Retrograde Extramedullary Lengthening of the Femur Using the PRECICE Nail: Technique and Results

Christopher A. Iobst, MD and Anirejouritse Bafor, MD

Background: Lengthening of long bones by distraction osteogenesis is now possible using intramedullary lengthening nails. Constraints of bone size, medullary canal obstruction, and the presence of an open physis are contraindications in skeletally immature patients. We present a technique describing the "off-label" use of a magnetic lengthening nail placed extramedullary and in retrograde manner, for lengthening of the femur in skeletally immature patients.

Methods: A retrospective review of 5 skeletally immature patients with significant length discrepancy of the femur are presented along with a description of the surgical technique. Data collected included age, sex, date of surgery, diagnosis, presence of associated deformities, the magnitude of length discrepancy, the amount of length gained, the amount of time to achieve full weight-bearing, the time to hardware removal, and any complications.

Results: There were 5 patients (3 females). The mean age was 7.2 ± 2.7 years (4 to 10 y). The mean limb length discrepancy was 6.5 ± 3.7 cm (3.5 to 11 cm). A mean length of 3.46 ± 0.4 cm (3.1 to 4 cm) was achieved which represents 12.9 ± 1.8% (10.32 to 13.47%) of the bone length. The time taken to achieve full weight-bearing ambulation was 89.2 ± 19.3 days (60 to 109 d) or 12.7 weeks. All hardware was removed 247.6 ± 215.6 days (99 to 628 d) after surgery. Patients were followed up for a mean duration of 19.2 months (11 to 30 mo). No supplemental fixation was required and no complications were noted. Acute deformity correction was also performed at the time of surgery in 2 patients who had distal femur valgus deformity.

Conclusions: Retrograde extramedullary lengthening of the femur is an option that should be considered for limb length equalization in skeletally immature patients. It avoids the inconvenience of external fixation and can be used to simultaneously correct deformities of the distal femur. Although the total amount of length gained is modest, we believe it is a promising limb lengthening technique that merits further investigation.

From the Nationwide Children's Hospital, Columbus, OH.

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Reprints: Christopher A. Iobst, MD, Nationwide Children's Hospital, 700 Children's Drive Suite T2E-A2700, Columbus, OH 43205. E-mail: christopher.iobst@nationwidechildrens.org.

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The history of limb lengthening surgery dates back more than 100 years.[1,2] Initially achieved by acute lengthening with traction devices, the procedure eventually evolved to gradual distraction using external fixator constructs. The intramedullary lengthening nail has gained popularity since its first reported use in the 1980s.[3] The current designs have proven to be very reliable and effective in achieving distraction osteogenesis.[4–8] Because it is an internal rather than external device, intramedullary lengthening nails are more comfortable for patients, avoid pin site issues, and allow better maintenance of range of motion than external fixators.[9–11] These nails have also demonstrated that deformity correction can be safely combined with limb lengthening, making them the current device of choice for limb lengthening.[12]

However, there are several instances where intramedullary lengthening nails cannot be used. In small patients, the length of the bone or the diameter of the intramedullary canal may not safely meet the minimum nail size dimensions which prevents the use of an intramedullary implant. In skeletally immature patients, inserting a retrograde femoral nail or an antegrade tibial nail is not recommended to avoid the risk of causing a subsequent growth disturbance to the violated physis. Skeletally immature patients also carry the risk of developing femoral head avascular necrosis as a result of damage to the blood supply during the process of inserting an antegrade femoral nail.[13,14] To creatively avoid the need for an external fixator in such patients, the concept of using the intramedullary nail in an "extramedullary" manner has been developed. Two previous reports describe the "off-label" technique of utilizing the lengthening nail in an extramedullary location for femoral and tibial lengthening.[15,16] Each report describes femoral lengthening with the use of the nail in an antegrade direction. In the first report of the use of a magnetic lengthening nail by Dahl et al,[15] secondary deformity of the regenerate during lengthening was noted to be an issue. Shannon et al[16] addressed this potential problem by utilizing an intramedullary rod as supplementary fixation. The senior author has used an alternative method where the nail is inserted in retrograde manner. The hypothesis was that by placing the larger diameter nail screws in the larger metaphyseal region of the distal femur, the stability of the construct would improve and help to prevent deformity of the regenerate bone. The technique also allows for the osteotomy to be performed in the desired distal femoral metaphyseal location which could potentially improve the formation of the regenerate bone. The purpose of this case series is to describe the technique for extramedullary lengthening of the femur using a lengthening nail passed in retrograde manner and to present our findings using this technique.

