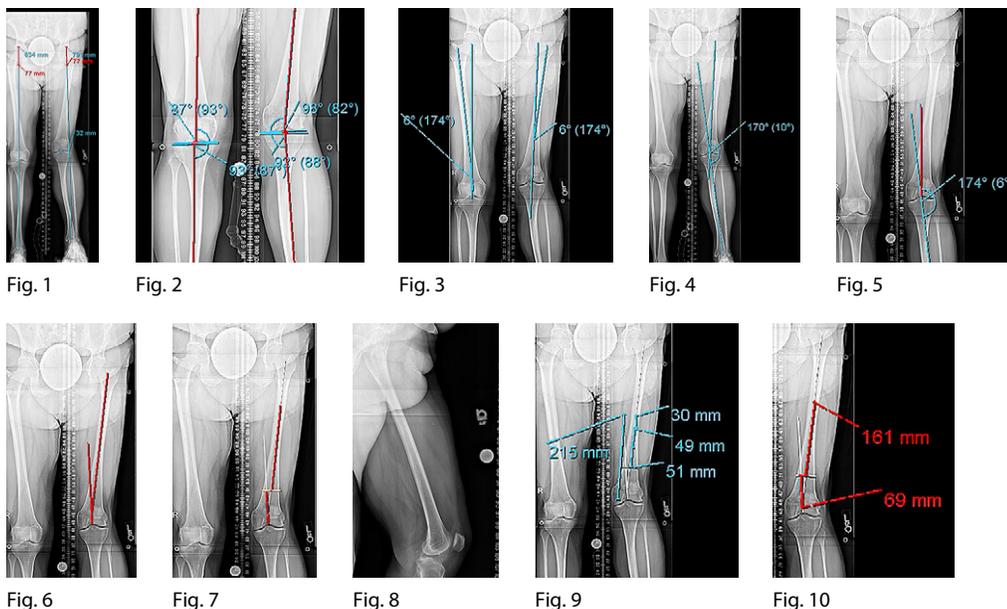


Fig. 1 This 51-in (130-cm) anteroposterior radiograph shows the patient standing on a 2-in (5-cm) block with a level pelvis. The distance measured from a horizontal line on the radiograph to the superior aspect of the femoral head is equal (77 mm) on either side, confirming a 2-in limb-length discrepancy. The mechanical axis deviation (MAD) is 32 mm lateral, indicating a valgus deformity at the knee.

Fig. 2 An anteroposterior radiograph showing the measurements of the joint orientation angles, which indicate the femur as the source of the valgus deformity. The lateral distal femoral angle on the right side is 93°, while the same angle on the left is 82°, indicating a discrepancy of >10°.

Fig. 3 The anatomic-mechanical variance is measured on the right side (6°) and recreated on the left side to establish the proximal femoral axis.

Fig. 4 The distal femoral mechanical axis is located by extending the tibial axis line proximally. This establishes the magnitude (10°) and location of the CORA (center of rotation of angulation).

Fig. 5 This mechanical axis planning is then translated into anatomic axis planning. This new line is drawn 6° more valgus than the mechanical axis.

Fig. 6 A mid-diaphyseal line is drawn in the proximal part of the femur. The angle between the mechanical axis and the mid-diaphyseal line should be the desired correction of 10° with a center of rotation of angulation at the same or similar location.

Fig. 7 An osteotomy site is selected. The osteotomy needs to leave a large enough distal femoral fragment that the nail can control it. The osteotomy is not at the center of rotation of angulation, so translation is needed to correct the deformity.

Fig. 8 A lateral radiograph of the femur allows for preoperative planning.

Fig. 9 The length of the nail is planned. Measuring from the osteotomy site proximally, 51 mm of the thick section of the nail needs to remain in the canal, 49-mm lengthening is planned, and the tip of the nail is 30 mm long. Therefore, 130 mm of nail is needed proximal to the osteotomy site. The shortest nail, measuring from the femoral notch, that will extend 130 mm beyond the osteotomy site, is a 215-mm-long nail.

