Limb Lengthening With Precice Intramedullary Lengthening Nails in Children and Adolescents

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Background: The Precice intramedullary bone lengthening nail has been used in our department since 2013. We sought to determine the efficacy and safety of intramedullary limb lengthening with Precice nails in children and adolescents.

Methods: We retrospectively investigated patients 18 years and younger who underwent lower-limb lengthening using the Precice nail. Radiologic and clinical outcome data were obtained from a prospective database. The minimum postimplantation follow-up was 12 months. Between March 2013 and March 2020, 161 patients underwent limb lengthening with a Precice nail; 76 patients met the inclusion criteria.

Results: We used 84 nails in 76 patients (68 femurs and 16 tibias). Femoral nails were inserted using an antegrade approach in 57 patients and a retrograde approach in 11. The mean age at surgery was 16 years (range, 9 to 18 y). The mean lengthening was 33 mm (range, 14 to 80 mm) with additional acute axial or rotational malalignment correction in 16 segments. At the last follow-up (mean = 2.1, years; range, 1 to 5 y), all regenerates had healed and all patients were mobile with full weight-bearing. Complications that necessitated surgical revision occurred in 6 patients (8%), and the desired lengthening was not achieved in 2 patients. Postlengthening malalignment occurred in 4 patients (5 tibial nails). The weight-bearing index, defined as days from surgery to full weight-bearing/cm of lengthening, was a mean of 45 days (range, 7 to 127 d/cm).

Conclusions: The Precice nail facilitated reliable and safe bone lengthening and was associated with a low complication rate. Correction of additional malalignment was possible by applying intraoperative acute correction or guided growth.

Level of Evidence: Level IV—therapeutic study investigating the results of treatment.

Key Words: limb lengthening, Precice intramedullary nails, pediatric patients, adolescent patients

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Compared with limb lengthening using external fixation, intramedullary limb lengthening is associated with shorter rehabilitation, less pain, and greater patient comfort.[1] The use of the first clinically approved lengthening nails, such as the intramedullary skeletal kinetic distractor (Orthofix International, Verona, Italy) and the Fitbone nail (Wittenstein Intens, Igersheim, Germany) was challenging in pediatric patients. The intramedullary skeletal kinetic distractor femoral and tibial nails were sufficiently small for use in certain adolescents; however, the high associated complication rates, particularly uncontrollable distraction speed,[2–5] contraindicated their use in our patients. The Fitbone nail introduced in the late 1990s has a controllable distraction mechanism; however, this nail was available to selected centers only.[6,7] We used this nail in 50 patients between 2007 and 2013. The smallest nails measured 11 mm in diameter and were too large for many adolescents and young adults. The introduction of the Precice nail (NuVasive Inc., San Diego, CA) expanded the indications and made intramedullary lengthening possible in children and adolescents. The availability of small-sized nails (8.5 mm) renders intramedullary limb lenghtening more applicable to a pediatric and adolescent patient population, with promising clinical results reported in preliminary studies.[8–11] Antegrade femoral lengthening using a trochanteric entry approach proved to be safe with regard to the risk of avascular necrosis and growth disturbances in patients as young as 8 years.[12]

We began using the Precice nail system in 2013 in patients 18 years and younger. The outcomes after limb lengthening using Precice nails in pediatric patients have been reported in only small case series; only 1 study reported their use in a larger consecutive pediatric patient cohort.[13] We investigated the efficacy and safety of intramedullary limb lengthening with Precice nails in children and adolescents.

METHODS

With this single-center retrospective study that was approved by the local ethics committee, we investigated consecutive patients who underwent long-bone lengthening. Inclusion criteria were lower-limb lengthening with the Precice intramedullary lengthening nail and age of 18 years or younger at the time of surgery. Exclusion criteria were use of other bone lengthening techniques and

upper-extremity lengthening. Radiologic and clinical outcome data were obtained from our prospective database. The minimum postimplantation follow-up was 12 months.

Surgical Procedures

Precice implantation was performed based on the deformity, age, and etiology. A femoral antegrade approach was considered for children older than 8 years who did not have substantial frontal plane knee deformity or deformity that could be addressed with guided growth. Retrograde femoral nail implantation was used in patients with frontal or sagittal plane deformity with a closed distal femoral physis. Tibial nail implantation was performed for tibial shortening with or without deformity in patients with closed proximal tibial physes. Blocking screws were used to stabilize acute correction and to prevent regenerate deformity during lengthening with retrograde femoral and tibial nail implantation.

