

Retrograde Intramedullary Nailing of Pediatric Femoral Shaft Fractures Does Not Result in Growth Arrest at the Distal Femoral Physis—A Retrospective Cases Series

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Objective: To evaluate femoral growth after placement of retrograde intramedullary nails in the treatment of pediatric femoral shaft fractures.

Design: Retrospective case series.

Setting: Large urban trauma center in Mongolia.

Patients/Participants: Twenty-nine pediatric patients who sustained a diaphyseal femoral shaft fracture were included in the study.

Intervention: Retrograde intramedullary nail fixation with the standard, fin, or pediatric fin Surgical Implant Generation Network nail across an open distal femoral physis.

Main Outcome Measures: The main outcome measure was the distance traveled by the intramedullary nail with respect to the distal femoral condyles and distal femoral physis from initial surgery to follow-up.

Results: The mean age of patients was 10.7 years (range: 7–14 years). Follow-up occurred at a mean of 292 days (range: 53–714 days). Both condyle distance and physis distance were significantly positively correlated with follow-up days, with Pearson R values of 0.90 ($P < 0.001$) and 0.84 ($P < 0.001$), respectively. Multiple regression analysis revealed that follow-up days was the only significant predictor of physis distance, whereas age, sex, percent growth plate violation, and nail fully traversing physis were not significant predictors. The nail completely crossed the physis in 5 patients and no growth arrests were found.

Conclusions: This is the first study, to our knowledge, to evaluate treating femoral shaft fractures with a retrograde nail across an open distal femoral physis. In the pediatric population, the use of a retrograde femoral intramedullary nails does not seem to cause growth arrest of the injured femur during the postoperative period and may be a reasonable treatment option when other surgical options are not available. Additional study is necessary to further evaluate the safety profile.

Key Words: femur fracture, pediatric, skeletally immature, distal femoral physis, SIGN, retrograde intramedullary nail

Level of Evidence: Therapeutic Level IV. See Instructions for Authors for a complete description of levels of evidence.

(*J Orthop Trauma* 2021;35:e405–e410)

INTRODUCTION

In developed countries, several options are available for the surgical treatment of juvenile and adolescent femoral shaft fractures, including flexible intramedullary (IM) nails, rigid IM nails, and submuscular plate fixation.¹ In resource-poor countries, where rates of femoral fractures are significantly higher than developed countries,² the use of these devices is often precluded by cost and the lack of fluoroscopy, power reaming, and fracture table equipment.³ Levels of sterility and lack of equipment further limit open plating, and the lack of pediatric orthopaedic specialists limit the use of specialized pediatric implants. An IM nailing system was developed to allow placement of an IM tibial or femoral nail without fluoroscopy or power reaming equipment and has been widely used in adult and pediatric patients with satisfactory results in antegrade femoral nailing.^{4–6}

With plate fixation options also limited by equipment issues and risk of infection, surgeons have noted difficulty in treating children with distal femoral shaft fractures where limited femoral nail length options make antegrade nailing difficult. In these instances, one center has implemented retrograde IM nailing across an open distal femoral physis. The effect of the physeal insult sustained during this procedure on future growth remains unknown. Court-Brown et al⁷ found that IM nailing of tibial diaphyseal fractures in adolescents with open physes did not result in long-term growth problems. Knapik et al⁸ found using a sheep model that the distal femoral physis could tolerate violation up to 7% of its cross-sectional area without growth arrest and noted that in most clinical situations, violation of the growth plate should be 6% or less. Placement of telescoping

Accepted for publication January 26, 2021.

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Orthopaedics Corp: Royalties paid to R. W. Liu's institution, a portion of which is placed into a research fund that R. W. Liu controls, which is not relevant to this study. L. G. Zirkle is an unpaid consultant of SIGN Fracture Care International. The remaining authors report no conflict of interest.