METHODS

This was a retrospective chart review of a single surgeon's experience. Consecutive patients who had femoral lengthening using a PRECICE nail placed on the lateral side of the femur in retrograde manner between April 2018 and October 2019 formed the population for this study. Following approval by our institutional review board, demographic data for all patients who met the inclusion criteria were extracted from their charts.

Data collected included age, sex, date of surgery, diagnosis, presence of associated deformities, the magnitude of length discrepancy, the amount of length gained and percentage gain, the amount of time taken to achieve full weight-bearing, and time taken to the removal of hardware. The incidence of complications, if any, were also recorded.

Surgical Technique

Patients were selected for this technique if there was a femoral limb length discrepancy and an intramedullary lengthening nail could not be used in the traditional manner due to the femur being too small to safely accommodate the smallest size of the existing available implants. To be eligible for this technique, the femur had to measure at least 19 centimeters in length from the distal femoral physis to the greater trochanter. This bone length allows the shortest femoral nail (190 mm) that still has 2 interlocking screws proximally and distally to be utilized. Standing anteroposterior bilateral lower extremity radiographs with dedicated anteroposterior and lateral views of the entire femur were obtained for preoperative deformity analysis and planning. Because of the extramedullary position of the implant fully threaded screws rather than pegs are necessary for this technique.

Using the nail in the retrograde manner allowed the osteotomy to be planned in the distal femoral metaphysis which provides a large surface area for new bone formation. This location also placed the osteotomy closer to the apex of the deformity in all the patients in this review. Depending on the preoperative plan of the nail location, either a straight nail or the trochanteric entry nail was used (Figs. 1A, B). If the nail needed to be placed along the distal femoral metaphysis, the trochanteric bend in the nail accommodated the flare of the distal femoral metaphysis to allow near anatomic fit of the nail along the lateral cortex of the femur. If the patient did not have much bend to the distal femur or if the length of the femur allowed the nail to be placed slightly more proximally, then a straight nail could be utilized.

FIGURE 1. A, For this patient undergoing an acute correction, the straight nail was chosen since its shape fit the contour of the femur. B, A trochanteric entry nail was chosen for this patient since the nail shape followed the contour of the distal femoral metaphysis.

The patients were placed supine on the operating room table and positioned close to the edge of the bed. A bump was placed under the hemipelvis until the patella was facing directly anteriorly. The length of the nail was confirmed to be appropriate by using the radiolucent ruler. The location of the distal femoral physis was marked on the skin. A 3 to 4 cm incision over the lateral distal femur was made and the vastus lateralis was elevated to expose the lateral distal femur. An elevator was inserted and advanced proximally in a sub-muscular manner to create a path for the nail. The nail was inserted to judge the desired location of the proximal and distal portions of the nail. A small counter incision 1 to 2 cm in length was made over the lateral proximal femur at the level of the proximal interlocking holes. The proximal end of the nail was visualized and centered on the bone. Once the position was confirmed, the drill bit for the most distal and the most proximal holes in the nail were inserted to verify that bi-cortical screws would be possible. The nail position with the drill bits in place was checked with fluoroscopy in orthogonal views (Fig. 2). If the position was not acceptable it was readjusted by redrilling a new hole in the appropriate location. Before removing the nail, a drill hole anterior or posterior to the nail was placed to mark the desired osteotomy level in the metaphysis proximal to the path of the distal interlocking screws. The nail was removed and the rest of the osteotomy holes in the femur were drilled. If desired, a 5 mm counter-incision directly

FIGURE 2. Lateral view of the femur demonstrating the nail is centered on the bone both proximally and distally.

anterior at the osteotomy level could be utilized to make additional drill holes oriented anterior to posterior. The nail was reinserted and the previous interlocking screw drill holes at the most distal and most proximal nail holes were filled with the appropriate length screws. Before fully tightening the initial screws the osteotomy was completed with an osteotome. By leaving the screws slightly loose, the nail could be pulled away from the bone allowing space for an osteotome to be inserted anterior and posterior to the nail to complete the osteotomy. Once the osteotomy was completed and verified, the 2 screws were fully tightened. The second screw hole in the proximal and distal interlocking screw cluster were then be drilled and filled. The nail function was checked by performing an acute 1-mm lengthening. The location of the magnet was marked on the skin.