Patients with shortening secondary to a longitudinal deficiency and knee instability underwent lower-limb bracing using a knee-ankle-foot orthosis during lengthening. All patients received postoperative physiotherapy initiated on the first postoperative day. After a latency period of 6 to 7 days, lengthening was started at a rate of 1 mm/d (0.25 mm 4 times) for femoral lengthening and 0.75 mm/d (0.25 mm 3 times) for tibial lengthening. A latency period of 7 days was considered if the patient was older, for diagnoses of congenital femoral deficiency (CFD) and fibular hemimelia , and generally for all tibial lengthenings. Touch-down to partial weight-bearing mobilization was recommended depending on patients' weight, nail diameter, and compliance until consolidation of 2 to 3 cortices. In patients who received Precice Stryde nails, partial weight-bearing was introduced as soon as tolerated and full weight-bearing (FWB) was initiated after confirmation of consolidation of 1 or 2 cortices. The weight-bearing limits prescribed in our clinic were lower than the weight-bearing limits recommended by the implant manufacturer for both Precice and Precice Stryde nails.

Postoperative follow-up was conducted once a week with radiographs that included the adjacent joints during the lengthening process. The callus formation was monitored at each follow-up, and the rate of distraction was reduced in cases of poor callus formation. Afterward, patients were seen and radiographs were obtained every 6 weeks. Full-length anteroposterior and lateral view radiographs (hip to ankle) of both lower extremities were obtained in standing position using a calibration marker preoperatively and at various time intervals during follow-up. Removal of the Precice nail was typically performed 9 to 12 months after complete circumferential healing. In some tibial lengthening cases, removal of the fibula transfixation screws and/or blocking screws and/or far end nail locking screws was performed before removal of the Precice nail when circumferential healing took a longer time despite FWB.

Deformity analysis was performed based on standard measurements[14] using only full-length standing radiographs. The residual limb length deformity (LLD), mechanical axis deviation (MAD), and neck-shaft angle (NSA) were measured.

Between March 2013 and March 2020, 161 patients underwent lengthening with a Precice nail; 76 patients (38 female and 38 male patients, 84 nails) met the inclusion criteria (Table 1). The mean patient age at the time of surgery was 16.3 years (range, 9 to 18 y), and 47 patients (62%) were age 16 years and younger. Epiphysiodesis was performed in 28 patients before Precice implantation, with permanent epiphysiodesis in 10 patients, guided growth in 14, and a combination of these procedures in 4. External fixation had been used for fracture treatment or previous limb lengthening in 28 patients.

We used 84 nails in 76 patients; 70 patients underwent lengthening of 1 bone segment, 2 underwent simultaneous bilateral lengthening (4 nails), 2 underwent simultaneous femoral and tibial lengthening (4 nails), and 2 underwent consecutive lengthening [femur in 1 patient (2 nails) and femur and tibia simultaneously in the other (4 nails)].

We performed 68 femoral lengthening procedures (57 antegrade approach, 11 retrograde approach) and 16 tibial lengthening procedures. For types and diameters of the Precice nails, see Table 2. Deformity correction was combined with lengthening in 16 patients (retrograde approach: 11 femurs, 7 tibias; antegrade approach: 1 femur). The mean follow-up was 2.1 years (range, 1 to 5 y). At the time of the last follow-up, 70 nails had been removed and 9 patients with 9 nails were scheduled for nail removal.

RESULTS

Mean bone lengthening of 34 mm (range, 16 to 80 mm) was the goal, and mean bone lengthening of 33 mm (range, 14 to 80 mm) was achieved. Both-leg standing radiographs

TABLE 1. Indications for Precice Lengthening

Diagnosis	Patients, N = 76 (n)
Posttraumatic shortening	20
Hemi-hypotrophy	27
Congenital limb deficiency	15
Post-infectious shortening	5
Stature lengthening (1 epiphyseal dysplasia)	4
Rare conditions (multiple hereditary exostosis, avascular necrosis of the hip, Ollier disease, gigantism, and fibrous dysplasia)	5

TABLE 2. Types and Diameters of Precice Nails Used

Precice Nail Type and Diameter (mm)	Antegrade Femur	Retrograde Femur	Tibia
Precice 8.5	7		2
Precice 9 reinforced	3		3
Precice 10 Stryde	6		1
Precice 10.7	29	6	8
Precice 11 Stryde	2		1
Precice 12.5	10	5	1
Total	57	11	16

