Anterior Distal Femoral Hemiepiphysiodesis in Children With Fixed Knee Flexion Deformities: Does Screw Position Matter?

Akshay Seth, MD, Colyn J. Watkins, MD,†‡ Patricia E. Miller, MS,† and Benjamin J. Shore, MD, MPH†‡*

Background: Anterior distal femoral hemiepiphysiodesis (ADFH) using 2 percutaneous screws is an effective technique for the treatment of fixed knee flexion deformities in children with neuromuscular disorders. The role of sagittal screw position on the outcome of the procedure is unknown.

Methods: This is a retrospective case series of patients who underwent ADFH at a single pediatric hospital from 2013 to 2020. Radiographs were evaluated for sagittal screw position and the associated change in lateral distal femoral physeal angle over time. The position of the 2 screws was classified as either being both in the anterior third of the physis (AA), one screw in the anterior third and the other screw in the middle third (AM), or both screws in the middle third of the physis (MM).

Results: The study population included 68 knees in 36 patients. The mean physeal angle at the time of surgery was 93 degrees (SD 4.0 degrees), which increased to 102.4 degrees (SD 5.7 degrees) at 12 months, for a change of 9.4 degrees ($P < 0.001$). At 24 months, the mean physeal angle was 104.6 degrees (SD 6.3 degrees) for a further change of 2.9 degrees ($P < 0.001$). When stratified by screw position all screw configurations resulted in an increase in the physeal angle at 12 months. At the 24-month follow-up, the physeal angle in knees with AA screws continued to increase another 3.5 degrees ($P < 0.05$), there was a minimal change in knees with AM screws (1.47°, $P > 0.05$) and knees with MM screws saw a reversal of physeal angle change (−7.1 degrees, $P < 0.05$).

Conclusions: ADFH using percutaneous screws results in an increase in the lateral distal femoral physeal angle. The rate of correction is largest in the first 12 months after the procedure. As such, this procedure should be considered in patients with less than 2 years of growth remaining. However, initial screw positioning influences the amount of change over time, and close postoperative surveillance until physeal closure is essential for all patients.

Level of Evidence: Level IV—retrospective case series.

Keywords: guided growth, knee flexion contracture, cerebral palsy

(*J Pediatr Orthop* 2024;44:e255–e259)

From the *Orthopedic, Sports Injury Clinic, Children's Hospital of Eastern Ontario, Ottawa, Ontario; †Department of Orthopaedic Surgery, Boston Children's Hospital; and ‡Harvard Medical School, Boston, MA.

No sources of funding were associated with this research.

The authors report no conflicts of interest.

Reprints: Benjamin J. Shore, MD, MPH, Boston Children's Hospital, Hunnewell 211, 300 Longwood Avenue, Boston, MA 02115. E-mail: Benjamin.shore@childrens.harvard.edu.

DOI: 10.1097/BPO.0000000000002599

In children with cerebral palsy (CP) and other neuromuscular conditions, fixed knee flexion deformities (FKFDs) can result in progressive crouch gait, knee discomfort, and limited mobility.[1–4] Multiple surgical techniques have been used to address this issue, including soft tissue lengthening, tendon transfers, and extension osteotomies. Soft tissue procedures have been associated with weakness, while acute bony correction can be a complex surgery with a lengthy recovery period.[5,6]

More recently, guided growth techniques have been demonstrated to correct FKFDs in skeletally immature patients.[7–12] Physeal tethering for the correction of coronal plane deformities around the knee has been widely adopted since the introduction of epiphyseal stapling by Blount and Clarke in 1949.[13,14] For sagittal plane deformity, the concept of anterior distal femoral hemiepiphysiodesis (ADFH) was initially introduced in 2001, and techniques continue to be updated.[7] The ADFH technique was initially introduced using staples to tether the anterior aspect of the distal femoral physis and was then revised to use tension band plates.[7,8] Both implants were found to be effective for treating FKFDs, but the need for parapatellar arthrotomies and the implants themselves have been associated with implant loosening, pain, and stiffness.[8–11]

In 2015, Kay and Rethlefsen published a technique for a percutaneous, extra-articular ADFH using 2 transphyseal screws for the management of fixed knee contracture in children with CP.[12] This technique has been found to be equally effective as tension band plates, with less postoperative discomfort.[10] Despite the promising outcomes that have been reported with this technique, there remains a lack of understanding of the technical elements of the procedure that are important for achieving success.[15] Therefore, the objective of this study was to determine whether the sagittal position of the screws used in transphyseal 2-screw ADFH affects the amount of lateral distal femoral physeal angle change over time.

