Research Article

Simultaneous Acute Femoral Deformity Correction and Gradual Limb Lengthening Using a Retrograde Femoral Nail: Technique and Clinical Results

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Abstract

Introduction: Patients with limb-length discrepancies often have concomitant deformity. We describe the outcomes of acute, fixator-assisted deformity correction with gradual lengthening using the retrograde femoral Precice nail (NuVasive).

Methods: We analyzed a retrospective series of 27 patients in whom an external fixator was combined with a Precice nail to correct angular or rotational deformity and limb-length discrepancy. The fixator was applied temporarily to restore normal alignment. The Precice nail was inserted and locked in place to hold the correction, with gradual restoration of limb length.

Results: The 27 patients (mean age, 28 years) had a mean follow-up of 13 months. Secondary deformities were mainly valgus (15 patients) and varus (10 patients). Postoperatively, 93% of patients had correction of limb length to within 3 mm of the discrepancy (mean lengthening, 30 mm). Mechanical axis deviation was corrected to within 8 mm of neutral (ie, zero) in 81% of patients. The mechanical lateral distal femoral angle was corrected to a mean of 88° postoperatively. Final Association for the Study and Application of Methods of Ilizarov (ASAMI)–Paley scores were excellent for 96% of patients.

Discussion: The use of intramedullary lengthening nails has revolutionized the field of limb lengthening. The results of our study show that a retrograde femoral Precice nail can be used safely and accurately to correct both limb-length discrepancy and deformity with minimal complications. The benefits of using this implant include the ability to maintain knee range of motion during the lengthening process. Rapid bone healing allows a relatively fast return to weight-bearing ambulation.

Conclusions: The Precice nail was effectively used to correct both limb-length discrepancy and deformity, with excellent overall outcomes. This surgical technique may help avoid the complications that can occur with prolonged postoperative use of an external fixator.

Level of Evidence: Level IV retrospective study

Patients with unequal femoral lengths often have concomitant deformity in the coronal, sagittal, or axial plane. External fixation has long been the standard for simultaneous surgical correction of leg

length discrepancy and deformity.[1-4] Despite the success and versatility of this method, it has drawbacks. External fixation is cumbersome and can be uncomfortable for patients. The experience may be psychologically difficult for the patient and family. Pin-track infections can occur.[5] To manage these infections, many patients require oral antibiotics, which increase the possibility of antimicrobial resistance and expose patients to adverse effects, such as gastrointestinal dysfunction and allergic reactions. Because of the pain associated with external fixation, prolonged courses of narcotics may be required, leading to associated problems. Transfixion of the soft-tissue envelope by half pins and wires makes it more difficult for the patient to maintain range of motion (ROM) during treatment.[6]

Intramedullary (IM) lengthening nails can be used as an alternative to external fixation in patients with limb-length discrepancies.[7-9] However, these devices do not have the capacity to perform additional deformity correction. Fixator-assisted nailing and plating techniques have been developed to help make acute osteotomy corrections more accurate.[10-13] A temporary external fixator is used intraoperatively to adjust the alignment until the desired correction is obtained. A plate or rod is then inserted to maintain the correction, and the external fixator is removed. Previous studies have demonstrated that this method can successfully correct deformities and restore limb alignment without the need for postoperative external fixation.[10-13] Alternatively, the surgeon can use the IM lengthening nail to maintain in-

traoperative, fixator-assisted, acute correction of the limb alignment and then gradually correct the limb-length discrepancy postoperatively. One concern, however, is that the gapping and loss of bone contact that occurs at the acute osteotomy site has a detrimental effect on the subsequent formation of regenerate bone.

This study presents the results of simultaneous deformity correction and lengthening using a retrograde femoral Precice nail (NuVasive). The aim of the study was to demonstrate the efficacy of the Precice nail in limb lengthening and deformity correction. Outcome measures included final alignment, limb length, consolidation index, and knee motion.

Methods

Design and Cohort

This study was a multicenter retrospective case series. Institutional Review Board approval was obtained at each institution (ie, Nemours Children's Hospital, Hospital for Special Surgery, and Loma Linda University). All 27 patients underwent simultaneous fixator-assisted acute deformity correction and insertion of a retrograde femoral Precice nail.