Fig. 10 A 230-mm nail is the next size after 215 mm and was templated on the radiograph.

Video 2 Preoperative planning for blocking screws.

Step 2: Insert the Rotation Marker Pins and Blocking Screws

Insert 2 Steinmann pins or half-pins into the proximal and distal aspects of the femur to mark any rotational deformity that is being corrected or to ensure that no rotational deformity is created (Fig. 11-A). The Steinmann pins need to be ≥ 3 mm in diameter to prevent bending with loss of rotational reference. We prefer 5-mm or 6-mm Schanz pins for this role. These sturdy pins may be used as a “joystick” for manipulating the distal fragment to achieve a correction.

- Insert the distal pin in the distal aspect of the femur posterior to the path of the nail. A cannulated technique can be used to insert the half-pin by first inserting a small wire into the ideal position and then overdrilling it. This ensures a well-placed half-pin (Fig. 11-B). Although this is a 2-step procedure for half-pin insertion, it is more reliable than trying to insert the pin in 1 step (Video 3).
- Insert the proximal pin at the level of the lesser trochanter bicortically. The nail will not reach this proximal a level so the pin can block the canal.
- When inserting the second pin, check the rotation with respect to the first pin. Use a goniometer to precisely mark the amount of rotation to be corrected. If correcting rotation, then angle the pin at the degree of the desired correction. If no rotation is to be corrected, then simply orient the pin parallel to the first pin.
- Consider placing these pins in a slightly posterior and lateral direction to prevent interference with the locking screw targeting device.
- Connect the femoral distractor to the pins, if desired. This can be done just prior to the osteotomy as well.
- Blocking screws are often needed to prevent loss of a deformity correction or to prevent the introduction of a new deformity during lengthening. When correcting a deformity, use the blocking screws to guide the reamer toward the correct path (Video 4).
- Measure the osteotomy site location from the joint line with the sterile ruler.
- Find the ideal blocking screw position under fluoroscopy on the basis of the preoperative planning.
- Make a stab incision, and predrill the screw-hole near the cortex.
- Check the drill position on fluoroscopy and then drill the far cortex (Video 5).
- Measure and insert the blocking screw (Video 6).



Fig. 11-A



Fig. 11-B

Figs. 11-A and 11-B Photograph and radiograph showing the placement of half-pins. **Fig. 11-A** Two half-pins are used to mark rotation and provide handles for deformity reduction. **Fig. 11-B** The distal pin is seen posterior to the medullary canal and out of the path of the nail.

Video 3 Placement of the distal rotation marker pin.

Video 4 PRECICE: retrograde nail technique. The PRECICE nail is manufactured by Ellipse Technologies.

Video 5 Insertion of the first blocking screw.

Video 6 Insertion of the second blocking screw.

Step 3: Prepare the Distal Fragment

This step includes the approach to and reaming of the distal fragment, which is critical to the limb alignment.

- Place a large sterile bump or radiolucent triangle under the knee.
- Make a medial parapatellar or transpatellar tendon incision.
- Incise the fat pad until the condylar cartilage is easily palpated. Creating this track allows for ease of removal of the reaming debris from the area.
- Insert the sharp guidewire into the wound and lay it against the intercondylar notch.
- Use anteroposterior and lateral fluoroscopic images to find the center of the notch.
- With the fluoroscopy unit in a lateral position, adjust the height of the knee bump until the guidewire is equidistant between the distal pole of the patella and the tibial tubercle. This ensures that the reamer will not disturb either.
- Aim the guidewire in the desired direction on the basis of the preoperative planning.
- Pass to the desired side of the blocking screw and stop just proximal to the planned osteotomy site.
- Use the starter reamer to open the canal (Fig. 12).
- Change to the ball-tipped guidewire.
- Perform sequential reaming of the distal fragment, overreaming by ≥ 2 mm. For example, for a 10.7-mm nail, ream to 13 mm, and for a 12.5-mm nail, ream to 14.5 mm.