METHODS

Institutional review board approval was obtained before study initiation. This study was a retrospective case series that included pediatric patients with neuromuscular disorders who were treated for an FKFD using a transphyseal 2-screw antegrade ADFH technique at a single pediatric hospital from 2013 to 2020. All patients had CP or a CP-like condition with a FKFD of 10 to 25 degrees and at least 2 years of growth remaining.

Using ICD-10 diagnostic and procedural codes, the institutional electronic medical record was queried to identify all patients who had undergone a transphyseal antegrade 2-screw ADFH procedure for an FKFD since the technique had been introduced. Surgical technique similar to the one described by Kay and Rethlefsen was used in all patients, with implantation of 2 antegrade transphyseal fully threaded 4.5 mm cannulated screws.[12] No patients underwent concurrent patellar tendon shortening or advancement as it was not routine practice and is only indicated in cases of extension lag >20 degrees.[15] Patient charts were reviewed to collect data on patient demographics and outcomes.

Radiographs were reviewed to evaluate the sagittal screw position and to quantify the change in the physeal angle over time. The sagittal position of the screws was evaluated on the lateral knee radiograph by drawing a line connecting the most anterior and posterior aspects of the physis, which was then divided into thirds. The position of the 2 screws was classified as either being both in the anterior third of the physis (AA), one screw in the anterior third and the other screw in the middle third (AM), or both screws in the middle third of the physis (MM) (Fig. 1A). Note that all screws placed in the middle third of the physis were anterior to the midline of the physis. The physeal angle was measured on the lateral knee radiograph as the angle between the lateral mid-diaphyseal line of the femur and a line extending from the most anterior to the posterior aspect of the physis (Fig. 1B).

Measurements were taken from the preoperative, intraoperative, and postoperative radiographs at 3, 6, 12, and 24 months where available. A subset of 39 radiographs was assessed by 2 authors (A.S. and B.S.) to evaluate inter-rater reliability of measurements. The primary author also performed a second set of measurements 4 weeks apart to evaluate intrarater reliability. Inter-rater and intrarater reliability were assessed by estimating the intraclass correlation coefficient (ICC) along with a 95% CI for each measurement. Inter-rater reliability was assessed using an ICC (2, 2) model, and intrarater reliability was assessed using an ICC (3, 1) model.[16]

Changes in physeal angle were calculated from intraoperative to 12 months, and from intraoperative to at least 24 months postoperative. Student *t* test was used to assess changes in each measurement and the mean difference was estimated along with a 95% CI. Analysis was also stratified by screw position using a one-way analysis of variance. All tests were 2 sided, and P-values <0.05 were considered significant.

RESULTS

The study population included 68 knees in 36 patients. The most common primary diagnosis was CP (n = 25, 69%), the median age at the time of surgery was 11.6 years (SD 2.1), and most patients had bilateral surgery (n = 32, 89%) (Table 1).

The mean physeal angle at the time of surgery was 93 degrees (SD 4.0 degrees), which increased to 102.4 degrees (SD 5.7 degrees) at 12 months, for a change of 9.4 degrees (95% CI: 8.1-10.8 degrees, $P<0.001$). At 24 months, the mean physeal angle was 104.6 degrees (SD 6.3 degrees) for a further change of 2.9 degrees (95% CI: 1.8-4.0 degrees, $P<0.001$) (Fig. 2).

When stratified by screw position, all screw configurations resulted in an increase in the physeal angle at 12 months. At 24-month follow-up, the physeal angle in knees with AA screws continued to increase another 3.5 degrees (95% CI: 2.1-4.9 degrees, $P<0.05$). However, there was no significant change in knees with AM screws (1.47 degrees, 95% CI: −2.8 to 5.7 degrees, $P>0.05$) and knees with MM screws saw a reversal of physeal angle change (−7.1 degrees, 95% CI: −11.9 to −2.2, $P<0.05$) (Fig. 3).

Intrarater reliability (ICC = 0.96) and inter-rater reliability (ICC = 0.86) were both found to be excellent.

