The Antegrade Femur Technique

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Summary: In this chapter, we examine the antegrade technique of insertion of magnetically controlled intramedullary lengthening implants. We discuss the indications, preoperative planning, surgical technique, and postoperative management, as well as tips and tricks for success.

Key Words: lengthening—antegrade—femur—PRECICE—Stryde.

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INDICATIONS

Shortening of the lower limbs can involve a single bone or multiple segments. It may be associated with other cardinal plane deformities (sagittal, frontal, or axial), and commonly results in a discrepancy of limb lengths. Uncompensated leg length differences of as little as 10 mm are the cause of chronic back pain[1]; greater deformities make orthotic correction challenging. In addition, bilateral shortening can be a severe functional problem for those of significant short stature, and a cause of preventable psychological harm for patients who wish to undergo "cosmetic" stature increase.

Historically, the Ilizarov method of a low impact corticotomy followed by gradual distraction has resulted in the formation of regenerate bone. The process is similar to intramembranous ossification, even though commonly referred to as "callus distraction." The Ilizarov method classically involved the use of external fixator frames, which have been challenging in the femur due to soft tissue tethering and pin-site infections leading to poor tolerance and difficulties with activities of daily living.[2] Conversely, the subcutaneous position of the tibia makes it more amenable to external fixation.

With intramedullary lengthening, however, the reverse is true. Lengthening of the femur is relatively straightforward, whereas the asymmetrical loading of the tibia and the presence of the tibiofibular joints can lead to pitfalls for the unwary and resultant deformities. For this reason, if faced with a shortening of both femur and tibia, often isolated lengthening of the femur is preferred.

The choice of the antegrade versus retrograde route for the insertion of the lengthening device also depends on various factors. Relative indications for selection of the retrograde approach include bilateral simultaneous lengthening, soft tissue thickness proximally of >5 cm (Fig. 1), hip or proximal femoral pathology or prosthesis, and for some deformities requiring realignment the retrograde route is easier. In very narrow femora or those with a gross anterior bow, the relatively wide distal metaphysis may allow the insertion of a short nail that would not fit from an antegrade route.

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The authors declare that they have nothing to disclose.
For reprint requests, or additional information and guidance on the techniques described in the article, please contact David Goodier, FRCS(Orth), at d.goodier@NHS.net or by mail at The Royal National Orthopaedic Hospital, Brockley Hill, Stanmore HA7 4LP, UK. You may inquire whether the author(s) will agree to phone conferences and/or visits regarding these techniques.

Relative theoretical disadvantages of the retrograde route are breaching the cavity of the knee joint and hence potential damage to the patellofemoral articulation, and the potential for leaving bone reamings in the joint where they may act as third body wear particles. The knee joint must, therefore, be thoroughly washed out. Although there is insufficient evidence from the lengthening implant literature, the evidence for retrograde nailing in trauma suggests knee pain may be greater,[3] though conflicting evidence suggests this may be transient.[4] In addition, the position of the corticotomy is usually in the metaphyseal/diaphyseal junction and can deform into varus and procurvatum unless blocking screws are used. The distal nature of the corticotomy also means more stretching of 3 components of the quads muscle group, whereas a subtrochanteric corticotomy leaves them to move distally with the femur. For these reasons, our preferred technique is antegrade whenever possible.

Conversely, lengthening from an antegrade route does not allow as much angular deformity correction, and with sufficient lengthening along the anatomic axis, there will be overall valgus created in the limb. This has been calculated to be 1 degree for every centimeter of length generated, but may not be functionally relevant other than for significant lengthening.[5] The retrograde route also means that the corticotomy is usually at the metaphyseal/diaphyseal junction rather than the diaphysis as in the antegrade route, hence the bone healing index is often shorter.

PLANNING

The radiographic assessment of length has been covered in the previous chapter. Once this has been decided, an appropriate implant can be selected, taking into consideration implant length, implant diameter, corticotomy position and trochanteric versus piriformis fossa insertion.

Intramedullary implants for trauma commonly have an anterior bow to match the 10-degree sagittal plane curvature of the femur. The mechanism for lengthening implants, however, has to be a straight rod, although the end may have an angled

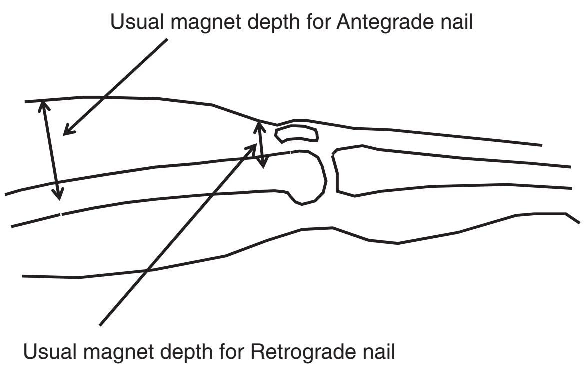

FIGURE 1. Magnet depth antegrade versus retrograde insertion.