At the time of surgery, the patients had a mean age of 28 ± 13.9 years (range, 13 to 57 years) and a mean body mass index (BMI) of 27.3 ± 6.9 (range, 16.6 to 43.0). The mean Limb Lengthening and Reconstruction Society (LLRS) AIM score was 4.6 ± 2.3 (range, 1 to 11). (The LLRS AIM score is a classification system used to standardize the complexity of the procedures.) All patients had a limb-

length discrepancy and secondary deformities, specifically valgus (15 patients), varus (10 patients), external rotation (1 patient), and apex anterior (1 patient) deformities.

Indications

Treatment with an IM lengthening nail can be considered for any patient with a limb-length deficiency that can be managed with long bone distraction osteogenesis. Juxta-articular deformity requires substantial translation at a metaphyseal osteotomy site and is difficult to control with an IM nail. Therefore, this technique is best suited for deformity in the diaphyseal or metadiaphyseal area.
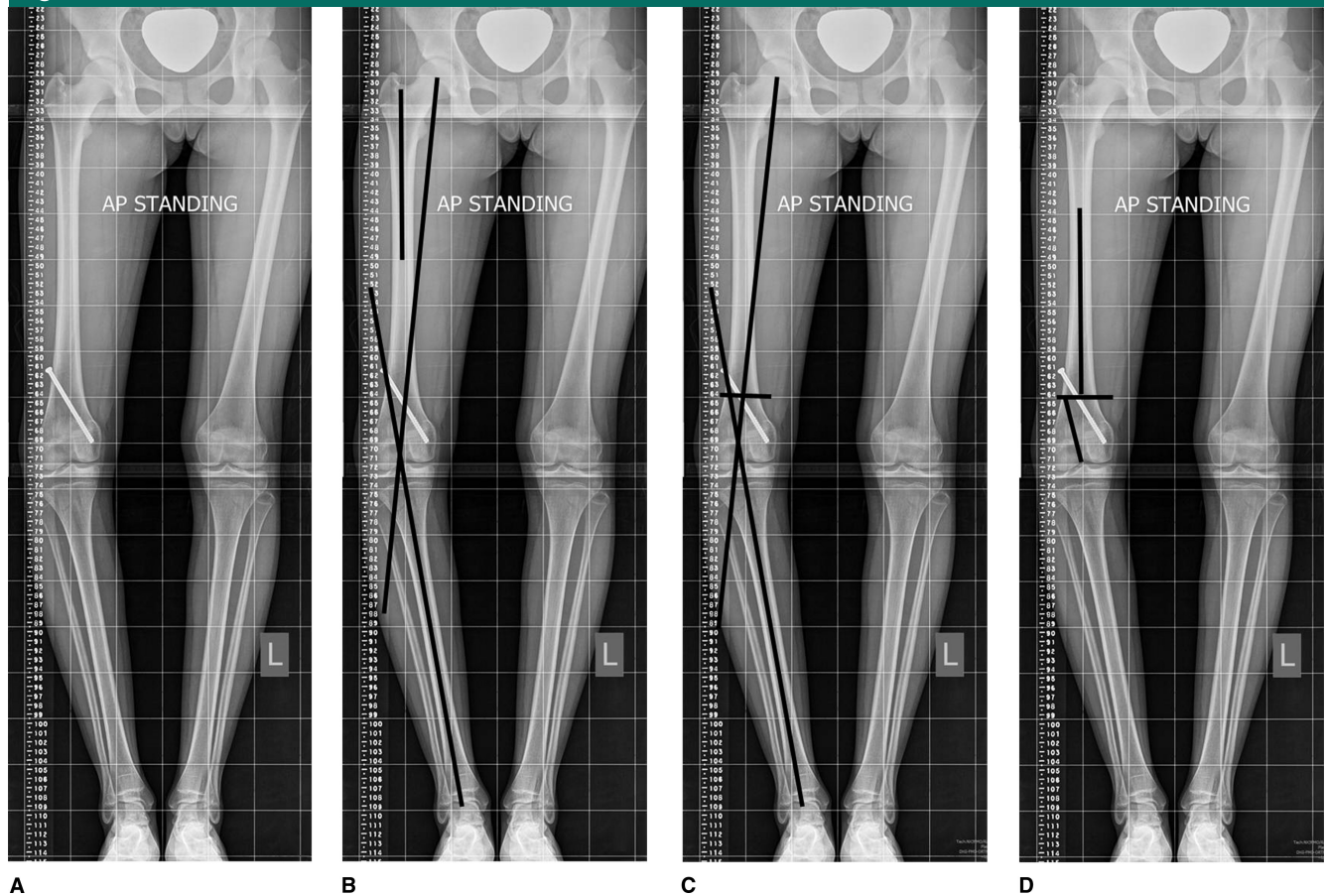
Contraindications