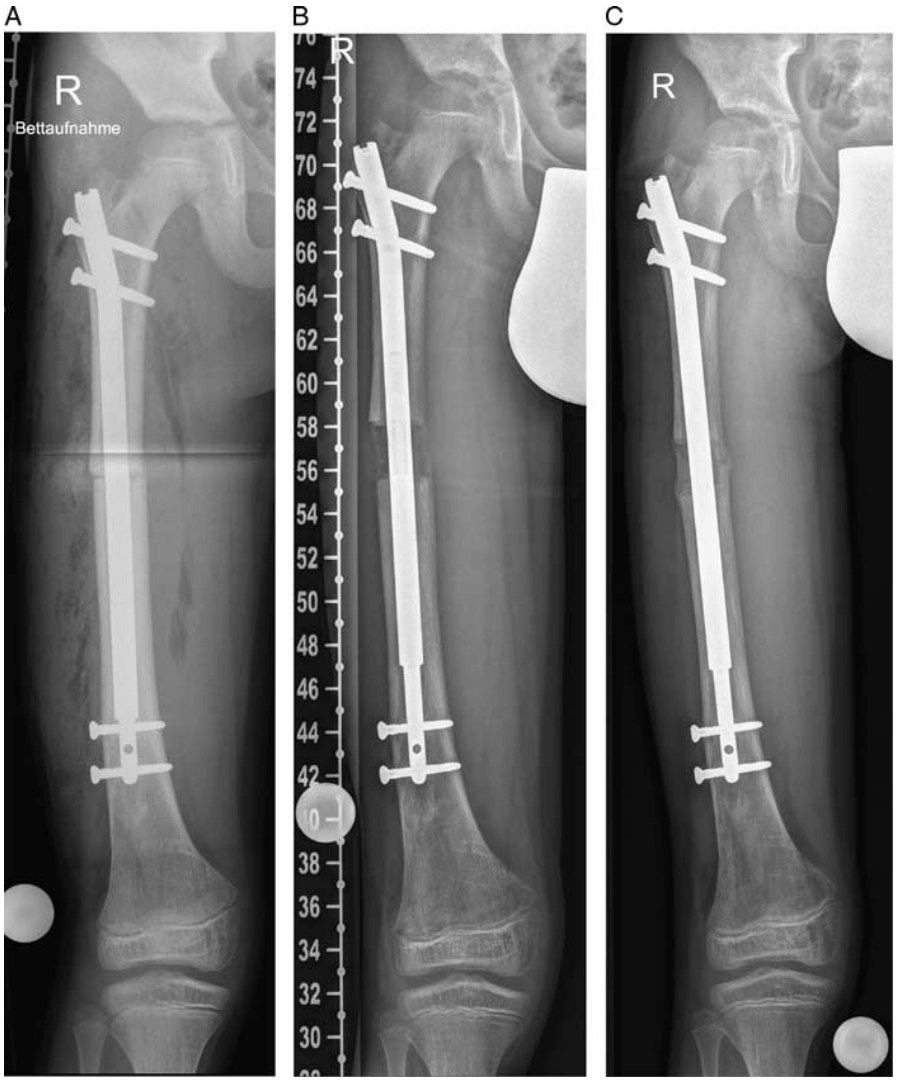

FIGURE 1. The youngest patient in this series presented with congenital femoral deficiency, anterior-posterior knee instability caused by cruciate ligament aplasia a limb length deformity (LLD) of 2 cm, and a predicted LLD at maturity of 5.5 cm. A 1-stage 5.5-cm lengthening at skeletal maturity would lead to a considerable risk of complications such as knee joint subluxation. In addition, the patient would have required a large shoe lift throughout his teenage years. A, A 2.5-cm lengthening was performed with a 10-mm-diameter Precice Stryde nail when the patient was age 9 years. Mild varus was present right after surgery which resulted (1) from the geometry of the femur and the relatively large nail but also (2) from the entry point. The entry point should have been more medial in regards to the anatomy. However, because the patient was very young, a very lateral entry point was chosen to minimize the risk of avascular necrosis. B, FWB was possible 2 weeks after surgery. C, Excellent bone healing was achieved 6 weeks after the end of distraction. A second Precice lengthening of the predicted residual 3 cm is planned at skeletal maturity.

after full consolidation were available for 70 of 76 patients. In 2 patients, the desired lengthening was not achieved secondary to complications. Leg-length equalization was not desired for 3 patients (Fig. 1). The remaining 65 of the 70 patients had a mean residual LLD of 3.5 mm (9 mm short to 5 mm over-lengthened) at treatment completion. An LLD $\leq$5 mm was observed at treatment completion in 59 of the 65 patients for whom it was desired (91%).

The mean time from surgery to FWB was 4.7 months (range, 0.5 to 11.5 mo). The time to FWB was >6 months for 6 patients with 8 nails (Table 3). The weight-bearing index (WBI) and healing index (HI) are summarized in Table 4. Based on Paley's[15] classification, we observed obstacles and complications in 11 (15%) of the 76 patients as follows: 3 obstacles in 3 patients (4%) and 11 complications in 9 patients (12%) (Fig. 2).

Device-induced complications occurred in 5 patients with 6 nails. The mechanism that prevents rotation between the male and the female nail components was broken (crown breakage) in 4 patients who received Precice P2.0 nails (diameter, 8.5 mm). The breakage resulted in delayed union with time to FWB of 10 months in 1 patient and residual LLD of 15 mm in another.

