Antegrade Humeral Lengthening With the Motorized Internal Lengthening Nail

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Summary: Humerus lengthening with internal lengthening nails (ILNs) has been used with success to avoid complications associated with lengthening using external fixators (eg, soft tissue tethering). ILNs can be used in skeletally mature patients with humeral shortening who have an intramedullary canal wide enough to fit the nail, and who has no active infection. Associated deformity (angular or rotational) can be corrected acutely using the ILN as long as it would be tolerated by the neurovascular structures.

Key Words: humerus—lengthening—motorized nail.

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INDICATIONS AND PREOPERATIVE PLANNING

Although humerus lengthening with external fixation has been successful, there are difficulties related to the external fixation pins such as infection and soft tissue tethering.[1] Humerus lengthening with an internal nail is indicated for skeletally mature patients with humeral shortening who have an open intramedullary (IM) canal with a large enough diameter to fit the IM nail, and with no active infection.[2,3] Associated angular deformity with an apex located anywhere between the proximal metadiaphyseal junction to the mid-diaphysis as well as rotational deformity can be corrected acutely using the internal lengthening nail (ILN).[4,5] The level of the osteotomy is planned preoperatively and should be performed at the apex of any existing deformity or at a location that would provide enough stability of the bone nail construct after nail insertion and at the end of distraction. The goal is to have 4 to 5 cm of the thick part of the nail positioned in the distal segment at the end of distraction.[6,7] It is advisable to place the osteotomy at the healthy bone and not sclerotic bone to improve the regenerative quality and if feasible, the osteotomy should be done just distal to the deltoid tuberosity, to avoid excessive traction on the deltoid. The nail length is chosen using the Shortest Nail Length analysis (Fig. 1). The longest nail possible should be used reaching as close to the olecranon fossa as possible. This enhances stability and also allows the most lateral based distal locking screw to be inserted in a safe zone relative to the radial nerve.

The entry point of the nail is at the proximal end of the anatomic axis, and the proximal humeral anatomy would dictate the location of that point. For patients with normal anatomy, the entry point would be on the medial side of the greater tuberosity medial to the rotator cuff insertion (Fig. 2). If proximal humerus varus deformity is present, the entry point would be located at the tip of the greater tuberosity which is lateral to the rotator cuff insertion (Fig. 3).

Humeral ILN were not commercially available which led to the creative off-label use of the commercially available ILN to lengthen the humerus, most commonly using the trochanteric entry antegrade femoral nails if a nail with proximal bend is needed or using a piriformis entry femoral nail if a straight nail is needed (Fig. 4).

Recently, motorized IM humeral nails designed primarily for the use in cases of humeral nonunion to act in compression mode have been commercially available. These nails can be also used in distraction mode to perform humeral lengthening.

Adjunct techniques can be used to facilitate acute deformity correction at time of nail insertion, such as fixator-assisted nailing, and to prevent secondary deformities that may happen during lengthening, such as the use of blocking screws, however these are not usually needed in the humerus. The IM canal diameter is small, and the nail is usually effective for any needed deformity correction. Prophylactic radial nerve release may be needed

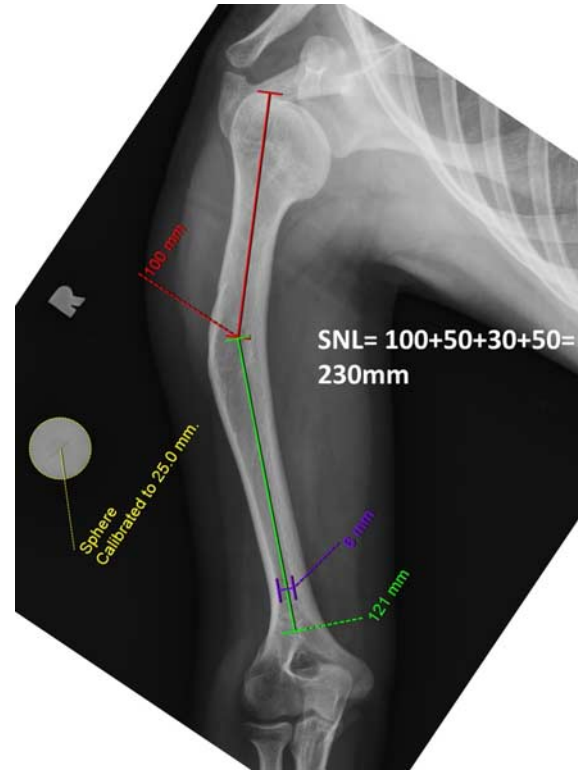

FIGURE 1. Shortest Nail Length (SNL) analysis.

