

# Expanded Indications for Guided Growth in Pediatric Extremities

Teresa Cappello, MD

Shriners Hospitals for Children, Chicago, IL

**Abstract:** Guided growth for coronal plane knee deformity has successfully historically been utilized for knee valgus and knee varus. More recent use of this technique has expanded its indications to correct other lower and upper extremity deformities such as hallux valgus, hindfoot calcaneus, ankle valgus and equinus, rotational abnormalities of the lower extremity, knee flexion, coxa valga, and distal radius deformity. Guiding the growth of the extremity can be successful and is a low morbidity method for correcting deformity and should be considered early in the treatment of these conditions when the child has a minimum of 2 years of growth remaining. Further expansion of the application of this concept in the treatment of pediatric limb deformities should be considered.

## Key Concepts:

- Guiding the growth of pediatric physes can successfully correct a variety of angular and potentially rotational deformities of the extremities.
- Guided growth can be performed using a variety of techniques, from permanent partial epiphysiodesis to temporary methods utilizing staples, screws, or plate and screw constructs.
- Utilizing the potential of growth in the pediatric population, guided growth principals have even been successfully applied to correct deformities such as knee flexion contractures, hip dysplasia, femoral anteversion, ankle deformities, hallux valgus, and distal radius deformity.

## Introduction

Guiding the growth of pediatric orthopaedic deformities is represented by the symbol of orthopaedics itself, as the growth of a tree is guided as it is tethered to a post (Figure 1). This concept has been successfully utilized in our field for decades beginning with Phemister's permanent techniques<sup>1</sup> to Blount's staples<sup>2</sup> and Metaizeau's screws.<sup>3</sup> Use of a tension-band plate developed by Stevens<sup>4,5,6</sup> has further expanded the use of guided growth in pediatric orthopaedics. While its use in correcting genu valgum and genu varum has been accepted, there are

other indications and uses for guided growth that may not have wide appreciation.

The success of guided growth techniques is based upon the Hueter-Volkman principles that demonstrate asymmetrical growth of the physis in response to compressive forces.<sup>7</sup> Holding or compressing one side of the physis while allowing the contralateral side to grow can lead to correction of the deformity. This has been clinically demonstrated to correct angular deformities in the

coronal or sagittal planes in a multitude of studies but has also shown to have an effect on rotational alignment in animals.<sup>8,9</sup> Concepts contributing to the success of guided growth techniques include preserving the periosteum and physis and operating at a time when adequate growth remains.<sup>4,7</sup>

Expanded indications for guided growth techniques in pediatric extremities include correction of hallux valgus, hindfoot calcaneus, ankle equinus, ankle valgus, rotational abnormalities of the lower extremity, knee flexion, contractures, coxa valga, and distal radius deformity.

### Surgical Methods to Guide Growth

Permanent complete epiphysiodesis is a standard procedure to equalize limb lengths, which can be performed in a number of ways. Physeal growth can be inhibited by insertion of a bony block across the physis, spanning both sides of the growth plate with an implant or more commonly, drill epiphysiodesis of the physis. A partial permanent hemi-epiphysiodesis has been used to manage angular deformities of bones. Certainly, timing of the procedure is important since it cannot be reversed and the potential for overcorrection exists.

Various other methods to guide growth via hemiepiphysiodesis utilize implants to temporarily inhibit a portion of physeal growth. Close follow-up is necessary in this patient population to determine when the implant should be removed. Blount and Clarke described the use of multiple staples for guided growth of the medial distal femur and proximal tibia in the correction of genu valgum. It was initially recommended that three staples be used to decrease the possibility of them bending or breaking.<sup>2</sup> Efficacy of staples is certainly well-established,<sup>10,11</sup> but many find that they migrate and may need revision<sup>2,12</sup> or that multiple staples do not correct as well as a single tension band plate and screws.<sup>13</sup> In theory, angular correction of the deformity begins near where the tips of the staples end within the bone, not necessarily allowing for use of the entire width of the physis for angular correction with growth (Figure 2).