A narrow diaphyseal canal diameter is a relative contraindication to deformity correction and limb lengthening using a retrograde femoral nail. The canal must be able to accommodate a 10.5-mm reamer for an 8.5-mm nail. Ideally, a larger nail can be used. A 5-mm thickness of cortex must remain circumferentially after reaming to reduce the risk of fracture.

A high body mass index is a relative contraindication to simultaneous deformity correction and lengthening using a retrograde femoral Precice nail because the thickness of the patient's thigh will affect the external magnetic signal. For an 8.5-mm nail, a distance of >38 mm between the IM lengthening nail and the skin surface will preclude the use of the nail. For a 10.7-mm diameter nail, the requisite distance is <51 mm. Because postoperative weight-bearing restrictions are necessary, the inability to comply

Figure 1

AP standing radiographs of the lower extremities demonstrating deformity correction in a 14-year-old girl with 14° of distal femoral varus and a 24-mm limb-length discrepancy after a traumatic, partial distal femoral physeal arrest. **A,** AP standing radiograph of the lower extremities prior to measurement of the mechanical axes. **B,** The mechanical axes are measured to assess the amount and location of the deformity. The long, black lines represent the mechanical axes of the proximal and distal femur. The intersection of these lines is near the knee joint and represents the apex of the deformity. The short line represents the anatomic axis of the proximal femoral segment. **C,** The proposed osteotomy site (transverse black line) must be far enough away from the joint that the intramedullary nail will be able to control the distal fragment. This osteotomy site will require translation because it will be distal to the apex of the deformity. **D,** The magnitude of the deformity and the necessary translation were transferred into an anatomic axis planning model. Because the intramedullary nail needs to occupy the canal proximally, all of the varus must be corrected in the distal fragment. The black lines represent the path of the intramedullary nail that will be required to fully correct the deformity. They must be collinear after the nail insertion, which will require substantial translation.

with partial weight bearing is a contraindication. Osteopenia is another contraindication; in patients with poor bone quality, the locking screws may loosen and back out of the nail. Alternatively, the bone may deform around the loose screws during lengthening.

Any active infection in the bone to be lengthened is a contraindication to the procedure. Patients who have undergone successful treatment for prior infections should be considered

high risk, although the procedure is not contraindicated in these patients. Patients who have had previous external fixation with possible history of pin-track infections are considered to be at moderate risk for deep infection of the IM lengthening nail. Finally, an open physis is a concern. Placing an IM lengthening nail across an open physis is a high-risk endeavor that should be approached with caution and requires substantial expertise to avoid physeal closure.

Preoperative Planning and Surgical Technique

Four surgeons (C.A.I., S.R.R., S.N., A.F.) performed the procedure using a similar method for preoperative planning and the surgical technique. Preoperatively, an AP standing radiograph of the lower extremities was obtained (Figure 1, A). The mechanical axes of the proximal and distal femur were measured (Figure 1, B). The surgeons selected an osteotomy site that would not be too

Figure 2

Intraoperative photograph of a thigh demonstrating the placement of half pins distal and proximal to the proposed osteotomy site. The incision for the percutaneous osteotomy is visible on the distal anterolateral thigh.

Figure 3

Intraoperative photograph of a thigh demonstrating maintenance of the acute correction with the use of a fixator mounted posterior to the planned path of the nail. A ball-tipped guidewire is visible entering the distal femur.

Figure 4

Intraoperative photograph of a thigh demonstrating anterior mounting of a second external fixator. The second fixator controls the flexion/extension of the segment and can be used if a sagittal plane correction is necessary.

distal to allow the IM lengthening nail to control the distal fragment (Figure 1, C). The magnitude of deformity and the necessary translation were transferred into an anatomic axis planning model (Figure 1, D). The planned lengthening was an average of 3 cm, which would have a minimal effect on the mechanical axis. Thus, special consideration was not given to correcting this expected mild valgus deformity. For patients who require a lengthening >3 cm, the surgeon must consider the effect that lengthening along the anatomic axis can have on the mechanical axis.