TABLE 3. Factors Associated With Time to Full Weight-bearing Over 6 Months for 6 Patients

Patients (n = 6; 8 Nails)	Description	Extent of Lengthening (mm)	Time to Full Weight-bearing (mo)
1	8.5-mm antegrade femoral nail, hemi-hypotrophy, partial nail failure and instability (crown breakage)	29	10
2	Bilateral 8.5-mm tibial nails, lengthening for correction of short stature	50 bilateral	10
3	8.5-mm tibial nail, fibular hemimelia, anteromedial callus deficit	26	11.5
4	8.5-mm femoral and tibial nails, simultaneous lengthening, epiphyseal dysplasia	98	7
5	12.5-mm tibial nail, posttraumatic deformity, anteromedial callus deficit	20	8
6	8.5-mm femoral nail, congenital femoral deficiency, multiple previous surgeries, out of the country, and inability to return for bone grafting	48	11

A Precice Stryde antegrade trochanteric nail (diameter, 10 mm) broke under the distal of the 2 proximal locking screws at the time of callus formation and resulted in mild varusization but did not necessitate nail exchange. Five of the 10 implanted Precice Stryde nails led to hyperostosis at the male-female junction, which could be attributed to an adverse tissue reaction. One of these 5 nails was removed because of suspected osteomyelitis.

Unplanned revision surgery was necessary in 6 patients (8%) (2 categorized as obstacles and 4 as complications based on Paley's classification).[15] Two patients who underwent retrograde lengthening required pseudarthrosis revision. One of those patients showed 3 healed cortices and was FWB; however, no bone healing was observed at the anterior aspect of the nail. Bone grafting was recommended for cases in which no increase of callus was observed on the radiographs obtained at 6-week intervals. Bone grafting was performed with an iliac bone graft and bone morphogenic protein BMP2 (Infuse; Medtronic, Minneapolis, MN). None of these cases showed signs of instability of fixation (eg, small nail:intramedullary canal ratio, lysis of screws). The nails were therefore not exchanged. Two patients required revision surgery to treat osteomyelitis. One patient who underwent tibial lengthening with a Precice Stryde nail developed a severe periosteal and endosteal reaction at the male-female junction after bone healing, which was attributed to possible osteomyelitis. The nail was removed, and the area underwent debridement. Histologic evaluation showed no abnormalities, and culture results were negative (Fig. 3). Another patient, in whom we performed antegrade femoral lengthening for Ollier disease using a Precice 2.1 nail, had chronic osteomyelitis of the bone anterolateral and superior to the distraction area when presenting for nail removal.

TABLE 4. Mean Weight-bearing and Healing Indices by Approach

Approach	Mean WBI	Mean HI
Antegrade femoral lengthening	40 d (range, 7-120 d/cm)	63 d (range, 13-358 d/cm)
Retrograde femoral lengthening	48 d (range, 25-70 d/cm)	125 d (range, 25-349 d/cm)
Tibial lengthening	65 d (range, 39-127 d/cm)	101 d (range, 39-309 d/cm)
Overall	45 d (range, 7-127 d/cm)	77 d (range, 13-358 d/cm)

WBI is defined as number of days from surgery to full weight-bearing/cm of lengthening.

HI is defined as number of days between surgery and full bone healing/cm of lengthening.

HI indicates healing index; WBI, weight-bearing index.

Postlengthening malalignment or deformity overcorrection occurred in 4 patients (5 extremities and 5 tibial nails, 5%), which was categorized as a complication. Joint subluxation was observed in 1 patient with CFD treated using a retrograde femoral nail, which was reversed with nail compression but led to residual LLD of 16 mm. Joint range of motion (ROM) returned to within 5 degrees of the preoperative ROM in all patients except 3 who underwent sagittal plane deformity correction. In those patients, knee ROM changed relative to the sagittal plane deformity correction. No intraoperative complications occurred and no avascular necrosis was found during follow-up of any patient who underwent antegrade femoral lengthening.

Standing radiographs were available for 50 of 57 extremities with antegrade femoral lengthening and showed a mean MAD change of 2.8 mm (range, 0 to 9 mm). We observed no association between lengthening and increased valgus, but we observed a change of >2 degrees between preoperative NSA and NSA at final follow-up in 27 patients. The NSA decreased (mean, 6 degrees; range, 3 to 11 degrees) in 19 patients and increased by >2 degrees in 8 patients (mean, 4.5 degrees; range, 3 to 9 degrees).

In all patients who underwent retrograde femoral lengthening (n = 11), malalignment was corrected. Additional rotational correction was performed in 2 patients, and correction of an additional sagittal plane deformity was performed in 1 patient. The mean preoperative MAD of 23 mm lateral (range, 3 to 36 mm lateral) was corrected to 2.8 mm medial (range, 8 mm medial to 5 mm lateral) (Fig. 4).