Fig. 12

Fig. 12 The acorn reamer is seen traveling along the desired path to the medial side of the blocking screw.

Step 4: Osteotomy

Perform the percutaneous osteotomy, which allows for correction of the deformity, prior to reaming the proximal segment.

- Find the osteotomy site and make a small lateral incision down to bone.
- Bring the fluoroscopy unit into the operative site in the anteroposterior position.
- Using a drill sleeve and a 4.8-mm drill, drill the femur in 1 plane with multiple drill passes. This will perforate the femur, encouraging it to crack in a transverse orientation.
- Using a 7-mm osteotome, finish the corticotomy (Fig. 13).
- Manipulate the limb into the correct alignment. The rotation markers may be used to assist with this. If thin wires were used to mark rotation, they will bend easily and should not be touched. If half-pins were used, they can be manipulated and included into a femoral distractor to maintain the corrected alignment (Fig. 14).
- Attach the femoral distractor or external fixator, if desired (Fig. 15).



Fig. 13

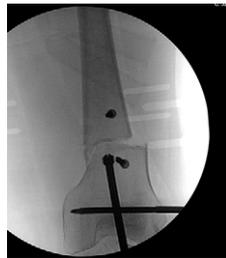


Fig. 14



Fig. 15

Fig. 13 The second blocking screw has been placed, the drill-holes for the osteotomy have been created, and the osteotome is inserted to complete the osteotomy. Note that a proximal blocking screw was added to prevent recurrence of the valgus during lengthening.

Fig. 14 The osteotomy is complete and the reduction is performed. Reaming of the proximal fragment can start.

Fig. 15 The rotation marker pins are seen with the attached external fixator, which helps to ensure maintenance of the reduction during final reaming.

Step 5: Prepare the Proximal Fragment

While holding the distal fragment in the reduced position, prepare the proximal fragment for nail insertion.

- Insert the ball-tipped guidewire and ream through the distal fragment, across the osteotomy site, and into the proximal part of the femur.
- Perform sequential reaming until dilating the canal 2 mm over the desired nail diameter. This is our recommendation for flexible reamers. At times it is necessary to ream a further 0.5 mm in order to allow for atraumatic passage of the nail.
- Ensure that there is no loss of reduction at the osteotomy site during reaming as the nail will follow the path of the reamer.
- Clean out the wound with irrigation to ensure that no reaming debris remains in the joint.

Step 6: Nail Insertion

Insert the nail in a standard fashion, avoiding excessive force that could damage it or jam it into the proximal fragment.

- Attach the nail to the insertion jig and wiggle it down the canal by hand (Video 7).
- A mallet can be employed to gently tap the nail into the final position.
- If the nail requires strong blows with the mallet, check that it is not stuck at the osteotomy site. If it will still not pass, remove the nail and overream by 0.5-mm increments, reattempting nail insertion each time until it goes in easily.
- Ensure that the distal end of the nail is buried under the articular surface on the lateral image.
- At this point, the deformity is corrected and the nail is holding the correction. It is difficult to assess the accuracy of the correction with fluoroscopy. An electrocautery cord can be used to estimate the mechanical axis. Compare the alignment with the preoperative planning. If the surgeon thinks that the correction is not ideal, then the Schanz pins can be used to manipulate the alignment prior to inserting the locking screws. The overreaming creates a loose fit with some space for correction even after nail insertion. Once the locking screws are inserted, no changes can be made to the alignment.

Video 7 Insertion of the intramedullary nail.

Step 7: Lock the Nail

Lock the nail from the distal or proximal end first. The femoral distractor helps to keep the rotation accurate during locking and helps to serve as a handle to obtain perfect overlapping circles of the locking screw site on fluoroscopy. However, the external fixator may be obstructive for distal locking in particular. The fixator can be removed for distal locking and reattached for proximal locking (Video 8).