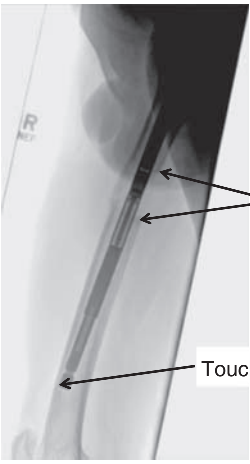

FIGURE 2. Potential anterior cortical impingement.

extension to allow trochanteric entry. This means that care must be taken to not erode (or even perforate) the anterior cortex of the femur, yet preserve the maximum mechanical working length within the femur (Fig. 2).

The combination of nail length and corticotomy level should be calculated such that the stronger barrel of the nail remains across the regenerate gap after lengthening. This avoids potential bending forces at the junction of the barrel and piston end if they are within the soft regenerate. The position of the corticotomy is the choice of the surgeon; a proximal corticotomy in the immediate subtrochanteric region produces excellent regenerate, but at the risk of lack of stability in the proximal fragment allowing it to tip into varus, for which a poller blocking screw may be needed. Conversely, a mid-diaphyseal osteotomy has a greater ratio of cortical to the medullary bone and hence may not produce such good regenerate, but the 3-point fixation accorded by a more distal corticotomy gives greater stability.

Our practice is to plan the osteotomy to be 10 to 12 cm below the lesser trochanter and allow 4 to 5 cm of the nail to be within the distal segment after lengthening. It follows that the amount of required length plus a short distance (in our experience 4 to 5 cm) will allow bridging of the regenerate after lengthening (Fig. 3). A calculation can, therefore, be performed by adding the length of the nail tip (30 mm) plus the desired lengthening in mm plus the amount of nail remaining in intact bone after lengthening is completed (40 to 50 mm). This is the length of the implant that needs to be distal to the planned osteotomy site, and hence once the level of osteotomy is decided, the correct implant length can be determined.

This should then be templated on a lateral view to ensure the anterior femur will not be at risk; if there is too much risk of erosion then a more proximal corticotomy with a shorter nail can be contemplated.

The maximum possible nail diameter should be used, both for the mechanical strength and size of the magnet for more reliable magnetic field interaction. The piston end is narrower than the barrel, so full diameter reaming for the entire nail length is not always necessary. To reduce friction during lengthening, however, it is recommended to over-ream the canal by 2 mm, ensuring at least 5 mm of cortex remain after reaming.

Once the nail size and corticotomy level have been planned, there is the choice of piriformis or trochanteric entry. Trochanteric entry is often easier and involves less dissection through the abductors. It does, however, mean the straight part of the nail will hit the medial cortex of the femur and if the corticotomy is relatively proximal can result in displacement. Piriformis fossa entry conversely enables the nail to run straight down the femur and allows more accurate reaming if rigid reamers are preferred. Piriformis fossa entry is contraindicated in skeletally immature patients to reduce the risk of femoral head avascular necrosis due to damage of the medial circumflex artery.[6]

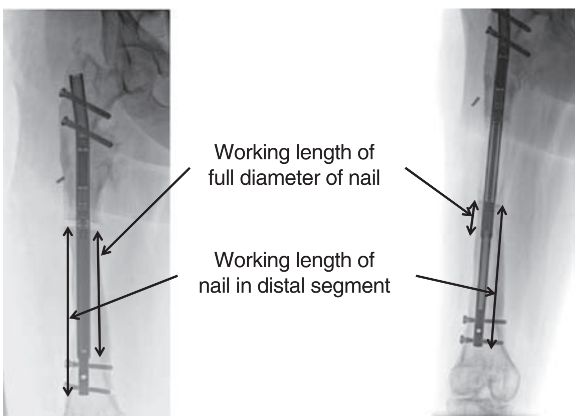

FIGURE 3. Keep barrel within the distal segment after lengthening.

SURGICAL TECHNIQUE

The patient can be positioned lateral, supine, or on traction, with access for an image intensifier, and prepared and draped from the iliac crest to below the knee.