**Figure 1.** Symbol of orthopaedic surgery  
(Image ID: 62034064/shutterstock.com)

Temporary percutaneous epiphysiodesis using transphyseal screws (PETS) has been shown to be effective in correcting angular deformities such as genu valgum and ankle valgus.<sup>3,14-21</sup> They have also been used in the attempts to correct or improve coxa valga related to cerebral palsy<sup>22,23,24</sup> or hip dysplasia.<sup>25,26,27</sup> As with the staple, the angular correction begins at the location where the screw crosses the growth plate and theoretically through only part of the physis, not the entire physeal width.

Guided growth utilizing an extra-periosteal small plate and screws was developed by Peter Stevens (8-Plate Guided Growth System, Orthofix, McKinney, TX). Since this placement of the tension band plate puts the fulcrum of angular correction outside of the bone, it theoretically allows greater correction with growth, which avoids those considerations with use of staples or screws (Figure 3).

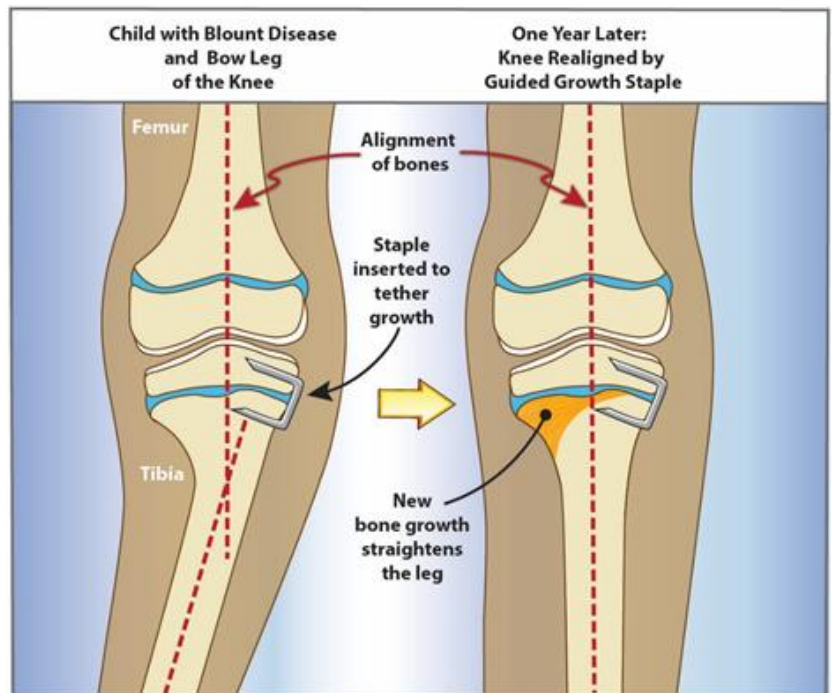
It's possible that the flexible nature of the plate and screw construct may also allow better (faster) correction than rigid staples or transphyseal screws.<sup>4,12,28</sup> Yet, it is difficult to actually prove whether one implant is better than another in humans. This is due to the heterogeneity of the patients who differ in diagnosis, intrinsic growth potential, the location and degree of deformity, and surgical technique. It would take a very large study with ample power to isolate the variable of implant de-

sign on outcome. In animal models that can better control the ability to “produce” deformity, the difference between fixed implants and modular plate and screw constructs show similar results in lambs.<sup>29</sup> In rabbits, the plate and screw construct corrected angular deformity at the same rate as a single staple but better than the traditionally used two or more staples.<sup>13</sup> Despite similar results of modular plate and screws with a rigid staple in humans and in animal models, the ease of placement and efficacy of deformity correction with the use of a modular plate and screw construct makes it the most common implant used for coronal plane deformity correction at the knee.<sup>6,7,10,12,17,19,28,30,31</sup>

The following highlights indications and methodology of guided growth at locations other than for coronal plane deformity of the knee.