Presented in part at the Annual Meeting of the American Academy of Orthopaedic Surgeons (AAOS), March 24–28, 2020, Orlando, FL (virtual meeting); the Annual Meeting of the American Academy of Pediatrics (AAP) Section on Orthopaedics, October 25–29, 2019, New Orleans, LA; and in poster format at the Annual Meeting of the Pediatric Orthopaedic Society of North America (POSNA), May 15–18, 2019, Charlotte, NC.

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DOI: 10.1097/BOT.0000000000002076

intramedullary rods across the distal femoral physis has been performed for years for deformity correction in children with osteogenesis imperfecta without growth arrest⁹; however, it is important to note that the relatively narrow isthmus and wide physis in these patients result in a much smaller percentage of cross-sectional violation as compared with typical pediatric femoral shaft fractures. The purpose of this study was to use a clinical cohort to evaluate the effect of placing a locked IM nail across the distal femoral physis on postoperative growth in otherwise healthy children.

MATERIALS AND METHODS

Design and Setting

This was a retrospective review using the Surgical Implant Generation Network (SIGN) online surgical

registry¹⁰ to evaluate pediatric patients sustaining a femoral shaft fracture and subsequently treated with a rigid retrograde IM nail who presented to a single urban trauma center in Mongolia between 2009 and 2018.

Participants

Patients who met the following inclusion criteria were eligible for inclusion in the study: (1) age less than 18 years at the time of injury, (2) open distal femoral physis at the time of injury, (3) sustained a femoral shaft fracture treated with a retrograde femoral nail, and (4) at least one postoperative and subsequent follow-up radiograph were available for review. As part of the registry protocol, radiographs were photographed by the surgeon and then uploaded into the registry database. Patients with radiographs that did not include the distal femoral condyles were excluded from the condyle measurement group, and those with radiographs that excluded

TABLE 1. Summary of Demographics, Intramedullary Nail Characteristics, and Follow-Up of Patients Included in the Study

Patient #	Age (y)	Sex	Laterality	Nail Type	Nail Diameter (mm)	Distal Nail Diameter (mm)	% Physis Violation	Nail Length (mm)	First Follow-up (d)	Second Follow-up (d)	ΔCondyle at Final Follow-up (mm)	ΔPhysis at Final Follow-up (mm)
1	11	M	L	Fin	10	10	4.12%	240	301§	—	—	12.00
2	14	M	L	Standard	10	10	—	300	435‡	—	12.20	—
3	10	M	R	Ped fin	7*/6†	8.18	2.22%	280	400§	—	—	8.65
4	9	M	R	Fin	8	9	3.90%	240	384§	—	—	13.19
5	9	M	L	Ped fin	8*/6†	8.18	3.63%	240	342§	—	—	2.76
6	10	M	L	Fin	9	9	—	240	556	714§	26.30¶	18.70
7	13	M	L	Fin	8	9	—	240	632	—	23.74	22.28
8	12	M	R	Fin	9	9	3.22%	280	338§	—	—	9.6
9	11	M	R	Fin	7	9	—	190	281	—	10.29	10.41
10	10	M	R	Ped fin	8*/6†	8.18	2.41%	240	421§	—	—	10.53
11	8	M	R	Fin	8	9	2.71%	240	229	—	12.93	10.58
12	13	M	L	Fin	8	9	—	240	53	—	0.23	0.11
13	14	M	R	Fin	8	9	—	240	205	—	10.01	11.03
14	13	M	R	Ped fin	8*/6†	8.18	2.22%	240	456	—	20.65	12.17
15	7	F	L	Ped fin	7*/6†	8.18	—	240	255	—	6.08	5.49
16	7	F	R	Ped fin	7*/6†	8.18	—	200	255	—	8.41	7.71
17	9	F	R	Fin	9	9	3.35%	280	295	—	12.00	12.40
18	10	M	L	Fin	9	9	3.15%	280	299	—	12.80	8.30
19	13	M	L	Fin	10	10	2.88%	280	204	—	11.00	6.70
20	8	M	L	Fin	8	9	3.18%	240	198	—	8.66	8.44
21	14	M	L	Fin	9	9	2.60%	280	89§	274§	—	2.10
22	14	M	R	Fin	9	9	2.31%	240	428	—	9.10	8.80
23	13	M	L	Fin	9	9	—	280	170	—	3.70	6.60
24	13	M	R	Fin	9	9	—	280	170	—	5.50	4.00
25	10	M	R	Fin	9	9	—	280	245	—	7.90	9.50
26	9	M	L	Fin	7	9	—	240	66	339	11.96	12.09
27	8	M	R	Fin	8	9	—	240	67	237	9.90	7.65
28	8	F	R	Fin	10	10	—	280	144§	—	—	5.50
29	9	M	L	Ped fin	8*/6†	8.18	—	240	167	—	6.03	7.46