The tip of the trochanter is identified on imaging, as well as the proposed corticotomy site.

A Steinmann pin is inserted either via the piriformis fossa or trochanteric tip, and the cortex breached to allow the insertion of a guide wire. Positioning the pin relatively anterior compared with the position for a trauma nail allows a slightly longer nail to be used if anterior impingement is a concern (Fig. 4).

Before the reaming, the position of the corticotomy is marked. If an intramedullary saw is to be used, then a venting hole should be made to reduce pressure on the marrow, and hence the risk of fat embolism syndrome. If, however, a classic DeBastiani corticotomy is performed, then the cortex is marked with drill holes that should vent the femur sufficiently.

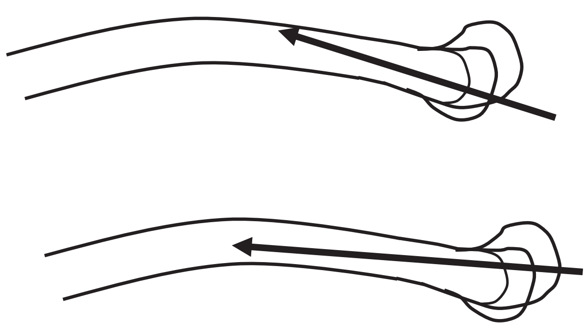

FIGURE 4. More anterior entry point reduces anterior cortical impingement.

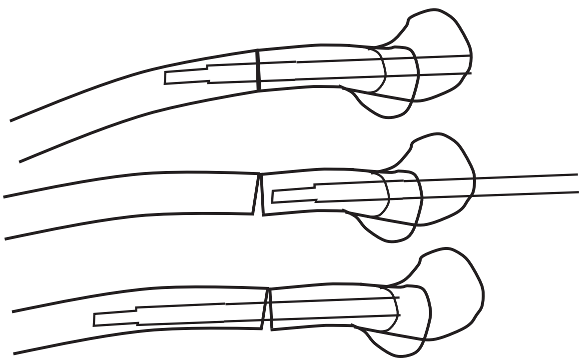

FIGURE 5. Extension of the osteotomy reduces the risk of anterior cortical impingement by creating a "gull-wing" deformity.

If there is a concern that rotational alignment may be lost after corticotomy, then Kirschner-wires may be inserted behind the line of the nail to act as rotational markers. Since the soft tissues may deform a 2 mm Kirschner-wire, if a rotational correction is needed as well as lengthening, then a thicker pin is needed (a 3.2 thread tipped guide pin or 4 mm Steinmann pin in our practice). This can be inserted either before reaming or behind the nail once the proximal part of the nail has been inserted. The distal pin can be inserted beyond the distal extent of the nail.

The femur is reamed to 2 mm more than the nail width, using flexible reamers. If rigid reamers are preferred, it may be indicated to complete the corticotomy first to reduce the risk of anterior cortical impingement (Fig. 5).

With flexible reamers, the osteotomy is not completed until reaming is finished. This results in the extrusion of reamings into the surrounding soft tissues via the drill holes and produces more florid callus than (for example) an intramedullary saw cut or classic Ilizarov osteotomy without drilling. The nail should be inserted to just short of the osteotomy site before completion of the osteotomy to better control any displacement once completed, as the psoas will tend to pull the proximal fragment into adduction, flexion, and internal rotation. If the nail starts to deform the proximal fragment into varus, the nail can be withdrawn and a blocking screw positioned.[7]

Locking proceeds as for standard intramedullary nailing. The PRECICE Intramedullary Limb-Lengthening System (ILLS; NuVasive Inc., San Diego, CA) uses bolts that are threaded only on the lateral cortex; for if the lateral cortex is not drilled to 5 mm then the screws might back out. The Stryde nail has a threaded step-screw bolt which bites into the medial cortex to reduce the risk of loosening (Fig. 6).

After nail insertion, consideration should be given to soft tissue releases. A major source of postoperative tightness is the iliotibial band, which can be released via a separate distal incision at the level of the upper pole of the patella. It is important to divide back to (and if necessary include part of) the intermuscular septum.[8] The release can be performed more proximally but may result in muscle hernia if performed over the tensor fascia lata muscle, though in practice a release through the corticotomy incision more proximally is often sufficient, and has become our routine practice.

Once locking is completed, the wounds can be closed in a standard fashion, and dressings applied.