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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 Sherif Galal Hassan, MD, PhD, at hassans@hss.edu or by mail at Limb Lengthening and Complex Reconstruction Service, Hospital for Special Surgery, Weill Cornell Medical College, Cornell University, 535 East 70th Street, New York, NY 10021. You may inquire whether the author(s) will agree to phone conferences and/or visits regarding these techniques.

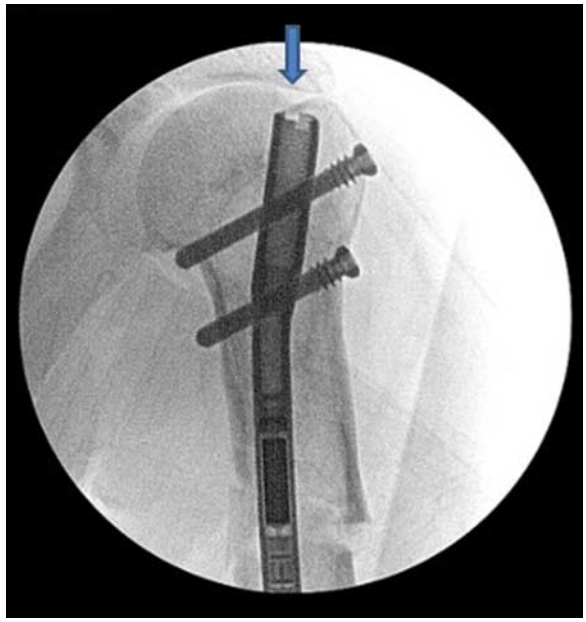

FIGURE 2. Nail entry point in cases with normal anatomy of the proximal humerus, located on the medial side of the greater tuberosity medial to the rotator cuff insertion (blue arrow).

during acute angular or rotational deformity correction especially if there is localized scarring.

SURGICAL TECHNIQUE

The patient is positioned supine on a flat radiolucent table, and a bump is placed under the ipsilateral scapula. Split sheets are used to drape the surgical site to include the axilla and base of the neck. The C-arm is positioned on the opposite side.

Step 1: Canal Venting

The planned osteotomy site is identified and marked on the skin. a 1-cm anterolateral incision is made and the periosteum is elevated to make a pocket for the reamings, multiple transverse drill holes are made using a sharp 4.8 mm drill to vent the IM canal at the osteotomy level.

Step 2: Entry Point

The proximal humerus entry point is marked on the skin, the shoulder is adducted. A anterolateral acromial approach to the proximal humerus is performed, the deltoid muscle is split bluntly, and the rotator cuff is longitudinally sharply incised (and later carefully repaired) expose the entry point which is located just medial to greater tuberosity. In cases where proximal humerus varus deformity is present, the entry point is located at the tip of the greater tuberosity (Fig. 3), and the starting wire can then be inserted percutaneously at the anterolateral border of the acromion. When proximal humerus varus is present, the percutaneous entry is lateral to the rotator cuff insertion. The starting point is checked under antero-posterior and lateral fluoroscopy (Fig. 5).

The starting wire is then driven into the canal and once this wire's position is confirmed, a 12 mm cannulated acorn reamer is placed over the starting wire, and a starting hole is created in the humerus. this is then replaced with a long beaded flexible guidewire inserted into the canal to the distal end of the bone.