*Fin diameter.

†Shaft diameter.

‡Excluded from physis distance analysis.

§Excluded from condyle distance analysis.

¶ΔCondyle at the first follow-up.

F, female; L, left; M, male; R, right.

the margin of the physis were excluded from the physis measurement group. Additionally, patients with radiographs of poor quality (eg, blurry, glare, distal end of the nail cut off) that precluded accurate measurements were excluded from analysis. A total of 120 patients less than 18 years old with open distal femoral physis were treated with a retrograde femoral nail for a femoral shaft fracture during the study period. Of those, 60 patients were lost to follow-up and 31 had poor-quality radiographs precluding accurate measurements. Four patients had 2 follow-up visits before nail removal and, thus, 4 additional time points for analysis. This left 29 patients with 33 sets of femur radiographs eligible for inclusion in the study (Table 1). In 10 sets of radiographs, the distal femoral condyles were cut off, leaving 23 sets of radiographs for analysis of the condyle measurement. In 1 set of radiographs, the lateral margin of the physis was cut off, leaving 32 sets of radiographs for analysis of the physis measurement.

Fracture Management

Femur fractures were treated operatively using SIGN (Richland, WA) IM nails inserted in a retrograde fashion. One patient was treated with a standard nail, 21 patients were treated with a standard fin nail, and 7 patients were treated with a pediatric fin nail (Table 1). All nails were made of stainless steel and were locked distally with a metaphyseal interlock screw using an aiming arm. Two proximal interlock screws were also placed using an aiming arm in the one case using the standard nail.

The standard nail was initially designed for use in adults and uses a long external aiming arm jig to allow placement of the proximal interlock screws without fluoroscopic guidance. Shaft diameters range from 8 to 12 mm for the standard nail (in 1-mm increments), with multiple length options ranging from 280 to 420 mm (in 20-mm increments).

The standard fin nail was also initially designed for use in adults, with the pediatric fin nail subsequently developed to accommodate the narrower femoral canals seen in pediatric patients. The fin design precludes the need for a proximal interlock screw; by underreaming the canal proximally, the channels of the fin can engage with the femoral canal and create an interference fit that provides adequate fixation to resist rotational forces. It is important to note that none of these nails were originally designed for retrograde use through an open physis and have not been labeled for this use.

Zirkle and Shearer¹¹ have described details regarding the surgical technique for placement of SIGN IM nails using the retrograde approach to the femur. In summary, the starting point is identified on the medial aspect of the femoral notch and bone entered using an awl. Open or closed reduction of the fracture is at the discretion of the treating surgeon. The canal is then reamed by hand until chatter is encountered; the diameter of the fin is 1 mm larger than this reamer. The canal is then sequentially reamed by hand to 2 mm larger than the shaft diameter of the nail, with care made to stop reaming before reaching the region where the fin will be placed proximally. The nail is then inserted and advanced just deep to the articular surface and a distal metaphyseal interlock screw placed using an aiming arm (see **Figure, Supplemental**

Digital Content 1, <http://links.lww.com/JOT/B385>, which shows the various SIGN nails, aiming arm, and hand reamer).

Postoperative weight-bearing and advancement of weight-bearing status were at the discretion of the treating surgeon. After radiographic and clinical evidence of fracture healing was achieved, the femoral nail was removed in patients who followed up.

Data Collection

The SIGN database was queried for pediatric patients treated for a femoral shaft fracture with a retrograde IM nail. Age at injury, sex, date of surgery, date(s) of follow-up, and nail diameter were recorded.