The magnet position must be identified. With the PRECICE ILLS, the magnet can be identified on the image intensifier view and its location marked on the skin (Fig. 7). With the Stryde nail, the magnet is more difficult to see, but with coning down, magnifying the image, and using the digital radiography setting, it can usually be seen. If not, the magnet position can be measured before insertion from the tip by using any ferrous surgical instrument to identify it, then the ends of the nail marked on the skin and the magnet position marked. It is important to mark both ends of the nail and measure between them to see if there is any relevant magnification.

If desired, a test lengthening can be performed, usually of up to 1 mm. This is often difficult to measure, but the of the rectangle around the bushing changes shape from a 4:1

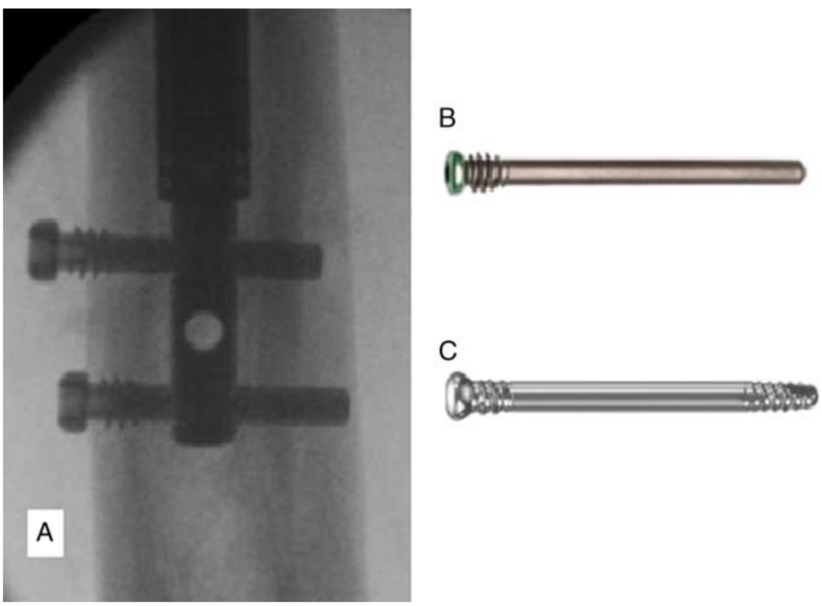

FIGURE 6. A, Backing out of locking bolt. B, PRECICE bolt. C, Stryde bolt.

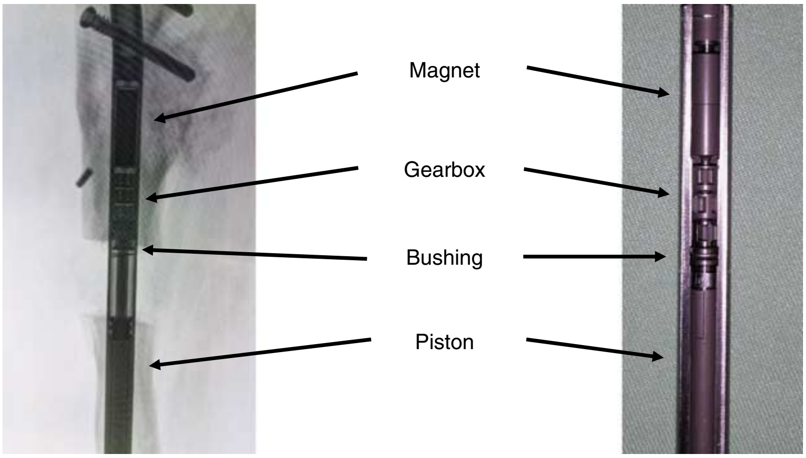

FIGURE 7. Radiologic identification of nail components.

rectangle to a 3:2 rectangle with 1 mm of length, and a change of this shape confirms the mechanism to be working (Fig. 8). The Stryde nail is more difficult to see if lengthening has occurred, but the distance from the crown to the distal locking bolts can be assessed but often needs a minimum of 2 mm to discern a difference. We do not routinely reverse this small intraoperative lengthening and have seen no detrimental effect on callus formation.

POSTOPERATIVE REGIME

Chemoprophylaxis against deep vein thrombosis should be considered in high-risk patients until mobile, and sufficient postoperative analgesia or nerve blocks are needed to allow early mobilization including active and passive range of movement exercises for the hip and knee.