If an acute correction was required, a half pin was drilled into the distal femoral segment from the medial side to be used as a joystick (Fig. 3). The osteotomy was completed before placing the drill bit for either of the distal interlocking screws. The distal piece was manipulated into the desired position with the half pin joystick and then the 2 distal interlocking screws were drilled to lock it into position (Fig. 4). These screws were centered on the bone in the lateral view but not necessarily orthogonal to the bone in the coronal view in order to accommodate the acute deformity correction.

RESULTS

Five patients who underwent retrograde extramedullary lengthening of the femur during the study period met the inclusion criteria. The mean age was 7.2 ± 2.7 years with a range of 4 to 10 years. A summary of the patient demographics is presented in Table 1.

FIGURE 3. A half pin inserted into the distal femoral metaphysis from the medial side can be used to direct and hold the amount of desired acute correction.

The mean limb length discrepancy was 6.5 ± 3.7 cm (3.5 to 11 cm). The mean length gained was 3.46 ± 0.4 cm (3.1 to 4 cm), while the mean percentage length gained was 12.9 ± 1.8% (10.32% to 13.47%). The mean time to full weight-bearing ambulation was 89.2 ± 19.3 days (60 to 109 d) or 12.7 weeks, while the mean duration of retention

FIGURE 4. Larger diameter interlocking screws matching the larger diameter of the bone help hold the acute correction.

TABLE 1. Summary Data for Patients Undergoing Retrograde Extramedullary PRECICE Nail Limb Lengthening

Patient No.	Age (y)	Sex	Diagnosis	Associated Deformity	LLD (cm)	Length Gain (cm)	% Length Gain	Time to FWB (d)	Duration of Nail (d)
1	4	F	Chondrodysplasia punctate	Midshaft varus deformity, distal femur valgus (acute correction)	4	3.5	15.2	60	196
2	10	F	Congenital femoral deficiency	—	10	3.5	13.46	84	99
3	6	F	Fibula hemimelia	Distal femur valgus (had GG)	11	3.1	13.47	89	628
4	10	M	Congenital femoral deficiency	Mid shaft femur varus (acute correction)	4	3.2	10.32	104	169
5	6	M	Traumatic physeal arrest from a lawnmower injury	Distal femur valgus (acute correction)	3.5	4	12.06	109	146

F indicates female; FWB, full weight-bearing; GG, guided growth; LLD, limb length discrepancy; M, male.

of hardware was 247.6 ± 215.6 days (99 to 628 d) or 35.4 weeks. Since there was solid healing of the regenerate bone in each case, no prophylactic implants were necessary following removal of the extramedullary nail. Patients were followed up for a mean duration of 19.2 months (11 to 30 mo). No complications were recorded in the immediate postoperative or follow-up period.

DISCUSSION

Achieving limb length equalization by distraction osteogenesis using an intramedullary lengthening nail has been shown to have several advantages over external fixation techniques. This method eliminates pin site complications and is more comfortable for patients allowing for a better maintenance of range of motion. In addition, intramedullary lengthening has been determined to be very accurate.[4,8,10] However, the use of an intramedullary lengthening device is limited to patients with long bones large enough to accommodate the size of the implant. If the implant cannot be safely placed inside the bone, then lengthening via an external fixator may be necessary. Open physes in the distal femur or proximal tibia further limits the use of retrograde femoral nails or antegrade tibial nails in skeletally immature patients for fear of causing permanent damage to the physis during the nail insertion process.