Intraoperatively, the knee was kept in approximately 40° of flexion. Through a percutaneous incision, multiple drill holes were made at the distal femoral osteotomy site. The osteotomy was made ≥5 cm proximal to the distal end of the nail because of the pattern of the locking screw used with the Precice nail. The osteotomy site should be as close to the apex of the deformity as possible. The anatomy and the quality of the soft tissue and bone may influence the location of the osteotomy. When the osteotomy level did not match the apex of the deformity, translation of the distal femoral fragment was performed to maintain the mechanical axis of the limb.

A half pin was placed perpendicular to the distal femoral mechanical axis and either anterior or posterior to the planned path of the nail. For extra precision, a guidewire may be inserted initially anterior or posterior to the proposed path of the nail. Once the guidewire position is found to be satisfactory, a cannulated drill may be used to prepare a path to ensure exact placement of the half pin and to avoid the IM canal. If necessary, a second half pin can be added in the distal segment. A single half pin was placed perpendicular to the mechanical axis of the femur proximal to the planned ending point of the nail (Figure 2). Placement of the pin perpendicular to the mechanical axis rather than to the anatomic axis of the femur allowed the lengthening to occur along the mechanical axis of the femur. This method helped to prevent inadvertent valgus deformity, which can result when lengthening occurs along the anatomic axis.[14] The percutaneous osteotomy was completed with the use of a thin, sharp osteotome. To avoid thermal necrosis of the bone, a sagittal saw was not used. Acute correction of the deformity was performed. The amount of correction was adjusted with the fixator half pins until the

mechanical axis was adequately corrected. The correction was confirmed with the use of either the electrocautery cord technique (placement of a tightly stretched cord over the center of the hip and the ankle) or a radiopaque straight-line grid placed under the patient on the operating table. After the desired alignment was achieved, the fixator pins were connected with a bar and locked in place (Figure 3).

If control of the flexion/extension of the segment was a concern, or if a sagittal plane correction was necessary, a second fixator was mounted anteriorly (Figure 4). These half pins were placed perpendicular to the femur at their respective levels in an anterior-to-posterior direction. The distal half pin was placed medial or lateral to the path of the nail, and the proximal half pin was placed proximal to the planned nail ending point. Alternatively, a single distal half pin was inserted and incorporated into the external fixator (Figure 5). A guidewire was inserted into the distal femur such that the guidewire was visible in the center of the femur on the sagittal fluoroscopic view and aiming toward the center of the proximal femoral canal on the AP fluoroscopic view. In

patients with a varus deformity, a slightly medial entry point in the trochlear notch was used to allow more angulation of the distal fragment. In patients with a valgus deformity, a slightly lateral entry point was used.

An entry reamer was placed over the guidewire and advanced into the distal femoral canal to the appropriate depth. With the entry reamer in place, blocking screws were placed to guide the path of the subsequent flexible reamers. The anterior-to-posterior blocking screws were placed on the concave side of the deformity as close to the entry reamer as possible. The lateral-to-medial blocking screw was placed posterior to the nail and close to the entry reamer. A cannulated drill over a guidewire was used to place the screw in an exact location. The drill bit was left in place during the reaming of the femur, and the screw was inserted at the end of the procedure. Alternatively, a 5-mm half pin was inserted and left in place during the reaming. A 5.5-mm screw could then be placed in the half pin hole at the end of the procedure. The entry reamer was removed, and a ball-tipped guidewire was inserted into the femoral canal and passed across the osteotomy site into the proximal femur. Sequential reaming of the femur was performed with flexible or rigid reamers over the ball-tipped guidewire. The canal was reamed to approximately 2 mm larger than the size of the Precice nail to be inserted.

The Precice nail was inserted carefully without force. Additional reaming was performed when necessary. The Precice nail comes in two types: a straight nail and a nail with a 10° distal bend. In patients with sagittal plane deformity, the nail with the 10° bend can be used to help obtain correction. The distal and proximal interlocking pegs were inserted into the nail. The drill bit or half pins used for blocking during the reaming were replaced with a 5.0- or 5.5-mm screw (Figure 6). The

Figure 5

Intraoperative photograph of the leg demonstrating an alternative method to control the sagittal plane of the distal segment using one anterior-to-posterior half pin incorporated into the fixator.

temporary external fixator was removed.