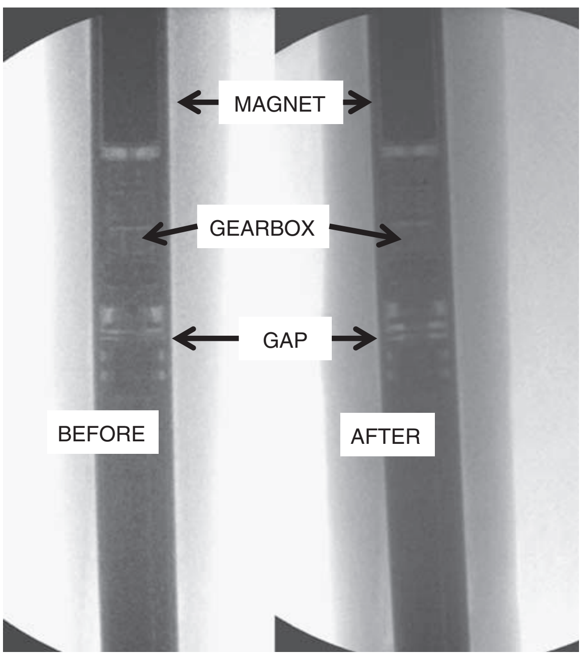

FIGURE 8. Widening of gap more visible as a change in shape rather than an absolute measurement.

Mobilization on the PRECICE ILLS is limited to flat foot partial weight-bearing up to 20 kg. The Stryde implant allows much greater weight-bearing depending on the diameter of the

FIGURE 9. Breakage at the barrel/lengthening segment junction.

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implant: 10 mm will allow 150 lbs (68 kg) maximum weight-bearing, 11.5 mm maximum 200 lbs (90 kg), and 13 mm maximum 250 lbs (114 kg). Caution may be needed, however, since loads when walking may exceed the patient's static body weight.

A latent period of 5 to 7 days is followed by lengthening at a rate typically of 1 mm/d, in increments of 0.33 or 0.25 mm, and adjusted depending on the appearance of the regenerate. It may be slowed if there are other factors that may delay regenerating formation (smoking, anti-inflammatory medication, poor soft tissues, etc.).

Lengthening is accomplished by use of the external remote control unit applied to the marked area, and usually performed by the patient themselves. The external remote control can be programmed to stop once target length has been achieved, or serial x-rays used to judge the length and stopped appropriately.

It is usually recommended that the weight limitations of the implant must be followed until the consolidation of the regenerate occurs on at least 3 cortices on 2 orthogonal radiographic views. The reamings that are extruded from the osteotomy site, however, produce a florid calcific mass that appears more akin to callus formation than classic Ilizarov corticotomy regenerate and earlier weight-bearing may be possible before 3 cortex consolidation. There remains a risk, however, that if the patient takes weight to early, the implant may fail to lengthen, or even break. If this occurs, it is often at the exit point of the piston from the barrel (Fig. 9).

Removal of the implant is recommended; this should not be performed until the regenerate is thoroughly consolidated.