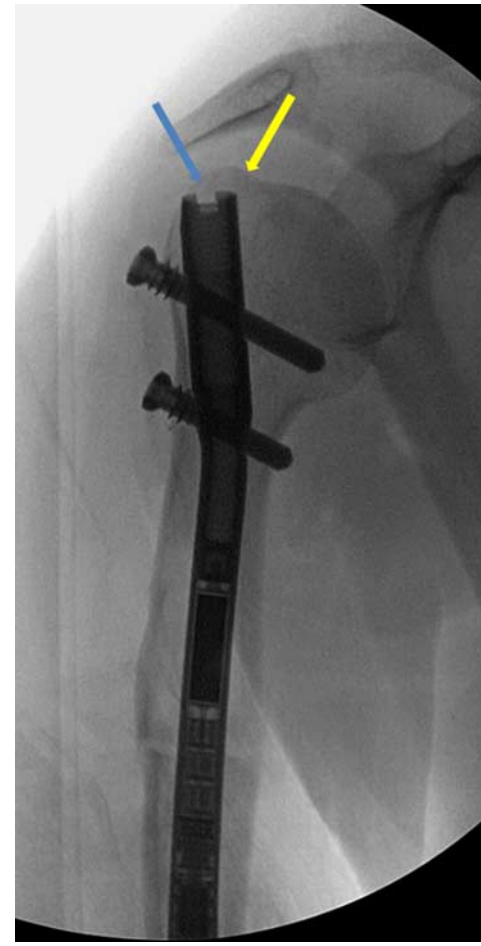

FIGURE 3. Nail entry point, could be either at: the tip of the greater tuberosity which is lateral to the rotator cuff insertion (blue arrow) in cases with proximal humerus varus deformity, or medial to the rotator cuff insertion (yellow arrow) in cases with normal anatomy of proximal humerus.

Step 3: Canal Reaming

Flexible reamers are used to ream the IM canal 1.8 to 2 mm greater than the diameter of the planned nail. The reamings exits through the drill (vent) holes.

Step 4: Rotation Markers

Once the reaming is complete the guidewire is removed and the motorized ILN is then inserted down to a level about 1 cm proximal to the planned osteotomy site. Steinmann pins or temporary external fixation pins are placed in the proximal and distal bone segments away from the nail path to mark rotation. If there is rotational deformity, the pins are placed with the desired axial plane divergence; if there is no rotational deformity present, pins are placed parallel in the axial plane (Fig. 6).

Step 5: Osteotomy

An osteotome is used to complete the osteotomy, if there is an angular deformity, a fixator-assisted nailing technique may be needed to hold bone segments in the correct alignment to allow for the nail passage. The nail is then passed across the osteotomy site (Fig. 6).

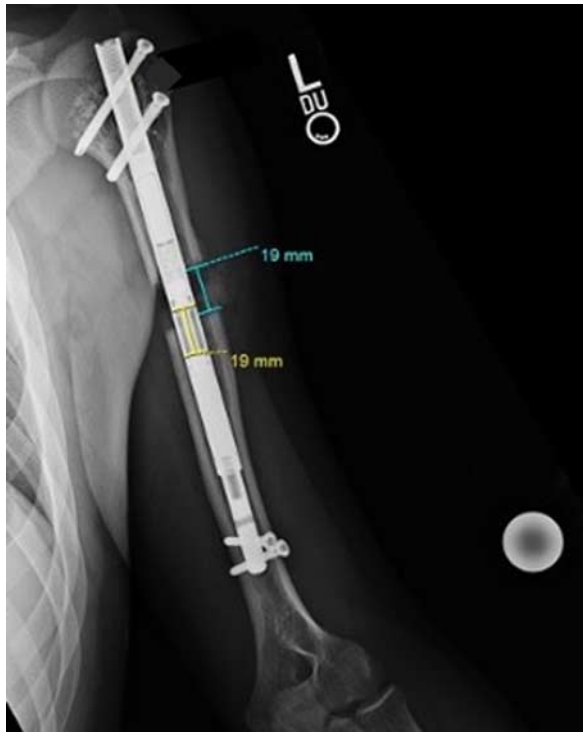

FIGURE 4. A piriformis entry femoral nail is used if a straight nail is needed.