DISCUSSION

The management of knee flexion contractures in children with CP is a critical component of their care and has evolved considerably over the last quarter century. ADFH has proven to be a safe and effective treatment for FKFDs in children with neuromuscular disease with remaining growth potential.[10] However, our understanding of the factors influencing the timing and degree of expected correction for knee flexion contractures in children treated with ADFH is poor. We sought to further explore how sagittal position of the screws used in transphyseal 2-screw ADFH can affect the amount of physeal angle change that is imparted over time. We observed that the greatest change was observed when screws were placed in the anterior third of the physis, and this change was seen at 1 and 2 years after screw insertion. A secondary finding was that there is a slowing of physeal angle change after 12 months, regardless of screw position, and in knees with screws in the middle third of the physis, there was an observed reversal of change of physeal angle, highlighting the importance of anterior third screw positioning at insertion.

In their original technique paper for ADFH with percutaneous screws, Kay and Rethlefsen write that screws should be placed in the anterior third of the physis.[12] However, there is no supporting evidence for

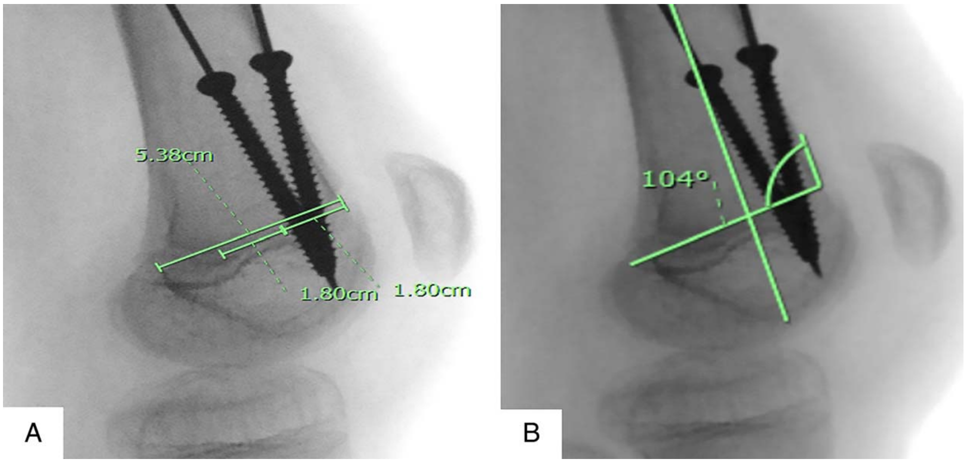

FIGURE 1. Radiographic measurement of sagittal screw position (A) and lateral distal femoral physeal angle (B).

why this part of the technique is important. Conceptually, placing the screws as anterior as possible makes sense if attempting to maximize the differential growth between the anterior and posterior aspects of the physis. However, screws placed anywhere in the anterior half of the physis should be effective in creating an anterior tether that would result in an increase in the physeal angle over time. In the current study, we found that screws placed in the middle third of the physis (but anterior to the midline) result in an initial increase in physeal angle change, but after 1 year a reversal of the physeal angle can be appreciated. This phenomenon was only seen in knees where both screws were placed in the middle third of the physis, confirming that initial sagittal screw position affects the physeal angle change seen over time.

While the above finding was only observed in knees with both screws starting in the middle third of the physis, all knees demonstrated a slowing of physeal angle change after 12 months. The cohort of knees with AA screws saw a continued increase in the physeal angle but the rate of change slowed and knees with AM screws did not see a significant change in the physeal angle after 12 months. It is notable that the initial 9.4 degrees increase in the physeal angle seen in our cohort is similar to the change of 8 to 10 degrees that has been previously reported.[9,10,17,18] However, we believe this is the first study to identify that the degree of physeal angle correction decreases with time.

A decrease in the efficacy of the screws after the first 12 months of treatment raises the question of whether the indications for ADFH need to be reconsidered. In a recently published Delphi study that made recommendations for indications for the procedure, there was consensus that the procedure should only be performed in children with at least 2 years of growth remaining.[15] Our findings suggest that the benefits of treatment diminish after the first 12 months, which suggests that ADFH may be effective for improving knee motion in children who only have a year of growth remaining. It is possible that performing the procedure in a patient approaching skeletal maturity may be useful for increasing motion and function or reducing the need for more invasive osteotomy options that would otherwise be considered. This is an avenue of study that warrants further investigation in the future.