Postoperatively, patients were allowed 50- or 70-lb weight bearing depending on their nail diameter (10.7 or 12.5 mm, respectively). Venous thromboembolic prophylaxis was initiated on postoperative day 2 in adult patients. Patients' medications varied depending on the postoperative protocol at each medical center. Medications included aspirin, rivaroxaban, and enoxaparin. Because this study was retrospective, we did not control for the choice of venous thromboembolic prophylaxis. Lengthening adjustments began after 4 to 7 days at a rate of 0.99 to 1.0 mm per day. Adjustments were performed four times daily in 0.25-mm increments or three times daily in 0.33-mm increments. Patients were seen for follow-up every 1 to 2 weeks, at which time radiographs were obtained and rate adjustments were initiated.

Data Collection

Study data were recorded using REDCap (Research Electronic Data Capture),[15] which is a secure, web-based application that is designed to support data capture for research studies, providing an intuitive interface for validated data entry, audit trails for tracking data manipulation and export procedures, automated

Figure 6

Intraoperative lateral fluoroscopic image of the distal femur demonstrating the open physis and typical placement of blocking screws in the coronal and sagittal planes to maintain the correction during the lengthening process in an adolescent patient. The authors have observed that physeal closure will not occur if the nail remains across the physis. If the nail is removed, a physeal bar will form. An end cap can be added later to prevent excessive involution of the nail (with growth) past the physis in a younger child.

export procedures for seamless data downloads to common statistical packages, and procedures for importing data from external sources. Preoperative demographic data, LLRS AIM scores, and relevant anatomic angles of the lower extremity were recorded.[16] Pertinent surgical data that were recorded included the Precice nail diameter and length, the length of surgery, and surgical blood loss. Postoperative outcomes included final corrected anatomic angles, including the mechanical axis deviation (MAD), mechanical lateral distal femoral angle (LDFA), posterior distal femoral angle (PDFA), and limb-length discrepancy; knee ROM; the amount of lengthening obtained;

the percentage of desired lengthening achieved; the percentage of preoperative bone length gained; the number of lengthening days; the rate of lengthening; the rhythm of lengthening; the time to full weight bearing; the time to full consolidation; a bone-healing index; and the Association for the Study and Application of Methods of Ilizarov (ASAMI)–Paley score,[17] which assesses return to function after surgery. Although it has not been validated, the ASAMI–Paley score has been used as an outcome measure for many years in the field of limb deformity correction. It was used in this study as a postoperative measure of success or failure. This score consists of a subjective pain/function outcome score and an objective bone score. An excellent score is achieved with full healing at the osteotomy site and a minimal residual limb-length discrepancy. A good score denotes persistent angular deformity or limb shortening despite surgical correction. In addition to postoperative assessment, patients were observed for postoperative complications.

Statistical Analyses

Descriptive statistics were calculated as mean ± SD. The preoperative and postoperative measurements were compared with standard values for normal limb alignment: LDFA, 88°; PDFA, 83°; and MAD, <10 mm medial to the center of the knee joint.[18] Comparisons were made using pairwise two-tailed unpaired Student t-tests or one-sample Student t-tests, with $P < 0.05$ defining statistical significance. Statistical analyses were performed using Instat (GraphPad Software).

Results

Preoperatively, the mean LLRS AIM score was 4.6 ± 2.3 (range, 1 to 11). All patients had a limb-length dis-

crepancy and secondary deformities, including valgus deformity (15 patients), varus deformity (10 patients), and external rotation (1 patient) and apex anterior (1 patient) deformities. The mean preoperative MAD was 22.1 ± 12.6 mm. The mean limb-length discrepancy was 30.9 ± 12.9 mm. With 88° considered as the normal LDFA, the patients had an average 7.6° of deformity preoperatively (maximum, 15°). The mean deviation from 88° was statistically significant for patients with varus or valgus deformity ($P = 0.0004$ and $P < 0.0001$, respectively; one-sample Student t-tests). The PDFA was an average of 82.1° ± 7.2° preoperatively. Preoperatively, the average knee extension was 2° short of full extension (two patients had 10° less than full extension, and two patients had 20° less than full extension). Knee flexion was an average of 127° ± 23.1° preoperatively (four patients had <130° of knee flexion). The average preoperative knee arc of motion was 125° ± 22.5°.