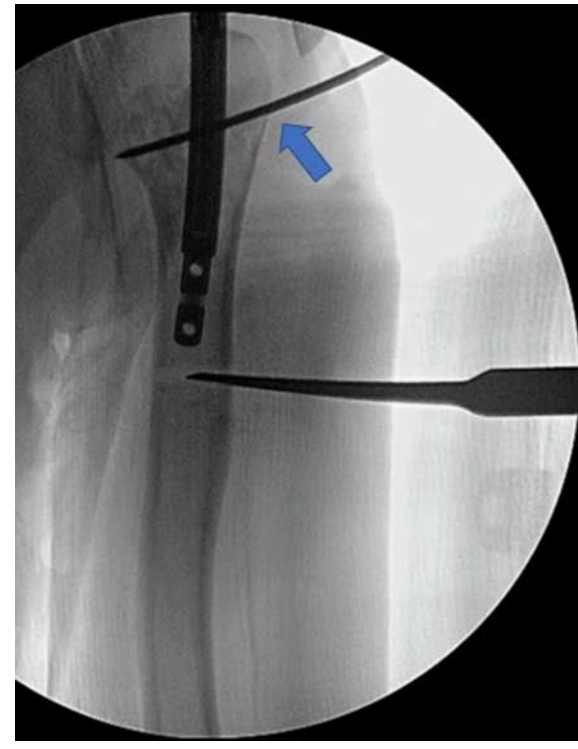

FIGURE 6. Rotation marker (blue arrow) and nail advancing down to osteotomy site.

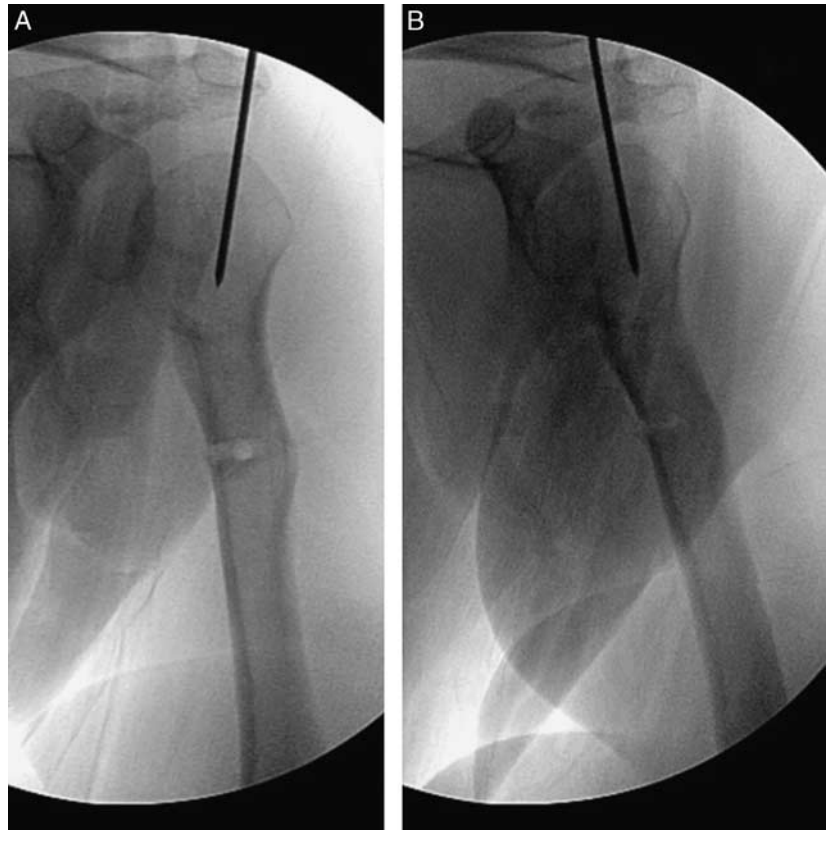

FIGURE 5. Fluro images showing the position of the starting wire. A, Antero-posterior view. B, Lateral view.

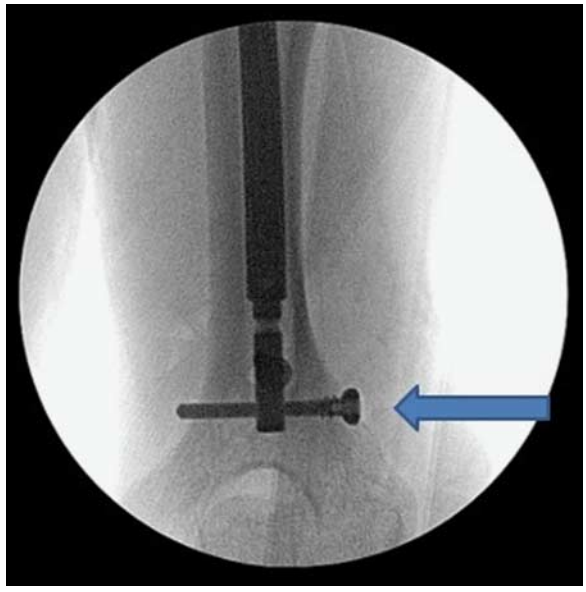

FIGURE 7. Distal lateral locking screw (blue arrow) inserted just adjacent to the olecranon fossa.