Measurements

Measurements were performed digitally using Surgimap software (Nemaris Inc, New York, NY) on anteroposterior radiographs of the knee and/or femur. The known distal nail diameter was used for calibration.

Measurements were made with respect to 2 different radiographic landmarks: the distal femoral condyles and the distal femoral physis. For the condylar measurement, a line was first drawn tangent to the medial and lateral distal femoral condyles (Fig. 1A). Next, a second line parallel to the first was drawn tangent to the most distal aspect of the nail. Finally, the distance between the 2 parallel lines was measured, representing the condyle distance. For the physis

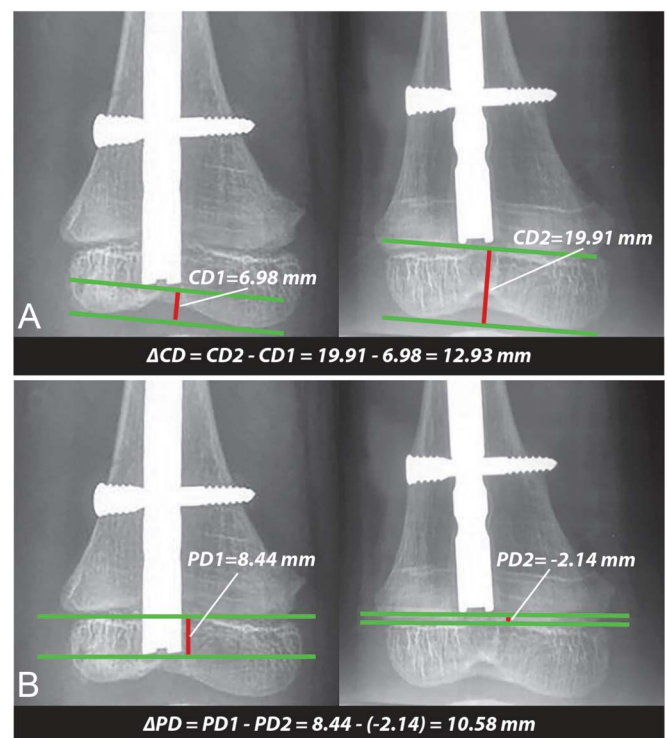


FIGURE 1. Sample measurements of femoral growth over a retrograde intramedullary nail in an 8-year-old boy (patient 11 in Table 1) immediately postoperatively and at 7.5 months of follow-up with reference to the (A) distal femoral condyles and (B) physis. CD, condyle distance; PD, physis distance.

measurement, a line was first drawn through the medial and lateral margins of the physis (Fig. 1B). Next, a second line parallel to the first was drawn tangent to the most distal aspect of the nail. Finally, the distance between the 2 parallel lines was measured, representing the physis distance. For the physis distance, if the line tangent to the distal aspect of the nail was distal to the physis, the measurement was assigned a positive value; if the line tangent to the distal aspect of the nail was proximal to the physis, it was assigned a negative value. The difference between the postoperative and follow-up condyle distances was called Δ Condyle, whereas the difference between the postoperative and follow-up physis distances was called Δ Physis.

Measurements were performed on 20 radiographs by 2 readers (a fellowship trained pediatric orthopaedic surgeon and orthopaedic surgery resident) (R.W.L., A.B.) independently to assess for interrater reliability, with an intraclass correlation coefficient of >0.988 for all measurements. The remaining measurements were performed by one reader (an orthopaedic surgery resident) (A.B.).

The cross-sectional area of the distal femoral physis at the time of surgery was modeled as an ellipse, whereas the nail was modeled as a circle, based on conventions previously reported.⁸ Percent violation can then be calculated in a simple manner practical for clinical use, by dividing the width of the nail by the width of the physis on each the AP and lateral views and multiplying the 2 ratios.