Several techniques for achieving limb length equalization in skeletally immature patients have been reported in the literature.[17–19] Growth modulation and epiphysiodesis for limb length equalization involve procedures to slow the growth of the longer limb. Both techniques have been used to manage limb length discrepancy. They have the benefit of being minimally invasive in nature but can be unreliable in providing precise restoration of length equality, with 8-plate growth modulation demonstrated to be less accurate than percutaneous epiphysiodesis.[20–23] Lengthening the short limb with an external fixator has been the standard method of lengthening for the last 30 years. It has been shown to be more successful than epiphysiodesis in correcting limb length discrepancy.[24] While allowing length to be obtained, external fixators have multiple disadvantages including patient discomfort, pin site infections, long duration of treatment and risk of fracture after external fixator removal.[25–29] Hybrid procedures, such as lengthening over a plate, were developed as a means to find ways to remove the fixator quicker.[30–32] Unfortunately, these procedures require a staged return to the operating room to fully lock the plate and remove the external fixator at the end of distraction. This technique also risks allowing a pin site infection to spread to the internal hardware.

A novel approach has been developed to lengthen skeletally immature long bones by placing an intramedullary lengthening nail in an extramedullary position. This "off-label" use of a lengthening nail enables skeletally immature patients have length equalization surgery using an internal fixation technique. There have been 2 previous reports of extramedullary lengthening using a PRECICE nail in skeletally immature patients. Shannon et al[16] reported their technique of extramedullary lengthening of the femur and tibia in 13 patients (10 femur and 3 tibia). In their report, the PRECICE nail was inserted in a submuscular antegrade manner on the lateral side of the femur. A SLIM rod or a Rush nail was also inserted into the medullary canal to prevent deformation of the regenerate as lengthening occurred. In order to bring the nail as close to bone as possible, further reducing bending forces acting on the nail, they created a docking hole in the flare of the distal femoral metaphysis. Creating this docking site for the nail required a separate distal approach to the femur. The achieved a mean lengthening of 48.5 mm in their series.

Dahl et al[15] reported their findings with extramedullary lengthening of the femur in 11 patients. Utilizing the PRECICE nail, inserted in submuscular antegrade manner, they gained an average of 32.3 mm of length in their series. Unlike Shannon and colleagues, they did not utilize any intramedullary stabilization techniques to prevent deformation of the regenerate as lengthening occurred. They noted deformation of the regenerate bone in 7 out of the 11 patients in that series, with 3 of the patients requiring additional surgery to manage the deformity.

Our technique involves the use of the PRECICE nail inserted in retrograde submuscular manner rather than an antegrade direction. This orientation has several possible advantages. The ten-degree bend of the trochanteric end of the nail matches the metaphyseal flare of the distal femur bone allowing it to follow the contour of the bone without having to create a notch. The retrograde technique also allows the osteotomy to be performed in the distal metaphysis rather than the diaphysis. The increased surface area of bone helps to improve the formation and healing of the regenerate bone. The more distal osteotomy site can also be helpful whenever there is distal deformity since it is closer to the deformity apex. Finally, the retrograde technique allows the larger diameter screws to be placed in the larger diameter bone of the metaphysis rather than in the diaphysis as required in the antegrade technique. This helps to increase the stability of the construct and prevents the creation of a stress riser when the nail is ultimately removed. This combination of factors may explain why we observed no deformation of the regenerate bone in comparison to the series by Dahl and colleagues. We also did not require any additional hardware as in the series by Shannon and colleagues.

One theoretical concern with the retrograde technique is housing the larger portion of the nail under the thinner lateral distal femoral soft tissue envelope rather than more proximally. We did not have any issues fitting the nail under the tissue intraoperatively. None of the patients had any pain or knee limitations from hardware prominence. One patient with a previous lawnmower injury tolerated this technique despite having skin grafts in the area of nail insertion (Fig. 5).

In this series, length gained ranged from 31 to 40 mm (34.6 mm), which translates to 10% to 13% of lengthening. This was achieved without any complications, and all patients were full weight-bearing within 4 months of surgery. In comparison, Shannon and colleagues achieved a mean lengthening of 48.5 mm, with 4 documented complications, including 2 hip subluxations that required open surgery for correction. Having a more distal osteotomy in the femoral metaphysis using the retrograde technique may help to alleviate some of the stress on the hip joint. Our series did not have any hip subluxations or dislocations.