- Using the distal targeting jig, lock the nail from lateral to medial.
- Tap the smooth screws into the drill-hole and then screw the threads into the near cortex (Video 9).
- Ensure that the screws are bicortical. “Better too long than too short.” A screw that does not engage the far cortex will not provide the support needed for the nail to lengthen the bone (Fig. 16-A).
- Check rotation again using the marker pins (Video 10).
- Lock the femur proximally, typically by removing the targeting guide and laying the leg flat.
- The anteroposterior screw can be inserted first, but this is the surgeon’s choice.
- Use the fluoroscope to obtain perfect circles of the locking screw site within the nail, and make a small anterior incision through skin and muscle fascia. Spread the tissues and predrill.
- Check that the drill-bit has passed through the locking hole and then insert the locking screw. Again, this needs to be bicortical so check a lateral image as well.
- Insert 1 of the sagittal screws from lateral to medial using perfect circles.



Fig. 16-A

Video 8 Overview of the setup with the external fixation detached for distal locking.

Video 9 Screw insertion into the intramedullary nail.

Figs. 16-A, 16-B and 16-C Insertion and locking of the nail and the placement of blocking screws. **Fig. 16-A** The nail is inserted and locked. The blocking screws prevent deformity during lengthening.

Video 10 Checking rotation with the marker pins prior to locking.

Step 8: Final Blocking Screws

Check the anteroposterior and lateral fluoroscopic images and decide how stable the nail is in the bone. Will the fragment shift into varus, valgus, or flexion?

- Another medial or lateral blocking screw may be needed to prevent deformity during lengthening. Now is the time to place this screw. If the nail is touching the cortex, then it cannot shift toward that direction, and the cortex acts as a blocking screw.
- Place a posterior blocking screw. The distal end of the femur tends to flex during lengthening. If there is a space between the nail and the posterior cortex, then insert a blocking screw close to the osteotomy site. If a straight retrograde nail is used, it tends to sit against the posterior cortex at the osteotomy site, making it unnecessary to use a posterior blocking screw (Figs. 16-B and 16-C).
- Remove the rotation markers.
- Irrigate and close the wounds.



Fig. 16-B

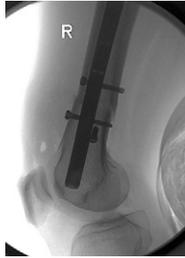


Fig. 16-C

Fig. 16-B The intramedullary nail is pressed against the posterior cortex of the distal fragment at the osteotomy site. This fragment cannot go into flexion as it lengthens and therefore does not require a blocking screw. **Fig. 16-C** In this example, there is space between the intramedullary nail and the posterior cortex of the distal fragment at the osteotomy site. The distal fragment could bend into flexion during the lengthening. This patient required a blocking screw to prevent a flexion (procurvatum) deformity.

Step 9: Mark the Magnet and Test the Nail

Mark the position and orientation of the magnet in the nail on the patient's skin to indicate where to place the external magnet for lengthening.

- Bring the fluoroscope into an anteroposterior position and find the magnet.
- Mark the proximal and distal positions on the skin with a marking pen (Fig. 17).
- Mark the direction of the magnet.
- A large, loose stitch can also be used to identify the position.
- Wrap the external magnet in a sterile bag and bring it into the sterile field to ensure that the internal magnet in the nail is functioning.
- Program the external magnet for 1 mm of length.
- Place the external magnet in the sterile bag over the area marked on the skin.
- Press start and hold for approximately 7 minutes while the nail extends.
- Make a fluoroscopic image to ensure that the rod has extended 1 mm.



Fig. 17

Fig. 17 A wire is used to mark the position of the magnet under fluoroscopy.

Step 10: Postoperative Care and Lengthening

Postoperative management involves nail distraction, venous thromboembolic (VTE) prophylaxis, and adherence to a specific weight-bearing protocol.