Statistical Analysis

Statistical analysis was performed using SPSS 25 (IBM SPSS Statistics for Windows, Version 25.0.; IBM Corp, Armonk, NY). Bivariate correlation analysis was performed and Pearson R values were calculated to assess the correlation between days of follow-up and the distance traveled by the nail with respect to the distal femoral condyles and the physis. Multiple linear regression was performed to identify significant predictors of distance traveled by the nail, including age, sex, follow-up days, percent growth plate violation, and whether the nail entirely traversed the physis, with specific interest in identifying any predictors associated with less distance traveled by the nail (ie, risk factors for growth inhibition). The intraclass correlation coefficient was calculated to assess interrater reliability for measurements. Statistical significance was defined as $P < 0.05$.

RESULTS

A total of 29 patients (25 male and 4 female patients) with an average age of 10.7 years (range: 7–14 years) were included in the study (Table 1). Follow-up imaging was obtained at an average of 292 days postsurgery (range: 53–714 days, SD = 156). Bivariate correlation analysis revealed a significantly positive correlation of both Δ Condyle (Fig. 2A and Table 2) and Δ Physis (Fig. 2B and Table 2) with follow-up days, with Pearson R values of 0.90 ($P < 0.001$) and 0.84 ($P < 0.001$), respectively.

AP and lateral radiographs were of sufficient quality to calculate physeal surface area and thus percent physeal violation for 14 patients. The mean percent violation of the

physis was 3.0% (range: 2.2%–4.1%). Multiple regression analysis revealed that follow-up days was a significant positive predictor of Δ Physis (standardized B = 0.56, $P = 0.04$), whereas age, sex, percent growth plate violation, and nail fully traversing the physis were not significant predictors. Only 7 of the patients included in the Δ Condyle analysis had percent growth plate violation data available and thus multiple regression analysis on this cohort could not be reliably performed with the numbers available.

The nail completely crossed the physis in 5 patients at a mean follow-up time of 424 days (range: 229–632 days, SD = 173) (see **Figure, Supplemental Digital Content 2**, <http://links.lww.com/JOT/B386>, which shows examples of femoral growth over the retrograde intramedullary nails where the nail completely crossed the open physis). Two femora exhibited minimal Δ Physis at the time of follow-up. In one case (patient 5 in Table 1), a review of the imaging revealed that the postoperative and follow-up images were taken in grossly different planes, likely resulting in a discrepancy between the measured and true distance traveled by the nail. In the other case (patient 21 in Table 1), a 14-year-old adolescent boy seemed nearly skeletally mature at the time of surgery and

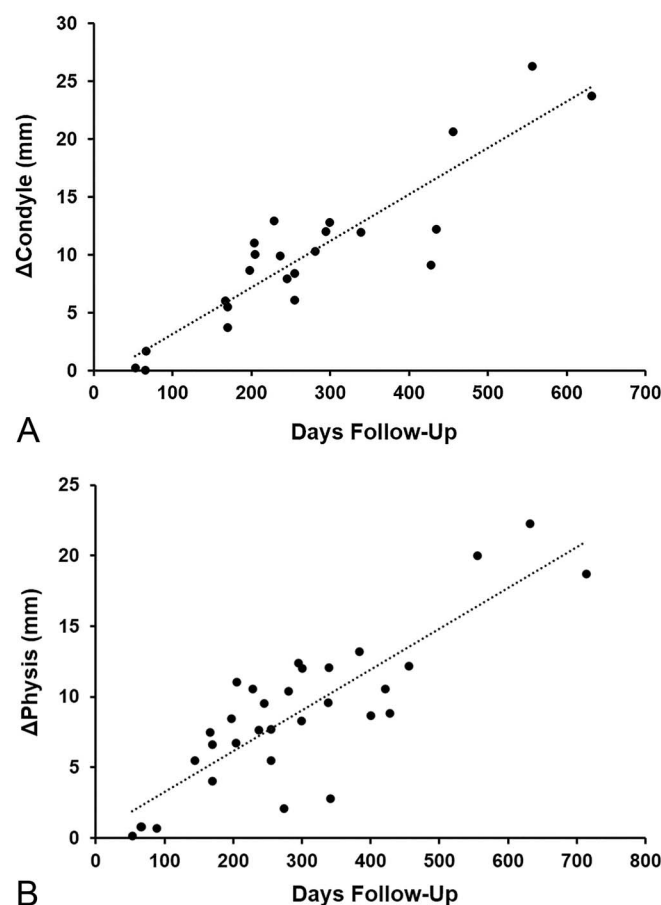


FIGURE 2. Scatterplots demonstrating a strong positive correlation between (A) Δ Condyle (mm) and follow-up days and (B) Δ Physis (mm) and follow-up days.