### Guided Growth for Hallux Valgus

Surgical treatment with metatarsal osteotomies of younger patients with painful hallux valgus deformities has routinely been avoided due to risk of recurrent deformity with growth. Guiding the growth of the 1<sup>st</sup> metatarsal base to correct this deformity could be performed at a younger age. Earlier procedures involved permanent 1<sup>st</sup> metatarsal lateral hemi-epiphyseodesis with a lateral bone plug, taken from the calcaneus.<sup>33,34,35</sup> Other studies utilized staples,<sup>36,37</sup> drill,<sup>38,39</sup> or screw hemi-epiphyseodesis<sup>40,41</sup> to stop the growth of the lateral portion of the 1<sup>st</sup> metatarsal base, thereby leading to a decrease in the hallux valgus alignment of the first ray with continued growth. The hallux valgus deformity can be improved by these procedures and pain improved if not relieved. However, the largest study<sup>40</sup> included 37 feet which demonstrated an improvement in alignment and return to full activity but did not specifically monitor pain. As is common with many guided growth articles, the general recommendations for timing of the procedure is to have 2 or more years of growth remaining.<sup>39,40</sup> Future study is required to determine if this technique routinely results in decreased pain.



**Figure 2.** Correction of angular deformity of bone with staples allows correction of deformity to occur presumably in the physis from the area where staple ends to the contralateral side of the bone (©2019 Rubin Institute for Advanced Orthopedics, Sinai Hospital of Baltimore, Baltimore, MD).

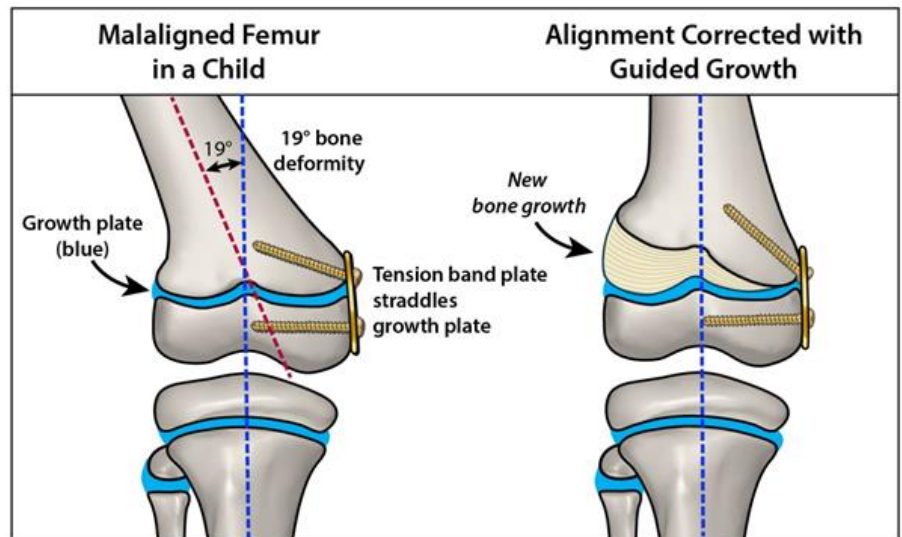
### Guided Growth for Ankle and Hindfoot Deformity

Calcaneus deformity of the hindfoot can occur after surgical clubfoot treatment, but it can also be related to a neuromuscular etiology or post-traumatic deformity. It can be quite difficult to treat. Sinha et al.<sup>42</sup> performed guided growth of the posterior distal tibia physis using tension band plates in 11 ankles with calcaneus deformity of the hindfoot with an average age at surgery of 10 years old. Radiographic alignment of the position of the calcaneus in relation to the distal tibia did improve, and four ankles needed hardware revision due to maximum divergence at 1 year, demonstrating a response to the procedure. Certainly, future studies are needed to further explore this potential guided growth treatment of utilizing the growth potential of the distal tibia to correct a hindfoot deformity (Figure 4).