TIPS AND TRICKS AND PITFALLS

Extended indications	Traumatic bone loss	Avoid the temptation to preserve dubious diaphyseal bone, radically debride and shorten, fix with a trauma nail, and exchange later to a lengthening nail (Fig. 10)
	Nonunion	Can excise and acutely shorten nonunion, and once united can exchange to a lengthening nail
	Metaphyseal comminution	As with traumatic bone loss comminution can be debrided and shortened, but a lateral locking plate is often deployed. A proximal lengthening nail can be inserted either simultaneously, or once the union is certain
	Overlapping implants	If a lengthening rod will overlap with a metaphyseal implant, the use of a piriformis fossa entry rod allows it to be rotated such that if can be locked either side of the plate (Fig. 11)
	Using short implants	If abnormal distal bone exists, then short implants can be used in the proximal femur to correct length and rotation. A few degrees of varus can also be corrected by the use of a 10-degree trochanteric implant via the piriformis fossa (Fig. 12)
Surgical technique	Patient positioning	With piriformis fossa entry, access along the line of the femur can prove difficult. If the patient is on a traction table, too much forced adduction can lead to perineal injuries including local numbness and pressure effects on the skin. It is often easier to place the patient in a lateral position to make this easier and screen the insertion with a cross table anteroposterior view
	Transverse locking screws	The very shortest implants have proximal locking screws that run horizontally rather than obliquely and may not get a cortical fix in the femoral neck and can back out. This can be alleviated by rotating the nail and locking anterior to posterior
	Reaming after osteotomy drill holes	The extruded bone acts as a graft to create a florid callus mass, which matures significantly faster than classic Ilizarov corticotomy regenerate and hence earlier weight-bearing
	Rigid reamers	Rigid reamers are not generally needed provided a good quality lateral x-ray is used to template the eventual position of the implant. If there is a tendency to come up against the anterior cortex of the femur with the implant, then erosion of the posterior cortex at the osteotomy site (or even slight comminution of it via the osteotomy incision) is preferable to the erosion of the anterior cortex which can give rise to a stress fracture
	Nail insertion	Nail insertion should not be traumatic—if it is not entering the canal easily, then withdrawal and further reaming may be needed. Hitting it may jam the mechanism and prevent lengthening
		When using poller blocking screws, the rather square end of the PRECICE implant can catch, but the more tapered tip of the Stryde implant alleviates this and is a relative indication to use Stryde
		Blocking screws must be of a similar metal; most intramedullary implants are titanium, so standard titanium intramedullary locking screws can be used; for the PRECICE Stryde implant a stainless steel screw should be used to avoid potential galvanic corrosion
Postoperative	Soft tissue stretching	Stretches should be taught preoperatively where possible, and intensive physio arranged for throughout the lengthening phase
		There is a "honeymoon period" for the first few weeks whereby 2 or 3 cm can be regained with the little apparent problem. Patients (and often their therapist) may not realize that after the "slack" has been taken up, the hamstrings, quads, adductors, and iliotibial band rapidly tighten
		If simple knee flexion is advised as a quads stretch, the rectus femoris can tighten and lead to hip flexion contractures. This is particularly the case in bilateral simultaneous lengthening where the patient may be using a wheelchair to mobilize
	Sciatic nerve	Subtle neurological symptoms should also be asked about and may indicate nerve stretching. Slow, stop or reverse lengthening as appropriate
	Joint subluxation	Congenital shortening may be associated with ligament deficiency in the knee. Brace the knee during lengthening with the knee locked straight other than unlocking a couple of times a day for physio to maintain flexion
		One of the early signs of the subluxation is often central patellar pain; if this occurs then a small amount of backing up of the nail will commonly allow it to settle, and further length at a slower rate is usually successful

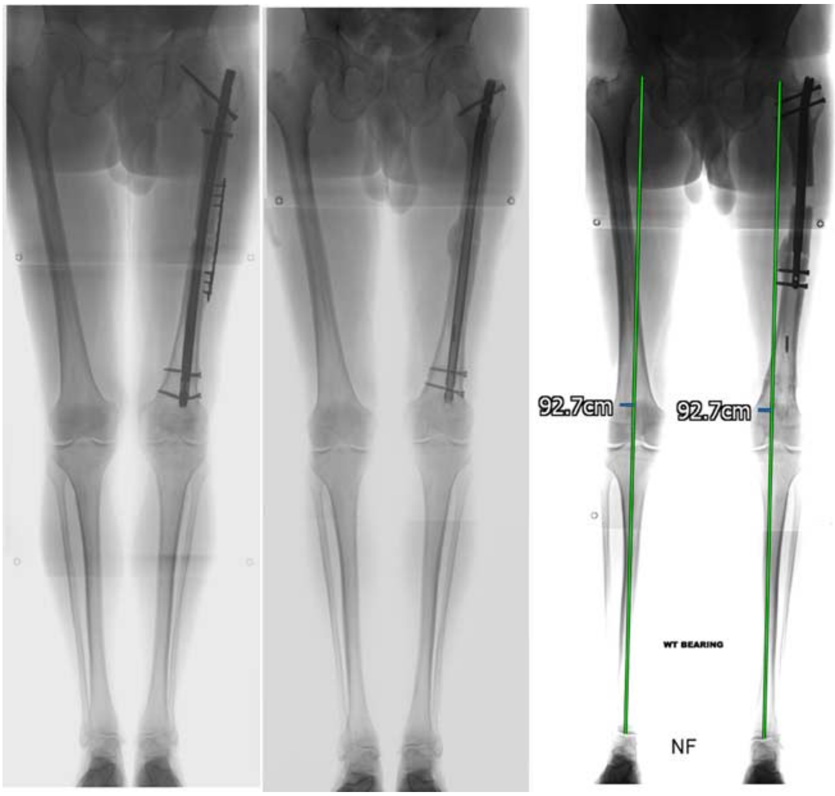

FIGURE 10. Excision of infected nonunion, lengthening once healing satisfactory.

FIGURE 11. Nonunion with bone loss. Metaphyseal shortening and lengthening from proximal.

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FIGURE 12. Slight correction of varus by using trochanteric nail via piriformis fossa.

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