TABLE 2. Summary of Follow-up, Distance Traveled by the Nail in Relation to the Condyle/Physis, and Bivariate Correlation Analysis

		Mean	SD	N	Pearson R	P
Condyle	Follow-up days	271 d	148 d	23	0.90	<0.001
	ΔCondyle	10.1 mm	6.6 mm	23		
Physis	Follow-up days	288 d	156 d	32	0.84	<0.001
	ΔPhysis	8.7 mm	5.4 mm	32		

thus had limited remaining growth potential compared with other more skeletally immature patients included in the study.

DISCUSSION

This is the first clinical study to our knowledge to evaluate treating femoral shaft fractures with a retrograde nail across an open distal femoral physis. We found that growth continued at a relatively linear rate after the placement of a locked IM nail across the distal femoral physis. No obvious partial or complete growth arrest was observed in the study population.

Knapik et al⁸ studied the placement of retrograde IM nails across an open distal femoral physis in 18 immature sheep. After euthanasia, they found that significant growth inhibition occurred only when 8% of the physal surface area was violated. No significant growth inhibition occurred when 3%–7% of the distal femoral physis was violated, and histologic analysis did not reveal the presence of physal bar formation in any of the specimens. Steinman pins were used for the study and spanned the growth plate throughout the study. Based on the results of this animal study, we would not expect to observe any significant growth arrest in our study population as our maximum physal violation was only 4.1%. Yoo et al¹² evaluated the effect of drilling across the distal femoral physis for transphysal ACL reconstruction in skeletally immature patients. Their average distal femoral physal violation was 2.3% (range: 1.6%–3.4%) and they noted MRI evidence of a distal femoral physal bone bridge in 1 of 43 patients, but no clinically evident growth disturbance. It is important to note that placement of a nail is different from soft tissue reconstruction in 2 key factors: first, the drill space is filled by metal rather than soft tissue, with likely some peripheral free space around the rod secondary to overreaming of 1 mm; second, the mechanical factors of the rod can potentially influence further growth, as was suspected in our previous study, which demonstrated that at 8% cross-sectional violation growth inhibition was noted.⁸ If the rod has a tight isthmic fit, then any obliquity to the physis could theoretically result in growth inhibition, with some obliquity arguably unavoidable due to the natural undulations.

Court-Brown et al⁷ studied the placement of IM tibia nails across open physes in 36 adolescent patients and similarly found no long-term growth disturbance. However, in his study, the nail was primarily placed across the tubercle

apophysis, which does not contribute to linear growth of the tibia, with minimal disruption of the proximal tibia physis. Thus, one would not expect a significant longitudinal growth disturbance, though in theory, anterior bar formation at the tubercle resulting in a recurvatum deformity is possible. However, this was not observed in their study. Notably, the average age of their patients were 14 years in female patients and 15 years in male patients, versus a much lower overall average of 10.7 years in the current study.

In 5 patients, the distal femur grew enough to pass across the distal aspect of the femoral nail. Although no apparent growth arrest was noted in our study, there was inadequate follow-up to determine when the nail cross the physis or comment on whether this effect results in any growth inhibition (each patient only had 1 follow-up visit ranging from 229 to 714 days from index surgery).