The external fixator construct consisted of one half pin in each segment for 22 patients (81%) and two distal half pins with one proximal half pin in 5 patients (19%). Twelve patients had 5-mm half pins placed, and 15 patients had 6-mm half pins. The average number of blocking screws (5.0 or 5.5 mm) placed per patient was 1.3 screws (range, 0 to 3 screws).

The latency period to limb lengthening averaged 5 days (range, 4 to 10 days). The mean postoperative limb-length discrepancy was 0.8 mm, with 25 of 27 patients (93%) corrected to within 3 mm. Two patients had 6-mm residual limb-length discrepancies. The average lengthening was 30 mm. The mean postoperative MAD was 6.1 ± 4.4 mm, with 22 of 27 patients (81%) corrected to within 8 mm of neutral (ie, zero). The LDFA was corrected to a mean of 88° post-

operatively. The mean postoperative LDFA values for the varus and valgus groups were not substantially different from 88° using one-sample Student t-tests. The mean postoperative PDFA was 88.4° ± 3.0°. The mean acute angular correction performed was 7°, with a maximum of 15°. Mean follow-up was 12.9 ± 5.2 months (range, 7 to 29 months). The mean consolidation index was 42 days/cm.

Postoperatively, knee extension was 0.6° ± 1.6°, with all patients within 5° of full extension. The mean knee flexion was 124° ± 21.7°. Flexion measured <130° in 10 patients (37%). The mean postoperative knee arc of motion was 123° ± 21.5°. The mean time to full weight bearing was 89 ± 33.7 days (range, 48 to 184 days). ASAMI–Paley scores were excellent for 26 patients (96%) and good for one patient. No patients had any infections, fractures, implant mechanical failures, or implant breakage. No patients had insufficient regenerate bone formation.

Complications developed in four patients (15%). One patient, who had chronic pain, required a slow lengthening rate that led to premature consolidation. Posterior tibial subluxation developed in one patient, requiring revision surgery. This patient had fibular hemimelia with a preoperative valgus deformity and an anterior cruciate ligament–deficient knee. The patient was undergoing simultaneous femoral and tibial lengthening. The subluxation resolved after excision of the fascia lata combined with hamstring and gastrocnemius-soleus complex lengthening. One patient required arthroscopic lysis of adhesions to improve knee flexion. In the other patient, a flexion deformity (malunion) developed during lengthening. This patient required an extension osteotomy of the distal femur with plating to correct this residual sagittal plane deformity. This patient's index surgery

was the first retrograde procedure performed, and the correct use of blocking screws was not implemented.

The preoperative characteristics of patients with valgus and varus deformity were similar (Table 1). The patients with valgus deformity had slightly better angular correction postoperatively, although all patients with varus deformity achieved the desired lengthening and had excellent ASAMI–Paley scores (Table 2). Three of 15 patients in the valgus group required secondary surgery; however, the proportion of patients in this group who required secondary surgery was not statistically significantly different from that of the varus group (0 of 10 patients; $P = 0.25$) (Fisher exact test).

Because the goal was correction of the MAD to <10 mm medially, a separate analysis of the five patients who had a final MAD of ≥10 mm was performed. Compared with the 22 patients with MAD of <10 mm, patients with a final MAD of ≥10 mm had no substantial differences in outcomes. Of the 12 patients whose deformity was corrected intraoperatively with 5-mm half pins, 4 patients had final correction with a MAD ≥10 mm, compared with only 1 of 15 patients in whom 6-mm half pins were used. Of the 17 patients in whom no blocking screws were used or one blocking screw was used, 4 patients (24%) had a final MAD of ≥10 mm. Only 1 of the 10 patients in whom two or more blocking screws were used had a final MAD ≥10 mm. One of the two patients with an 8.5-mm nail and 3 of the 15 patients with a 10.7-mm nail had a final MAD of ≥10 mm. Only 1 of the 10 patients with a 12.5-mm nail had a final MAD of ≥10 mm. Among the five patients with MAD of ≥10 mm, three short-length nails (215 mm, 230 mm, and 230 mm) and two long-length nails (330 mm and 355 mm) were used. Thus, the nail length did not seem to affect the

outcome. The average time to full weight bearing in the five patients with MAD of ≥10 mm was 79 days, compared with 92 days for the other 22 patients.