Step 6: Locking of the Nail

The overall position and rotational alignment of the humerus is checked. Proximal locking screws are inserted via the jig. The jig is then removed. The distal locking screws are then inserted. It's desirable to advance the ILN as distal as possible to avoid injury of the radial nerve. Ideally the distal lateral locking screw is inserted just adjacent to the olecranon fossa. This puts the surgical exposure posterior to the radial nerve that has already crossed anteriorly at a more proximal location. The exposure for the distal screws may be percutaneous with careful blunt spreading to the bone. With the use of regional anesthesia and with avoidance of a paralytic agent during anesthesia, one can look for hand and finger twitch as a precaution if the surgeon is close to the radial nerve (for the lateral screw) and the median nerve (for the anterior screw) (Fig. 7).

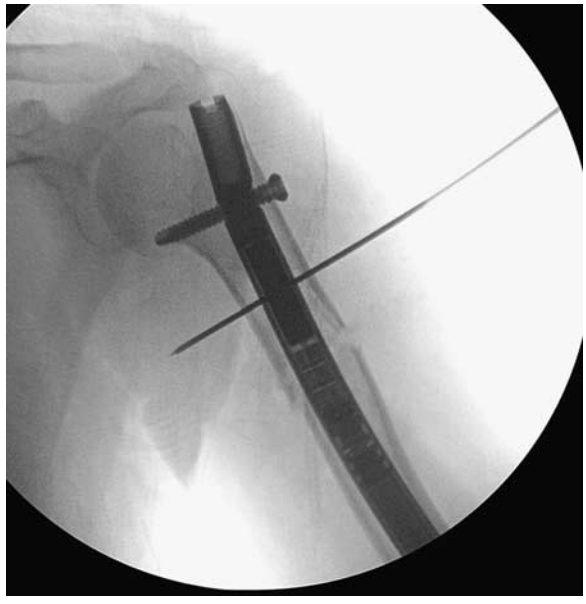

FIGURE 8. Marking the magnet.

TABLE 1. Tips for Success

Use longest possible nail ideally reach the olecranon fossa. This will maintain optimal stability and position distal lateral locking screw in safe position
Perform osteotomy using multiple drill hole technique with new drill and sharp osteotome
Osteotomy site is chosen at apex of deformity when there is malalignment
Osteotomy site is chosen proximal enough to provide adequate thick nail in distal segment at end of distraction
Entry into proximal humerus depends on shape of bone. With proximal humerus varus, entry may be percutaneous and lateral to the rotator cuff insertion. When proximal humerus is normal, rotator cuff is incised, and entry is medial to rotator cuff insertion on greater tuberosity
Rotational markers should be placed out of the path of the intramedullary nail
Since there is no dedicated humerus nail, one can use an antegrade femur nail (trochanteric or piriformis entry) or tibial nail based on the humerus shape, length, and alignment

Step 7: Mark the Magnet and Test the Nail

At the end of surgery, the internal magnet is localized with fluoroscopy and marked on the skin with a permanent marker so that the external remote controller (ERC) may be optimally placed for distraction. A trial distraction of 0.5 to 1.0 mm may be done in the operating room to confirm that the distraction mechanism is working properly. Patients are encouraged to re-mark the magnet location every few days so that it does not fade. The connection between the ERC and the magnet in the nail is critical for success. Furthermore, the ERC should be pressed firmly on the skin to minimize the distance to the magnet (Fig. 8).

Step 8: If a Rotator Splitting Approach Was Used, the Rotator Cuff Should be Meticulously Repaired Using Nonabsorbable Sutures

Antibiotic prophylaxis is administered to all patients in the form of 1 intraoperative dose of intravenous cefazolin. Tranexamic acid (10 mg/kg) could be administered during the perioperative period to minimize bleeding and hematoma development. Two doses are usually administered, the first dose is given with induction of anesthesia and the second dose is administered 3 hours after.

Table 1 summarizes technical tips we recommend when performing the technique, Table 2 summarizes what to avoid during surgery.