The most likely explanation for the above findings is that the screws used in the procedure experience a relative posterior migration along the sagittal physis with growth. The screws themselves do not move, but due to circumferential growth of the distal femur, the site at which the screws cross the physis becomes more posterior over time (Fig. 4). As a result, the tethering action of the screws is progressively seen more posteriorly across the physis, and the differential growth between the anterior and posterior

TABLE 1. Baseline Demographics for Patient Cohort

Cohort summary (N = 36 patients)		
Characteristic	**Frequency**	**%**
Male sex	20	56
Age at procedure [y; mean (SD)]	11.6	2.1
Ethnicity		
Not Hispanic	32	89
Hispanic	2	6
Unknown	2	6
Race		
White	19	53
Black	5	14
Asian	4	11
Other/unknown	8	22
GMFCS level		
II	10	28
III	7	19
IV	9	25
V	3	8
Unknown	7	19
Diagnosis		
Cerebral palsy	25	69
Myelomeningocele	3	8
Syndrome	6	17
Other	2	6
Bilateral	32	89

GMFCS indicate Gross Motor Function Classification System Level.

Copyright © 2023 Wolters Kluwer Health, Inc. All rights reserved.

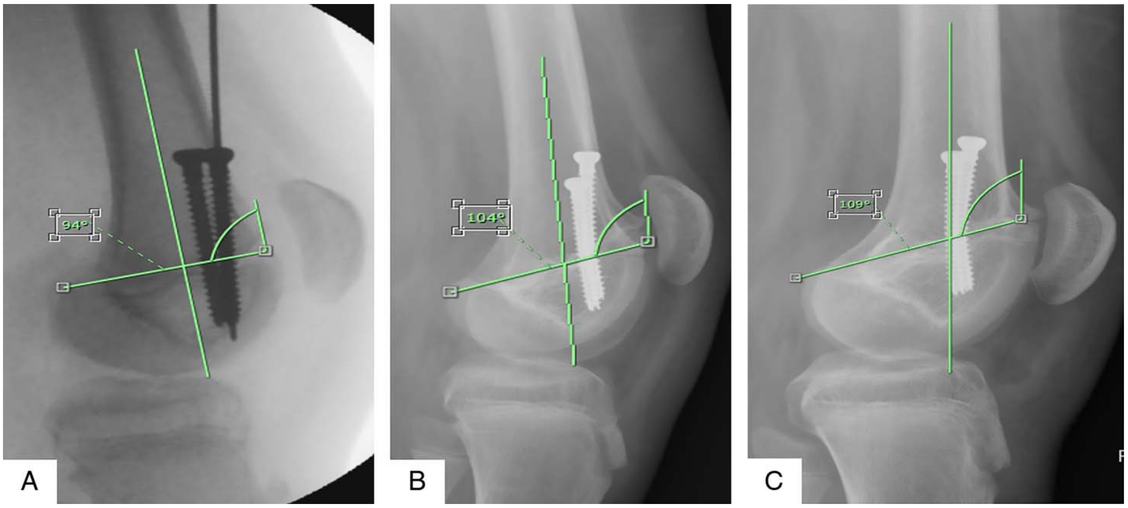

FIGURE 2. An Example of physeal angle change over 24 months including intraoperative (A), 12 months postoperative (B), and 24 months postoperative (C) radiographs.

portions of the physis is reduced. For screws that start in the anterior third of the physis, this results in a slowing of physeal angle change after 12 months. However, for screws that start in the middle third of the physis, the relative posterior migration can result in tethering of the posterior half of the physis over time and a reversal of the physeal angle change that is seen in the early months of treatment.

The findings outlined in this study highlight the same conclusion from the Mission Impossible experts in their Delphi analysis, underscoring the importance of ongoing radiographic surveillance while the physis is still open to ensure that all the screws are having the intended effect and to monitor for possible deformities that can be caused by relative migration of the implants.[15]