Residual ankle equinus in surgically treated clubfoot deformities can be difficult to address. In postoperatively treated clubfeet at 10+ years of age, Burghardt et al.<sup>43</sup> documented 48% of feet (25/52 patients) with ankle equinus, demonstrating this to be a common problem but the relationship to decreased ankle dorsiflexion was less clear. Al-Aubaidi et al.<sup>44</sup> documented 31 cases of anterior tibia guided growth with staples or plates and screws. Although radiographs documented improvement in alignment, it did not correlate with clinically measured dorsiflexion. However, Ebert et al.<sup>45</sup> demonstrated a statistically significant improvement in ankle dorsiflexion in postoperatively treated clubfeet with anterior distal tibia guided growth with plate and screws in 20/23 patients, deeming it a safe and effective procedure. Recommended age at surgery was 10 years old to assure there was enough future growth for improvement of the alignment. In yet unpublished data, Giertych et al. demonstrated in 20 clubfoot ankles an improvement in anterior tilt, amount of dorsiflexion and in walking capability with guided growth of the anterior tibia with plates and screws.<sup>46</sup> It appears this procedure may be beneficial in managing residual equinus deformity especially in the face of joint incongruity (Figure 5).

When performing anterior distal tibia guided growth in a younger patient, one should consider what to do when the deformity is corrected and if the child is at risk for overcorrection. Implant removal is an obvious choice, yet recurrence is not uncommon. It is for this reason that some will remove the implant and completely arrest the distal tibia and fibula with the understanding that a contralateral proximal tibia growth arrest may be needed for a limb length discrepancy of 2 centimeters or more.

Ankle valgus has been treated with guided growth routinely for more than a decade with reliable results using medial malleolar screw fixation<sup>14-19,21,26</sup> or medial distal tibia tension band plate and screws.<sup>17,19,28,48</sup> Although both methods have clearly demonstrated correction of



**Figure 3.** Correction of angular deformity of bone with extraperiosteal plate and screws allows correction of deformity to occur through entire width of physis (©2019 Rubin Institute for Advanced Orthopedics, Sinai Hospital of Baltimore, Baltimore, MD).

ankle valgus with growth, the rate of correction appears to be slightly faster with medial malleolar screw fixation. The age for implantation has varied significantly and has shown to be effective as early as 4.4 years of age<sup>12</sup> to 15.7 years of age,<sup>14</sup> which indicates this is an effective treatment for growing children of a wide age range. Overall, it is deemed a safe and effective procedure that is sufficient in correcting ankle valgus due to multiple conditions such as spina bifida, multiple hereditary exostoses, clubfoot, and cerebral palsy.

### Guided Growth for Rotational Deformity

Animal studies have demonstrated that rotational deformities of long bones can be produced by guided growth. Cobanoglu et al.<sup>49</sup> placed extra-periosteal plates and screws on the proximal tibia physis in rabbits. Medially the plates and screws were oriented from a proximal posterior to distal anterior direction. Laterally the orientation of the plate was in the opposite direction from proximal anterior to distal posterior. Growth of the bone resulted in the plates moving to a more longitudinal direction which resulted in a statistically significant decrease in internal tibial torsion. However, follow-up

study of the same specimens revealed changes in the tibial plateau geometry,<sup>8</sup> so further studies are warranted.