TABLE 2. Avoiding Pitfalls

Percutaneous approach is only safe if there is proximal humerus varus and the entry is lateral to the rotator cuff insertion
The radial nerve is at risk when inserting the distal lateral locking screw. When nail end is at olecranon fossa, this is safe as the radial nerve has crossed anteriorly at more proximal location
The median nerve is at risk when inserting the anterior distal locking screw. Blunt dissection and use of a drill guide is needed
Avoid a paralytic agent administered by anesthesia so that motor twitch feedback can be obtained if one is too close to the nerve
To avoid stiffness, begin shoulder, elbow, wrist, and hand range of motion immediately. If rotator cuff has been split, then limit shoulder to passive motion for first 6 wk

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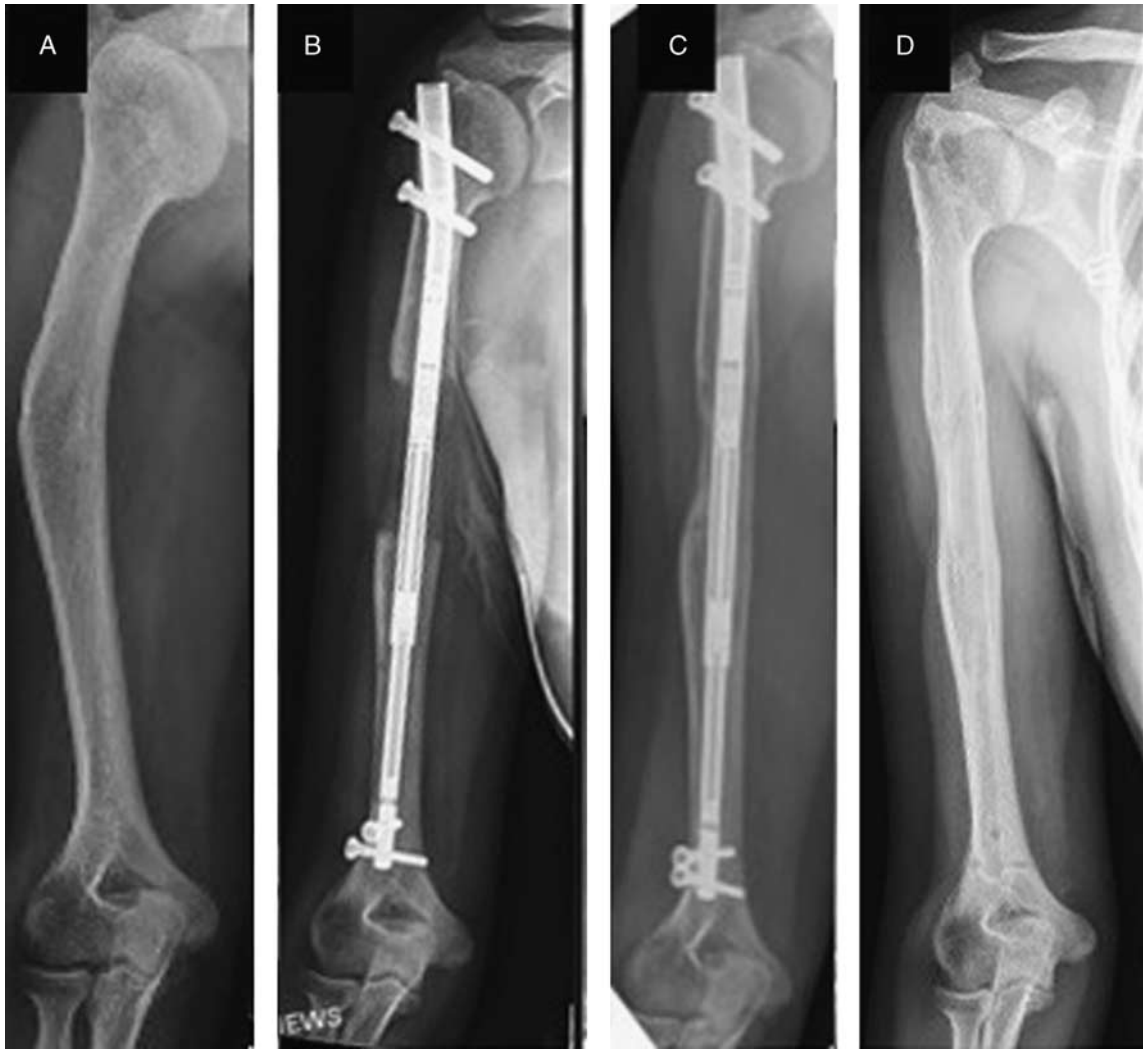

FIGURE 9. Case example (A) preoperative AP view. B, AP view at the end of distraction. C, AP view at the end of consolidation. D, AP view after nail removal. AP indicates antero-posterior.