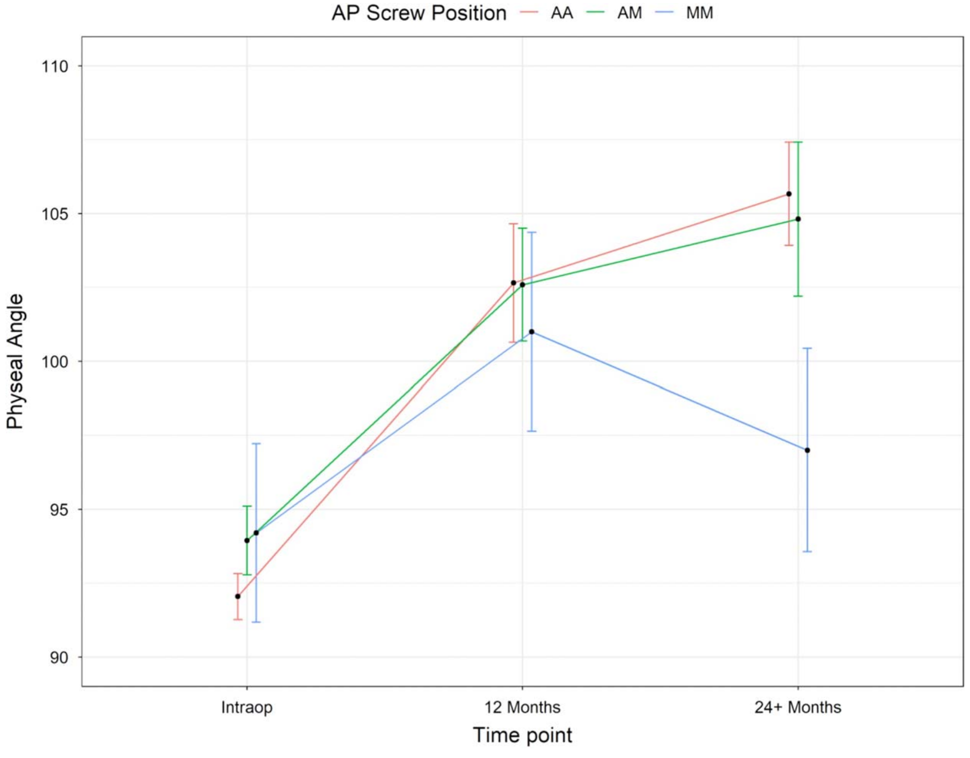

FIGURE 3. After 12 months, stratification by screw position shows continued increase of the physeal angle in knees with AA screws, minimal change in knees with AM screws and a decrease in physeal angle in knees with MM screws. AA indicates anterior-anterior; AM, anterior-middle; MM, middle-middle. AP, Anterior-Posterior Screw Position.

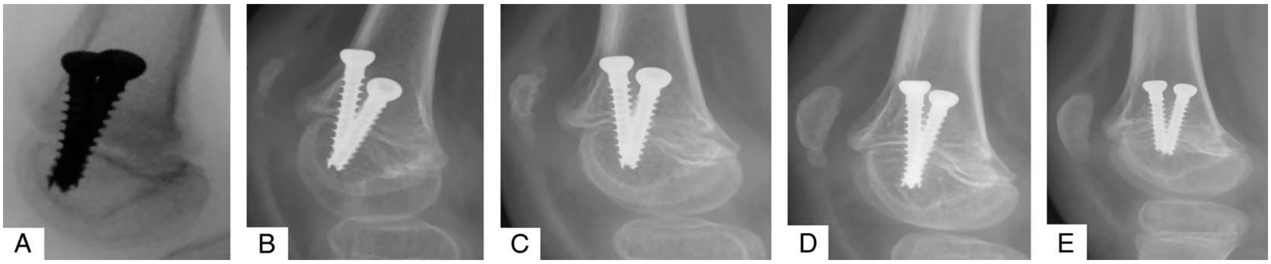

FIGURE 4. The relative posterior migration of screws is demonstrated in this series of radiographs. Intraoperative radiograph (A) shows the initial anterior placement of the screws. Over the course of 6-month (B), 12-month (C), 24-month (D), and 36-month (E) postoperative radiographs, the screws "migrate" into the middle third of the physis over time.

Despite the above conclusions, these should be considered with the following limitations. The limitations of this study are similar to other retrospective studies. The timing of radiographs was not standardized so not all patients have complete radiographic data sets. The leg position used for radiographs was not standardized, and differences in rotation could affect measurements. The study population was small and heterogenous limiting our ability to determine whether diagnosis had any effect on outcome. Reliable clinical information (eg, range of motion measurements) was not available to determine whether there is a relationship between postoperative protocols and outcomes or between radiographic findings and clinical changes in the range of motion. We believe that the change in physeal angle closely mirrors the clinical examination; however, there is currently no data to support this observation. Our conclusions would have been stronger if each patient underwent preoperative and postoperative gait analysis; however, as a tertiary level referral center where many of the postoperative visits were done remotely, preoperative and postoperative gait analysis was not possible.