For tibial lengthening (n = 16), simultaneous deformity correction was performed in 7 patients (7 nails). Tibial recurvatum was corrected in addition to frontal plane malalignment in 2 patients. In 1 of the 7 patients, varus MAD was over-corrected into valgus. Another patient experienced recurrence of the intraoperatively corrected valgus during lengthening. Tibial lengthening without deformity correction (7 patients, 9 nails) resulted

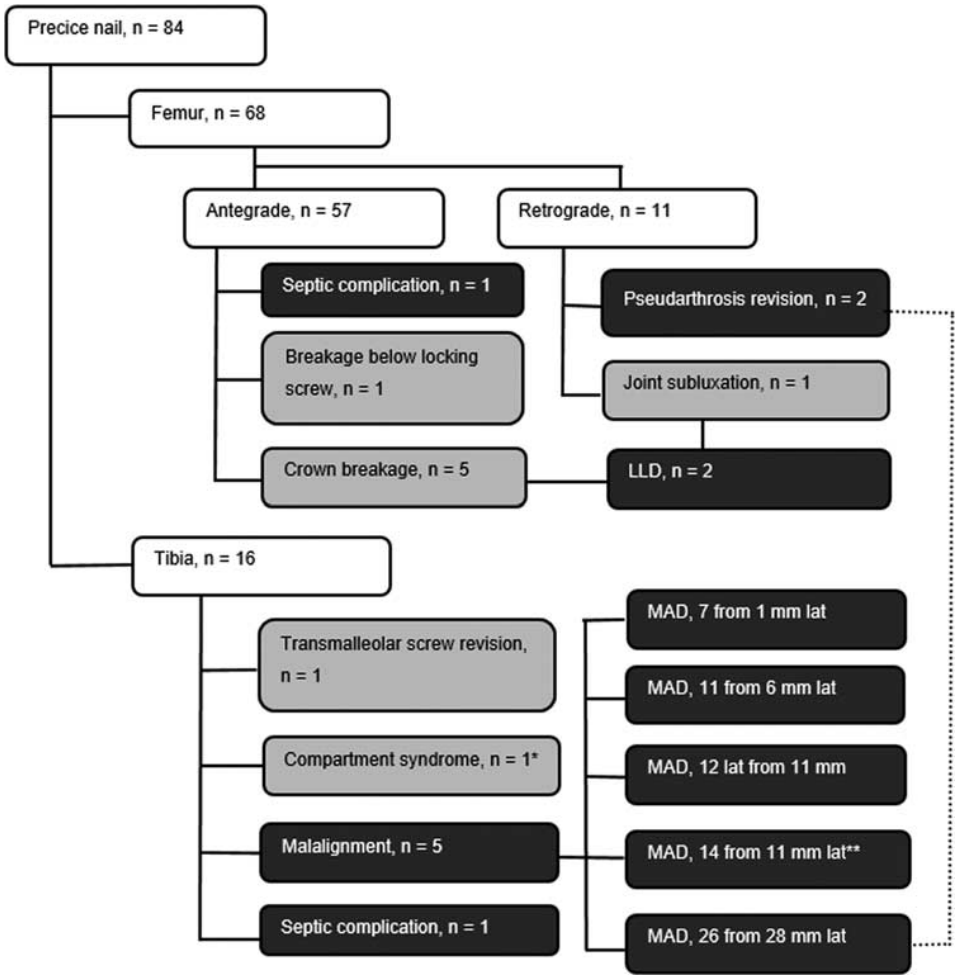

FIGURE 2. Difficulties occurring during limb lengthening were subclassified into problems (none), obstacles (gray), and complications (black) according to Paley's classification. LLD occurred because of crown breakage in 1 patient and because of giving up length to reverse joint subluxation in another. Malalignment developed in 5 patients, and a MAD 26 mm lateral was observed in 1 patient because of recurrence of intraoperatively corrected valgus during lengthening. The same patient underwent pseudarthrosis revision surgery on the distal femur (dotted lines). *Mild compartment syndrome occurred in a patient with a tibial nail, who underwent acute correction of valgus and recurvatum and was successfully treated with a percutaneous anterior compartment fasciotomy. **One patient with a varus MAD of 11 mm medial showed MAD of 12 mm lateral secondary to mild intraoperative over-correction and progression of malalignment during lengthening. lat indicates lateral; LLD, limb-length discrepancy; MAD, mechanical axis deviation; med, medial.

in valgus malalignment in 2 patients with 3 nails. The MAD remained unchanged (± 2 mm) in the remaining 5 patients with 6 nails.