POSTOPERATIVE PROTOCOL

Arm sling is allowed to be used initially for comfort only. Shoulder, elbow, wrist, and hand range of motion is started immediately. If the rotator cuff has been incised, then shoulder range of motion is limited to passive only for 6 weeks to allow the rotator cuff to heal. Use of the upper extremity is encouraged within the loading limits recommended by the manufacturer according to the diameter of the nail used. Full loading of the arm is only allowed after full regenerate consolidation (noted by presence of 3/4 cortices of bridging bone across the regenerate) is observed radiographically.

All patients are instructed to take calcium (1200 to 1500 mg/d) and vitamin D_3 supplementation (2000 to 5000 IU/d) starting from postoperative day 2.

Postoperative pain management is done using IV Tylenol (1000 mg 3 times/d) and IV Toradol (30 mg once) for the first postoperative day, followed by oral Tylenol (1000 mg 4 times/d for 2 to 4 wk) and Mobic (15 mg once/d for 2 to 4 wk). Intravenous patient-controlled analgesia is used during hospital stay. Oral Oxycodone 5 mg can be used as needed during lengthening if needed and Gabapentin 100 mg tid for neurogenic pain.

Distraction typically starts on postoperative day 7 at a rate of 0.2 mm 4 times/day. In cases where acute deformity correction was done or if there is fear of poor regenerate quality (eg, cases of malunion), the latency phase can be extended, and the distraction speed can be slowed.

Postoperative follow-up is advisable to be every 2 to 3 weeks; the patient is assessed both clinically for neurological function and adjacent joint range of motion as well as radiographically using calibrated radiographs for distraction length and regenerate quality (Fig. 9). The rate of distraction is adjusted accordingly. A clinical view from the back is useful to determine the end of distraction and equalization of arm lengths (Fig. 10).

It's worth noting that damage to the rotator cuff during nail insertion would have a detrimental effect on patients' outcome. There have been very few reports in the literature on humeral lengthening to fully evaluate this risk, we would recommend counseling patients on the possibility of shoulder discomfort and may be provide them with an alternative (such as lengthening using monoliteral fixators, which carries way less risk of shoulder problems if any); especially in patients who are high level athlete who need to do overhead activities.

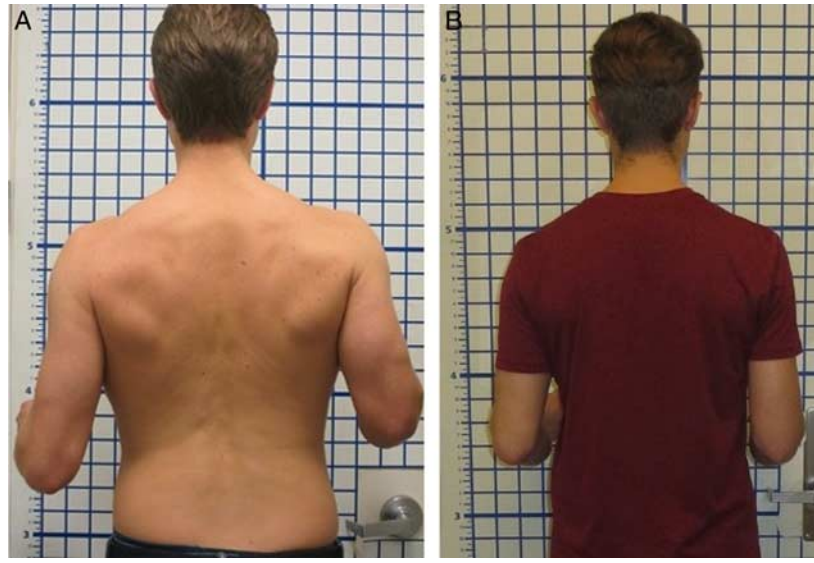

FIGURE 10. Clinical view of another patient from the back to assess arm lengths. A, Preoperative length. B, Final length.

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