- The lengthening process begins on postoperative day 4 at 0.33 mm 4 times per day for 4 days.
- The lengthening rate is then slowed to 0.33 mm 3 times a day for the duration of the lengthening process (Figs. 18-A and 18-B).
- VTE prophylaxis begins on postoperative day 2 and continues for a duration of 2 weeks. The use of tranexamic acid does not change the VTE protocol.
- Patients are allowed partial weight-bearing as per the company protocol (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). Weight-bearing as tolerated is allowed when 2 of 4 cortices are visualized on radiographs.



Fig. 18-A

Fig. 18-B

Figs. 18-A and 18-B Anteroposterior (**Fig. 18-A**) and lateral (**Fig. 18-B**) radiographs of the femur were made during the lengthening process. Note that the blocking screws prevent the loss of alignment.

Results

Femoral lengthening with the remote-controlled magnetic intramedullary nail has had excellent clinical efficacy³. To date, we have performed 24 femoral lengthening procedures. The average distraction was 35 mm (range, 14 to 65 mm), and the accuracy of the distraction was 97%. Correction of angular and rotational deformity was successful, and unwanted change in bone alignment during lengthening was minimal. There was minimal and only temporary loss of knee range of motion. Bone healing has been excellent, with only 2 delayed unions that were successfully treated with exchange nailing. There was 1 implant failure, which involved the first generation of the nail. It was successfully revised. No implant failure has occurred with the new generation of the implant^{3,4} (Figs. 19-A through 19-F).



Fig. 19-A

Fig. 19-B

Fig. 19-C

Fig. 19-D

Fig. 19-E

Fig. 19-F

Figs. 19-A through 19-F A patient managed with femoral lengthening of the left leg with a remote-controlled magnetic intramedullary nail. **Fig. 19-A** An anteroposterior 51-in (130-cm) radiograph, made with the patient standing on a 2.5-cm block, shows a varus deformity of the femur and shortening. The long blue lines indicate the mechanical axis. **Fig. 19-B** The patient is standing on a 2.5-cm block that levels his pelvis. The short blue lines indicate the pelvic and hip height discrepancy. The pelvic height is equal, indicating that the 2.5-cm block is the perfect height for this patient. The hip heights are within 1 mm of the pelvic height, which shows no meaningful iliac wing shortening.

Fig. 19-C Preoperative planning radiograph, made with the patient standing on a block, showed that the osteotomy site (blue line) would be proximal to the center of rotation of angulation, requiring slight translation of the distal fragment medially. **Fig. 19-D** Blocking screws were utilized to prevent loss of the varus correction during the lengthening process.

Fig. 19-E This distraction phase radiograph shows no loss of alignment and a healthy regenerate. **Fig. 19-F** A final standing hip-to-ankle radiograph, made after intramedullary nail removal, reveals a normal mechanical axis and equalization of limb lengths.

Pitfalls & Challenges

Placing the initial blocking screw to direct the reamer in the desired path is a challenge since it requires precisely recreating the preoperative plan in the operating room. Not placing this screw is a pitfall. In many patients, the distal end of the femur contains soft bone. Controlling the direction of the reamer can be impossible without the presence of this screw blocking the unwanted pathway.

When in doubt, use a blocking screw. We have needed to use up to 4 screws in some patients. It is far easier to prevent a deformity than to correct it.

- Be sure that all blocking and locking screws have bicortical fixation.
- There is minimal space between the locking screws and the locking hole in the nail. This is a design feature to improve the fixation of the nail and the screws. The pitfall is that this feature makes placing the proximal free-lock screws difficult.
- Avoid using nails that are too short. A critical amount of the thick portion of the nail needs to remain in the proximal fragment at the end of lengthening to prevent nail bending and deformity. We use 5 cm as a minimum amount.
- Avoid using nails that are too long. A nail that has several inches of the thick section in the proximal fragment will be at higher risk for incarceration and premature consolidation. There may be too much nail that has to slide through the lengthening fragment. Longer nails also tend to get caught in the bow of the femur, causing

them to bend. If a long nail is mandatory, then overream more and consider an osteotomy near the apex of the sagittal femoral curve.