DISCUSSION

This study is the largest case series to date that investigated the role of the Precice intramedullary lengthening nail for lower-limb lengthening in pediatric and adolescent patients. Patients with congenital deficiencies are more prone to complications because of associated joint instability. We had 1 patient with CFD with knee subluxation, which was corrected after partial reversal of lengthening. One patient with CFD showed delayed bone union with a consequent time to FWB of 11 months. Shabtai et al[9] investigated the role of the Precice nail in limb lengthening in patients with CFD, including in those older than 18 years, and observed similar complications, such as joint subluxation and delayed healing. We adopted a conservative approach that included careful patient selection based on joint stability, age, and compliance; reinforced bracing; and physical therapy. The conservative approach could have contributed to the relatively low complication rate in our study.

A history of epiphysiodesis or guided growth before lengthening surgery was frequent in our patients. Limb-lengthening surgery can be rendered less difficult by correcting deformity with guided growth. Epiphysiodesis was performed to reduce LLD, which can facilitate single-stage lengthening and can decrease the extent of lengthening required.

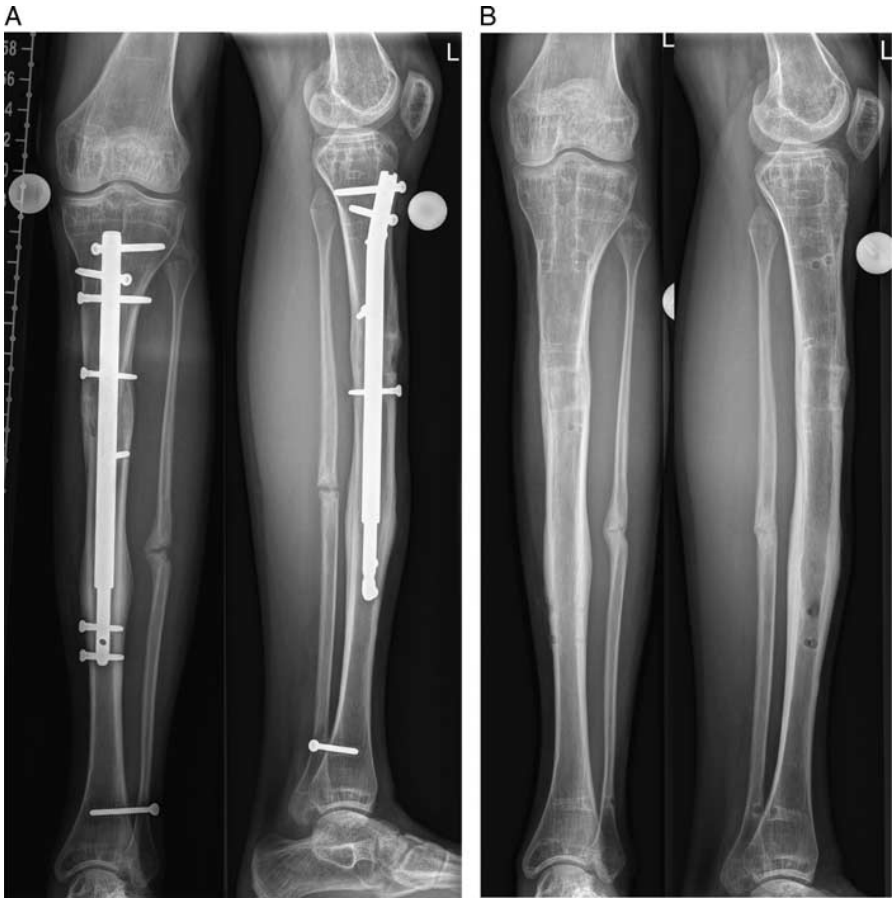

FIGURE 3. This patient with distal type fibular hemimelia complained of swelling and pain in the area of the distal end of the nail 6 months after implantation. The fibular head was lower already, and the amount of planned lengthening was rather small. We therefore decided not to apply proximal tibia/fibula fixation. A, Anteroposterior (left) and lateral (right) view radiographs reveal a severe periosteal and endosteal reaction at the male-female junction. Full bone healing can be seen. The nail was removed because of suspected osteomyelitis, and debridement was performed. B, Radiographs obtained 3 months later show that the bone alterations had mostly resolved.

Shabtai et al[9] reported a mean HI of 0.91 months with longer tibial healing time (1.1 mo/cm); we observed a substantially longer mean HI of 2.6 months. Calder et al[16] reported a mean HI of 31.6 d/cm, which also compares favorably with the 77 d/cm observed in our study. However, it is difficult to define HI with regard to lengthening nails. Calder and colleague defined healing as adequate union until a theoretical fixator could be removed. We defined healing as complete healing across all 4 cortices in anteroposterior and lateral views, which explains the high HI observed in our study. For intramedullary nail lengthening, the WBI seems most relevant. We defined the WBI as the time to FWB from the time of surgery/cm to describe the time of mobilization with crutches. Calder and colleagues reported WBI as the number of days from the end of lengthening to FWB/cm and reported periods of 23.7 and 24 days for antegrade and retrograde femoral lengthening, respectively, for the comparable cohort. When we recalculated our data based on this definition, we found an overall WBI of 31 days (range, 3 to 110 d), with means of 25.4, 32.8, and 48.4 days for antegrade femoral, retrograde femoral, and tibial lengthening, respectively.