Discussion

The use of IM lengthening nails, such as the Precice nail, has revolutionized the field of limb lengthening.[7-9,19-21] Instead of requiring months of postoperative external fixation, patients can now undergo limb lengthening with a completely internal device. Patients who undergo IM limb lengthening have less pain, maintain better ROM, and experience fewer infections compared with patients who undergo lengthening with external fixation.[22] Fixator-assisted nailing and plating techniques have been developed to allow surgeons to correct deformity with the use of internal implants only.[10-13] In these techniques, the external fixator is applied temporarily in the operating room to obtain the desired limb deformity correction, and then the internal hardware (nail or plate) is inserted to maintain the correction.

Table 1

Preoperative Characteristics of Patients With Valgus or Varus Deformity[a]

Preoperative Characteristics	Patients With Valgus Deformity (n = 15)	Patients With Varus Deformity (n = 10)
Mechanical lateral distal femoral angle (degrees)	81.5 ± 3.4	96.7 ± 5.0
Limb-length discrepancy (mm)	31.3 ± 10.4	30.3 ± 17.0
Mechanical axis deviation (mm)	23.7 ± 11.0	24.1 ± 12.5
Limb Lengthening and Reconstruction Society AIM index	4.06 ± 1.8	4.7 ± 2.3

[a] Values are mean ± SD.

Table 2

Postoperative Characteristics of Patients With Valgus or Varus Deformity[a]

Postoperative Characteristics	Patients With Valgus Deformity (n = 15)	Patients With Varus Deformity (n = 10)
Mechanical axis deviation (mm)	5.4 ± 4.4	6.9 ± 4.8
Mechanical lateral distal femoral angle (degrees)	87.3 ± 2.0	90.1 ± 3.7
Mean percentage of desired length attained	99.1	100
Percentage of patients achieving excellent ASAMI–Paley scores	93	100
No. of blocking screws used	1.3 ± 0.8	1.4 ± 1.3
No. of patients requiring secondary surgery	3 (20%)	None

ASAMI = Association for the Study and Application of Methods of Ilizarov
[a] Values are mean ± SD except as noted.

Figure 7

Intraoperative AP fluoroscopic image of the distal femur demonstrating appropriate translation and angulation after acute correction of the patient's deformity. Note the placement of a blocking screw on the concave side of the deformity (medial to the nail).

Baumgart[23] previously described femoral deformity correction with the use of the "reverse planning" method. In this technique, a series of preoperative templates is drawn to plan the surgery. As an alternative method, the fixator-assisted nailing technique can be used. The results of our study show that the retrograde femoral Precice nail can be used safely and accurately to correct both limb-length discrepancy and deformity with minimal risk of complications (Figures 6 to 8). On the basis of the final ASAMI–Paley scores, 96% of the patients had an excellent outcome. To our knowledge, this series represents the largest reported number of procedures performed using this technique. In our study, the average preoperative limb-length

Figure 8

Postoperative AP standing radiograph of the lower extremities demonstrating restoration of the mechanical axis and leg lengths after fixator-assisted femoral nailing with a retrograde Precice nail (NuVasive). The mechanical axis (white line) is slightly medial and well within normal parameters.

discrepancy was 31 mm. All patients had successful correction to leg lengths within normal limits (<10 mm final discrepancy). The final average limb-length discrepancy was 0.8 mm. Lengthening was

achieved in every patient to within 6 mm of residual discrepancy, and 93% of the patients achieved correction to within 3 mm. This result is similar to the findings in a previous study, in which the lengthening achieved with the Precice nail was found to be 96% accurate.[20] No device failure or breakage occurred during the lengthening process.

The ability to maintain knee ROM during the lengthening process is one of the major advantages of IM limb lengthening.[21] Our series reinforces this concept. After an average of 30 mm of lengthening, the average functional knee arc of motion was 123°, which is not markedly different from the preoperative arc of motion (125°). This outcome may have been influenced by the emphasis on daily ROM exercises during the postoperative rehabilitation. The excellent results demonstrate the advantage of postoperative physical therapy that is not hindered by the presence of an external fixator. In contrast, external fixation is associated with a reduction in final knee flexion and a need for quadricepsplasty.[24]