- Pediatric flexible reamers have made the preparation of narrow femoral canals possible by mitigating the damage caused by attempting to force a large starter reamer into a thin canal. This has been particularly useful in young patients with thick cortices and a narrow medullary passage.
- Creating the osteotomy prior to reaming the proximal fragment helps to prevent fat embolism. If the osteotomy is going to be done after reaming, we recommend creating the drill-holes for the osteotomy prior to reaming. These drill-holes serve as vent-holes for the femur. We have performed no more than 2 long-bone intramedullary nail insertions at the same setting. There have been no cases of fat embolism.
- Many authors have championed the use of rigid, straight reamers as a means of avoiding some of these pitfalls². Our experience is with flexible reamers.
- Patients need to be able to follow up in the office every 10 to 14 days. They are examined for contractures, weight-bearing restrictions are reviewed, and the rate of distraction may be modulated on the basis of radiographs made at that visit. The patients may be instructed to increase the frequency of distraction to prevent premature consolidation or to decrease the frequency to avoid a delayed union. By changing the frequency of adjustments, the external magnet does not need to be reprogrammed.
- The use of continuous passive motion early in the postoperative period may be useful in helping patients to regain knee motion rapidly.
- Physical therapy emphasizing knee flexion and hip extension can help to prevent contractures of the quadriceps.
- A limited quadricepsplasty may be needed in cases of knee extension contracture.
- A limited hip flexor release, including fractional lengthening of the sartorius, tensor fasciae latae, and rectus femoris, may be indicated in patients with a hip flexion contracture. Complete release of the long head of the rectus femoris is also an option.
- The cost of the magnetic internal lengthening intramedullary nail is considerable. However, its cost needs to be viewed in context. Before the advent of this technique, limb lengthening was done with the lengthening-over-the-nail method for lengthening femora. This required the use of a nail and an external fixator placed during 1 operation. When the desired length was achieved, the patient needed another operation to lock the nail and remove the external fixator. If a simultaneous deformity correction were to be done, we would often use 2 osteotomies and a custom-made intramedullary nail, further increasing the cost. Although the cost of the internal lengthening nail is greater than the cost of the basic trauma nail and the external fixator (and may be equal to the cost of the custom nail and fixator), the price of the additional operation makes the lengthening-over-nail technique far more expensive. Compared with the lengthening-over-nail technique, the internal lengthening nail saves the patient and insurance company 1 operation. This makes it a cheaper option in the overall treatment plan.
- Removal of these magnetic nails is recommended routinely. Patients are not permitted to have an MRI scan done while the nail is implanted. Nail removal has been uneventful and is an ambulatory procedure with minimal postoperative restrictions. We recommend removing the proximal locking screws first, and retaining 1 distal locking screw in the nail during insertion of the extractor. This will help to prevent pushing the nail further into the canal or rotating the nail during extractor placement.

Austin T. Fragomen, MD¹

S. Robert Rozbruch, MD¹

¹Limb Lengthening and Complex Reconstruction Service, Hospital for Special Surgery, Weill Medical College of Cornell University, New York, NY.

E-mail address for A.T. Fragomen: FragomenA@HSS.edu

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

References

1. Rozbruch SR, Fragomen AT. Lengthening of the femur with a remote-controlled magnetic intramedullary nail: antegrade technique. *JBJS Essent Surg Tech*. 2016 Jan 13;6(1):e2.
2. Baumgart R. The reverse planning method for lengthening of the lower limb using a straight intramedullary nail with or without deformity correction. A new method. *Oper Orthop Traumatol*. 2009 Jun;21(2):221-33.
3. Kirane YM, Fragomen AT, Rozbruch SR. Precision of the PRECICE internal bone lengthening nail. *Clin Orthop Relat Res*. 2014 Dec;472(12):3869-78.
4. Rozbruch SR, Birch JG, Dahl MT, Herzenberg JE. Motorized intramedullary nail for management of limb-length discrepancy and deformity. *J Am Acad Orthop Surg*. 2014 Jul;22(7):403-9.