In a pediatric patient series, Iliadis et al[13] investigated 50 lengthening segments that used the Precice nail and observed WBI of 21.7 and 20 for femoral and tibial nails, respectively. The authors reported that FWB was usually introduced within 4 weeks after the end of lengthening without considering bone healing. Although the femoral WBI was only slightly higher, the tibial WBI was substantially higher in our series at 48.4 versus 28 days. The WBI in our study includes our learning curve, specifically with regard to P1 nails, which showed a risk of backtracking, and P2.0 Precice 8.5-diameter nails that were associated with crown breakage. Therefore, we adopted a conservative approach to weight-bearing, which changed with the introduction of the P2.1 nail and particularly with the Precice Stryde nail.

With antegrade femoral lengthening, we did not observe increasing valgus or its correlation with the amount of lengthening, as expected and reported for lengthening along the anatomic axis.[17] This result concurs

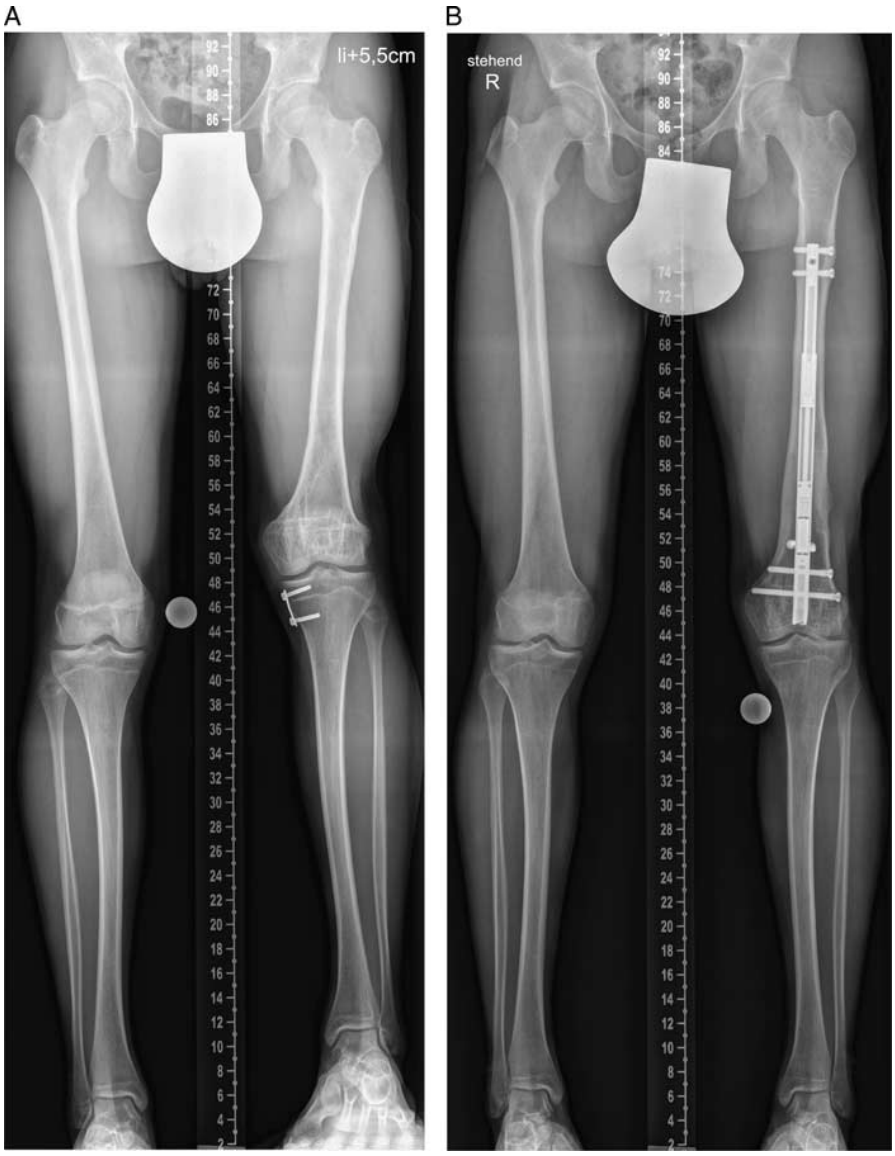

FIGURE 4. A, For this 17-year-old patient with a posttraumatic shortening of 57 mm, a retrograde approach was chosen because the preoperative mechanical axis deviation (MAD) as shown on the preoperative radiograph was 3 mm lateral, which likely would have increased with antegrade lengthening along the anatomic axis. B, Acute correction performed during retrograde nail implantation resulted in a physiologic MAD of 8 mm medial, identical to the contralateral side, as seen in the radiograph obtained before nail removal.

with the findings of previous studies.[18,19] Horn et al[18] suggested that postlengthening valgus might be counterbalanced or even overcompensated by changes in the NSA after varusization of the proximal fragment.