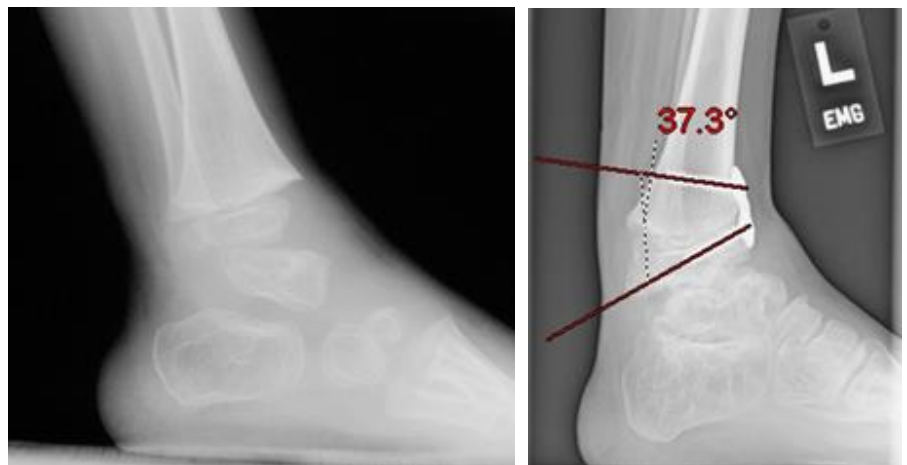
Improvement in human femoral anteversion has been postulated in biomechanical studies. In one study, saw-bone femora were cut at the location of the distal femoral

physis and plates and screws placed in opposite angulated manners. As the bone was distracted, such as with normal growth, the rotation of the distal femur was improved.<sup>50</sup> Taking this concept to animals, improvement of femoral anteversion in rabbits has also been demonstrated with plates and screws placed in the distal femur.<sup>9,51</sup> Plates were positioned to guide external rotation, and a statistically significant increase in external rotation of each femur was demonstrated in a predictable manner.

Metaizeau et al.<sup>52</sup> published the first study demonstrating a similar technique to correct medial femoral torsion in children due to idiopathic or neuromuscular etiologies. Two screws and a cable were placed around the distal femoral physis to convert the axial growth of the femur into rotational growth. Twenty knees in 11 children underwent the procedure with a mean age of 10.1 years (8.6-12.7 years). A total mean derotation of 25 degrees occurred over 22 months. External hip rotation increased by 23 degrees, and internal rotation decreased by 31 degrees. Mild recurvatum deformity occurred in eight knees but none required treatment. Certainly, this procedure warrants further study since it could decrease the need for femoral osteotomies, yet the possibility of iatrogenic angular deformity and limb length discrepancy do exist.



**Figure 4.** An 11-year-old boy with a history of clubfoot surgery as a child before moving to the U.S. His foot had excessive dorsiflexion, and he walked with a calcaneus gait. A) Preoperative x-ray, B) Intraoperative view, C) Follow-up after 20 months. Note divergence of screws and improvement of calcaneus alignment (Radiographs courtesy of Ken Noonan, MD, Madison, WI).



**Figure 5.** A) Maximum dorsiflexion lateral radiograph of a 5-year-old patient with arthrogryposis and residual ankle equinus deformity after three prior operations, B) Improvement of ankle equinus 2 years after implant placement demonstrating divergence of screws (Radiographs courtesy of Ken Noonan, MD, Madison, WI).

For instance, guided growth in the distal femur to correct femoral anteversion can result in a decrease in the longitudinal growth of the femur, demonstrated in both a rabbit model<sup>51</sup> and in children.<sup>52</sup> The use of guided growth to primarily treat rotational deformities is intriguing and may have potential, but before this is widely used, more work needs to be done to assess feasibility without creating length discrepancy or iatrogenic angular deformity.

## Guided Growth for Knee Flexion Contractures

Stevens et al.<sup>53</sup> described stapling of the antero-medial and anterolateral distal femur to treat fixed knee flexion deformities with successful results in 26/28 patients with multiple neuromuscular diagnoses, thereby avoiding distal femoral osteotomies. Noting limitations of stapling to include slow correction and hardware migration, Stevens later published the effective results of this procedure using plates and screws.<sup>5</sup> Despite the association of fixed knee flexion contractures with patella alta, surgical intervention via a potential patella tendon advancement for symptoms was not needed after the knee position was improved with guided growth. Plate and screw placement to achieve an anterior distal femoral hemiepiphysiodesis (Figure 6) to treat knee flexion contractures has shown repeated beneficial results by other authors in children with arthrogyposis and neuromuscular diagnoses.<sup>44,54-58</sup>