The indication for retrograde nailing in immature patients is a fracture distal to midshaft that cannot be treated with a growth plate sparing construct. Antegrade nailing in resource-poor countries can be limited by the lack of multiple implant length options and the lack of intraoperative fluoroscopy, both of which make it difficult to span a fracture more distal in the femoral shaft. Figure 3A demonstrates an example of a child (not included in the current study) treated with antegrade nailing with abundant callus suggesting lack of stability and likely failure if the fracture was more distal. In contrast, Figs. 3B–D shows an example of a more distal fracture treated via a retrograde technique with subsequent fracture union with appropriate callus formation. Options such as flexible nails and plating can also be challenging due to the limited implant options and lack of fluoroscopy.

This study has several limitations. First, as this was a retrospective study of registry data, we were required to rely on the data uploaded to the SIGN database by the treating surgeons. The radiographic images uploaded to the database were photographs taken of plain radiographs, which frequently resulted in poor-quality images that were unable to be included in the study. For the images that were used, we minimized any potential distortion effects by calibrating our images on the portion of the nail closest to the physis. Additionally, many of the patients treated at the institution where the femur fractures were treated came from rural areas of Mongolia and thus, follow-up was not feasible. The nail was never removed in these patients who did not follow-up; therefore, it is unknown how the continued presence of a locked retrograde IM nail affected long-term growth. For the patients who did follow-up for nail removal, no radiographs were available after removal to assess any growth consequences of the removal procedure. Finally, we were unable to evaluate any potential growth inhibition resulting in leg length discrepancy compared with the uninjured femur due to the lack of full-length radiographs of the contralateral femur nor was follow-up to skeletal maturity available.

In conclusion, this is the first study to our knowledge to evaluate treating femoral shaft fractures with a retrograde nail across an open distal femoral physis. In the pediatric population, a centrally placed retrograde femoral IM nail that crosses <5% of the distal femoral physis does not seem to cause growth arrest of the injured femur during the

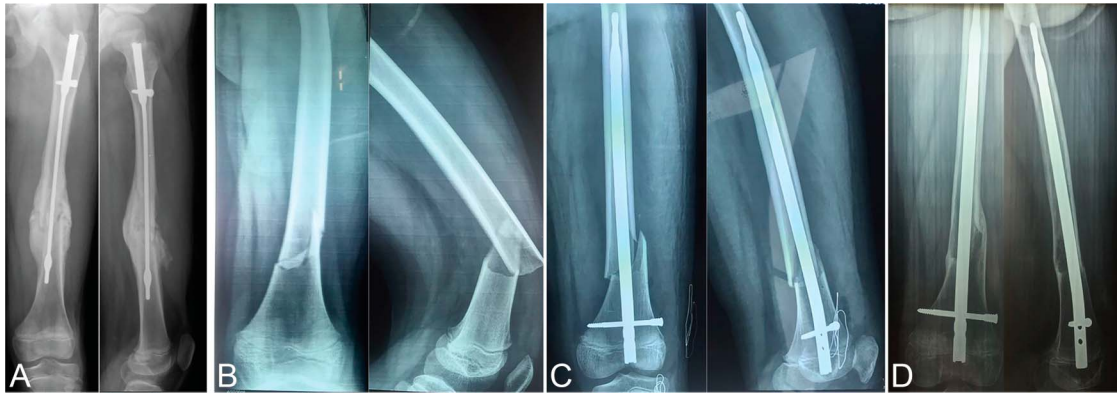


FIGURE 3. A, Example of an immature female treated with an antegrade fin nail for a fracture distal to midshaft. Although the fracture has united in an acceptable position, the abundant callus indicates a large amount of instability in the construct and leads one to question whether a slightly more distal fracture might be better treated with retrograde technique. B–D, Thirteen-year-old adolescent boy (patient 19 in Table 1) with (B) a distal third femoral shaft fracture that would be challenging to treat with antegrade nailing with limited nail size options and lack of fluoroscopy. C, A retrograde 10-mm standard fin nail violating 2.88% of the distal femoral physis was used, with appropriate growth noted (D) at 6.5 months of follow-up.

postoperative period and may be a reasonable treatment option when physis sparing treatment options are unavailable, as can occur in resource-poor nations. However, careful follow-up of each patient treated with this approach is essential and further study is warranted to fully assess the safety of this approach.

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