We observed a >2 degree reduction in the NSA (mean, 6 degrees) in 19 patients, which possibly compensated for postlengthening valgus. Horn et al[18] recommended caution with placement of the trochanteric entry point at the tip of the trochanter. We agree with this recommendation and propose additional careful preoperative planning to determine the entry point for each individual femoral configuration. Hawi et al[20] reported that the nail-to-medullary canal ratio and the distance between the lesser trochanter and the osteotomy site markedly affects varusization in antegrade nail lengthening. Although mild varusization might be clinically insignificant, higher degrees of angulation can result in an offset change and hip abductor weakness and might affect the femoral length.

In patients who underwent retrograde lengthening with deformity correction, the goal of correction was dependent on the contralateral limb, preoperative malalignment, and patient's age and sex. The defined goal was met within 2 mm of MAD in all these patients.

We detected postlengthening malalignment or deformity over-correction or under-correction only in cases

of tibial lengthening [5 of 16 tibial nails (31%)]; valgus malalignment occurred in all patients. Horn et al[18] reported 6 tibial lengthening procedures without post-lengthening changes in the MAD. In another patient cohort of 50 patients that included 7 tibial nails, a MAD change of > 10 mm was reported to have occurred in 4 of the 50 patients and a notable valgus and recurvatum malalignment in 1 patient who underwent tibial lengthening.[13] Wright et al[21] reported 17 tibial lengthening procedures achieved with the Precice nail in skeletally mature patients and observed a valgus deformity in 6, which is comparable with our results. Kirane et al[10] reported 8 tibial lengthening procedures and observed a mean 5-mm shift in the mechanical axis to lateral. They recommended blocking screws. Blocking screws were classically recommended by users of the Fitbone nail and have been described in detail for intramedullary lengthening.[22] We were introduced to the concept of blocking screws by Baumgart (Baumgart R, oral communication, 2007), and we use blocking screws for all tibial and retrograde femoral lengthening nails. In the patient with bilateral valgus deviation, the osteotomy was performed more diaphyseal; therefore, no blocking screws were placed. However, we did not consider the nail diameter versus intramedullary canal diameter,[20] which was the reason for the valgus malalignment in that case. In other cases, a blocking screw was placed only in the proximal segment, leaving enough room for deviation at the distal segment. We recommend extensive use of blocking screws in the tibia to prevent regenerate deformity.

We did not observe intraoperative complications; however, 9 patients (12%) experienced 11 complications during follow-up. Device failure with 6 nails resulted in a complication in only 1 patient. The low nail-induced complication rate could be attributed to our conservative approach to weight-bearing. Five of 10 Precice Stryde nails showed hyperostosis at the male-female junction, a complication that was reported in a recent study.[23] Osteomyelitis was suspected in 1 of the 5 patients, based on the severe periosteal reaction and focal lysis. We could not definitively conclude whether this was true osteomyelitis or an adverse reaction to the nail.

Nonunion necessitated bone grafting in 2 (3%) of our 76 patients. Both patients had undergone retrograde femoral lengthening. Calder et al[16] reported similar findings with nonunions at the distal femur.

In patients with delayed bone healing after tibial lengthening, we did not perform bone grafting, which might have decreased the WBI. Although, the HI is reportedly higher in the tibia than in the femur,[21] early intervention might be preferable in the presence of signs of delayed bone healing.[10]

The reoperation rate in the present study was 6 of 76 patients (8%), which compares favorably with rates reported in the literature (9% to 33%).[9,13,16,18] Joint contracture, reported in 5% of all cases in a systematic review of intramedullary bone lengthening,[24] did not occur in our series, perhaps attributable to the benign etiology and young age of our patients.

This study has several limitations. It is a retrospective review of a consecutive patient series. It includes different implant generations and our learning curve. Range of motion was not recorded during each outpatient visit but was recorded at at least 1 follow-up visit after bone healing. Both-leg erect standing radiographs after full consolidation were not available for all patients. Data collection and review were performed by surgeons familiar with the included cases.

CONCLUSIONS

The Precice lengthening nail is safe and effective for lower-limb lengthening in pediatric and adolescent patients. In our series, tibial lengthening had a higher rate of complications compared with femoral lengthening. Detailed preoperative planning and the use of blocking screws are important to achieve accurate lengthening and prevent malalignment.

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