The mean duration of retention of hardware in our series was about 35 weeks. This figure was affected by the relatively long period of retention of hardware in patient number 3. The mean duration of hardware retention would have been as short as 21 weeks if this patient had been excluded from the analysis. The reason for the extended period in this patient was the simultaneous insertion of a tension band plate for guided growth. The parents elected to wait until the completion of the process to avoid multiple surgical procedures.

We also noted a subjectively faster time of the regenerate bone healing, with 1 patient achieving full weight-bearing just 2 months following surgery. We believe that the undisturbed intramedullary blood supply of the bone combined with the limited disturbance of the periosteal blood supply accounted for this observation. The fact that this retrograde technique allows the osteotomy to be placed in the metaphysis of the femur rather than the diaphysis may have also contributed to this observation. The metaphyseal bone has a larger surface area and richer blood supply compared with the diaphysis which are both important factors in regenerate formation.

The small sample size and the retrospective nature of this chart review constitute limitations to this study. The "off-label" use of the intramedullary lengthening nail and a lack of a comparison group are further limitations of this study. Having an age and sex-matched external fixation lengthening group would have added strength to the observations of this study. This study also did not assess patient-reported outcomes.

Extramedullary lengthening using a magnetic lengthening nail placed in retrograde manner provides a potential alternative to femoral limb length equalization surgery with external fixation in skeletally immature patients. With careful patient selection and conservative lengthening goals, simultaneous correction of deformity and limb lengthening can be safely accomplished using this method.

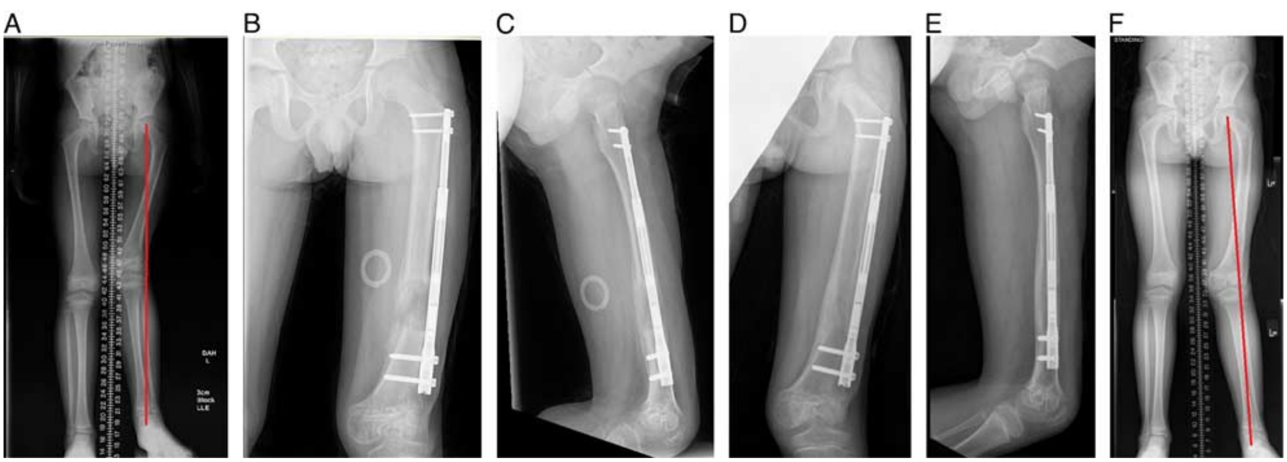

FIGURE 5. A, Preoperative standing radiograph of a 6-year old male after lawnmower injury to distal left femoral physis. The mechanical axis is laterally deviated at the knee due to the valgus deformity. B and C, Anteroposterior and lateral views of the left femur at the end of 4 cm distraction. Acute correction of the valgus has been maintained in the coronal plane and there is no apex anterior deformity in the sagittal plane (D, E) anteroposterior and lateral views at the end of consolidation. F, Standing radiograph after implant removal showing healed regenerate bone and equal leg lengths. There is improvement in the mechanical axis of the limb compared with the preoperative radiograph. The red lines represent the mechanical axis of the limb (center of the hip to the center of the ankle). full color online

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