In addition, bone healing after IM limb lengthening progressed rapidly, allowing patients to return to full weight bearing without assistive devices at an average of 89 days after undergoing 3 cm of lengthening. This relatively fast return to ambulation is probably related to two factors. First, because the nail is an IM device, it protects the regenerate bone from deformation during the healing process. Second, the smooth axial distraction produced by the Precice nail creates excellent regenerate bone despite a loss of bone contact at the initiation of distraction. Unlike mechanically actuated IM nail designs,[25,26] the Precice nail does not require twisting of the regenerate bone as it distracts. Because of its design, the Precice nail lengthens along the axial plane with pure distraction. No patient

required bone grafting, bone marrow aspirate injection, bone stimulators, or any other type of augmentation to achieve full healing of the regenerate bone. Healing progressed so well that one adult patient had premature consolidation. The low incidence of delayed union (none of 27 patients) is less than that observed during a study of lengthening over a nail without deformity correction (the standard for lengthening before the advent of the Precice nail), which was 1 of 22 patients (5%).[24] Higher rates of delayed union with the Precice nail have been reported in patients requiring tibial lengthening[20] and in patients with congenital femoral deficiency,[27] neither of which were included in this study. Other studies of the use of retrograde femoral IM lengthening nails with acute deformity correction have reported rapid healing with low consolidation indices.[28,29]

These prior studies all involved the use of a percutaneous osteotomy with minimal periosteal stripping. The osteotomy is predrilled, and then reaming is performed. This technique ensures deposition of the reamings at the lengthening site, which may contribute to healing. However, the risk of unwanted consolidation is higher. In our experience, an initial accelerated rate of distraction (4-day latency and 1.32 mm/d for 4 days) is recommended to avoid this complication. The acute deformity correction did not affect the ability to form robust regenerate bone. Although the maximum deformity corrected in this series was 15°, other series have shown that up to 20° of deformity can be corrected with this technique.[8,27-32]

The fixator-assisted technique used in our study allowed a correction of the mean MAD from 24 mm to 6 mm, with 81% of patients having final alignment restored to normal (MAD <10 mm). This result is similar to the accuracy of external fixation–mediated correction of femoral varus and valgus deformity, which has been reported to yield correction of the MAD to within 10 mm in 85% of patients.[13] This finding includes procedures in which a postoperative adjustment of the external fixator was used to fine-tune the correction.

The subgroup of five patients with a final MAD of >10 mm did not have worse preoperative deformity, worse LLRS AIM scores, or longer surgical times than did other patients. The size of the half pins used in the temporary external fixator construct and the number of blocking screws used may have influenced the outcome. Four of these patients had 5-mm half pins. These smaller-diameter pins may not have been able to control the femoral segments as well as the stiffer 6-mm–diameter half pins could have. One blocking screw or no blocking screws were used in four patients in this subgroup, which highlights the importance of the blocking screws and suggests that at least two screws be inserted to obtain optimal alignment. The blocking screws serve a dual purpose: They help to guide the reaming to create the ideal path for the nail, and they help to maintain the alignment in the femoral metaphysis during the lengthening and consolidation phases. Inserting a nail with a larger diameter seemed to improve the MAD outcome. The average time to full weight bearing was just 79 days, compared with 92 days for the other 22 patients. Placing full weight-bearing stress on the construct too early may cause a loss of alignment.

This study has several limitations. It is a retrospective, level IV study with the inherent shortcomings of this type of research. The series of patients is relatively small, and larger studies must be performed to confirm our findings. This series represents the results of procedures performed by four different surgeons from three different medical centers, and bias may have occurred. Finally, the study does not include data regarding outcomes after nail removal. Because this nail contains a strong magnet and has internal machinery, removal of the nail after completion of the treatment, typically 6 to 12 months after insertion, is recommended. The need for this additional procedure may cause increased morbidity that was not considered in this review.

Conclusion

This study confirms that deformity correction combined with gradual lengthening using a retrograde femoral Precice nail can be performed successfully. Acute correction of ≥15° is possible. Appropriately placed blocking screws are important to ensure maintenance of the acute correction. Close monitoring of the soft tissues during the lengthening process is mandatory to prevent joint contracture or subluxation.

References

Evidence-based Medicine: Levels of evidence are described in the table of contents. In this article, reference 5 is a level I study. References 6, 10, 22, 26, 28, and 29 are level II studies. References 1-4, 8, 13, 16, 19, 24, and 30 are level III studies. References 12, 17, 20, 23, 25, and 27 are level IV studies. References 7, 9, 11, and 14 are level V expert opinion.

References printed in **bold type** are those published within the past 5 years.

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