In conclusion, antegrade transphyseal 2-screw ADFH procedure is a powerful technique for altering sagittal distal femoral anatomy in the correction of mild to moderate FKFDs. While the rate of correction after 12 months may decrease, the initial screw position appears to influence the amount of physeal change that occurs over time. Practitioners should strive to place both screws in the anterior third of the distal physis to generate the greatest degree of knee flexion deformity correction. Close postoperative surveillance, while the physis remains open, is important to ensure that implanted screws do not eventually tether the posterior aspect of the physis, resulting in a decrease of the physeal angle and a possible loss of knee extension. Larger prospective study is needed to help identify the ideal surgical indications for this powerful technique for the correction of FKFDs in skeletally immature patients.

REFERENCES

1. Bell KJ, Ounpuu S, DeLuca PA, et al. Natural progression of gait in children with cerebral palsy. *J Pediatr Orthop*. 2002;22:677–682.
2. Rose GE, Lightbody KA, Ferguson RG, et al. Natural history of flexed knee gait in diplegic cerebral palsy evaluated by gait analysis in children who have not had surgery. *Gait Posture*. 2010;31:351–354.
3. Wright JG, Menelaus MB, Broughton NS, et al. Natural history of knee contractures in myelomeningocele. *J Pediatr Orthop*. 1991;11: 725–730.
4. Murray C, Fixsen JA. Management of knee deformity in classical arthrogryposis multiplex congenita (amyoplasia congenita). *J Pediatr Orthop B*. 1997;6:186–191.
5. Young JL, Rodda J, Selber P, et al. Management of the knee in spastic diplegia: what is the dose? *Orthop Clin North Am*. 2010;41: 561–577.
6. Stout JL, Gage JR, Schwartz MH, et al. Distal femoral extension osteotomy and patellar tendon advancement to treat persistent crouch gait in cerebral palsy. *J Bone Joint Surg Am*. 2008;90: 2470–2484.
7. Kramer A, Stevens PM. Anterior femoral stapling. *J Pediatr Orthop*. 2001;21:804–807.
8. Klatt J, Stevens PM. Guided growth for fixed knee flexion deformity. *J Pediatr Orthop*. 2008;28:626–631.
9. Wang KK, Novacheck TF, Rozumalski A, et al. Anterior guided growth of the distal femur for knee flexion contracture: clinical, radiographic, and motion analysis results. *J Pediatr Orthop*. 2019;39: e360–e365.
10. Nazareth A, Gyorfi MJ, Rethlefsen SA, et al. Comparison of plate and screw constructs versus screws only for anterior distal femoral hemiepiphysiodesis in children. *J Pediatr Orthop B*. 2020;29: 53–61.
11. Stiel N, Babin K, Vettorazzi E, et al. Anterior distal femoral hemiepiphysiodesis can reduce fixed flexion deformity of the knee: a retrospective study of 83 knees. *Acta Orthop*. 2018;89: 555–559.
12. Kay RM, Rethlefsen SA. Anterior percutaneous hemiepiphysiodesis of the distal aspect of the femur: a new technique: a case report. *JBJS Case Connect*. 2015;5:e95.
13. Blount WP, Clarke GR. Control of bone growth by epiphyseal stapling; a preliminary report. *J Bone Joint Surg Am*. 1949;31A: 464–478.
14. Stevens PM. Guided growth: 1933 to the present. *Strategies Trauma Limb Reconstr*. 2006;1:29–35.
15. Shore BJ, McCarthy J, Shrader MW, et al. Anterior distal femoral hemiepiphysiodesis in children with cerebral palsy: establishing surgical indications and techniques using the modified Delphi method and literature review. *J Child Orthop*. 2022;16:65–74.
16. Fleiss JL. Statistical Methods for Rates and Proportions2nd Ed.*ed*. Wiley & Sons; 1981.
17. Long JT, Laron D, Garcia MC, et al. Screw anterior distal femoral hemiepiphysiodesis in children with cerebral palsy and knee flexion contractures: a retrospective case-control study. *J Pediatr Orthop*. 2020;40:e873–e879.
18. Rethlefsen SA, Hanson AM, Wren TAL, et al. Anterior distal femoral hemiepiphysiodesis with and without patellar tendon shortening for fixed knee flexion contractures in children with cerebral palsy. *J Child Orthop*. 2020;14:415–420.

Copyright © 2023 Wolters Kluwer Health, Inc. All rights reserved.