Placement of two intra-articular plates can be challenging as one has to avoid the tracking of the patella, knee pain and stiffness can occur. To mitigate these challenges, guided growth of the distal femur can also be performed with two screws placed in a longitudinal manner across the anterior distal femoral physis medially and laterally.<sup>59,60,61</sup> An alternative is to place one screw in the central distal femur (Figure 7) which has demonstrated reliable improvement in knee extension and less postoperative pain than plates and screws.<sup>62</sup> Success of these procedures appears to be related to age at surgical intervention and severity of contracture. Efficacy of this procedure may be decreased in children close to skeletal maturity or with more severe flexion deformities, such as those > 45 degrees.<sup>53,55</sup> From review of these articles, surgical intervention is generally recommended at approximately 10–12 years of age.



**Figure 6.** A 13-year-old ambulatory boy with cerebral palsy and knee flexion contractures resolved with guided growth of anterior distal femur with plates and screws (Radiographs courtesy of Ken Noonan, MD, Madison, WI).



**Figure 7.** Guided growth of distal femur with one cannulated screw for treatment of knee flexion contracture (Radiographs courtesy of Ken Noonan, MD, Madison, WI).

Prior to correcting knee flexion contractures, one needs to consider some important factors. Total knee range of motion should be assessed prior to guided growth. A patient with a 20-25-degree knee flexion contracture can be corrected, but if the child only has 70-80 degrees of total motion, sitting will be more difficult due to the loss in knee flexion. One also needs to have a plan for implant removal which can be difficult. For instance, when using PETS with either one or two screws, the implants become parallel to the femur with correction and are hard to remove. In these cases, one could consider complete epiphysiodesis of the distal femur to avoid the difficult implant removal and the possibility of recurrence. When using modular plate and screws to correct knee flexion contracture at a younger age, the screws can penetrate the posterior femoral cortex as their location becomes metadiaphyseal with growth.<sup>63</sup> Therefore, screws should be removed before they lead to pain or encroachment of the posterior neurovascular structures.

### Guided Growth at the Hip

Screw fixation for guided growth of the proximal femur in patients with cerebral palsy and DDH has been used to treat coxa valga and prevent hip dislocation for the last decade.

The implant diameter chosen varies considerably in the studies but routinely it is a cannulated screw including a partially threaded 4.5-mm titanium screw,<sup>22</sup> a fully threaded 6.0-mm screw,<sup>23</sup> a partially threaded 7.0-mm screw<sup>23-26</sup> and even an 8-mm fully threaded diameter screw.<sup>26</sup> It is generally recommended that 2-3 screw threads are past the physis into the epiphysis. With time, the femoral head may grow off the screw so that the screw no longer crosses the physis. This can occur in 16-44% of CP patients<sup>22,23</sup> and 38-40% with DDH.<sup>25,26</sup> The screw can be replaced with a longer screw if deemed necessary.

Multiple studies have supported its use in children with cerebral palsy (CP), demonstrating a decrease in the hip joint migration percentage (MP) and improvement in proximal femoral neck-shaft angle (NSA), thereby decreasing the



**Figure 8.** AP x-ray of pelvis demonstrating proximal femoral guided growth in hip of 4-year-old patient with cerebral palsy with coxa valga and acetabular dysplasia (Radiograph courtesy of Haluk Altioik, MD, Chicago, IL).

need for larger surgeries such as a proximal femoral osteotomy and acetabuloplasty<sup>22,23,24</sup> (Figure 8).

Indications for surgery in cerebral palsy patients are not always clearly presented but have been shown to include MP between 30-50%, progressive hip subluxation, head shaft angle (HSA) > 155 degrees, and at least 2 years of growth remaining.<sup>23</sup> Age at implantation has been variable, between 4-12 years of age. The younger the patient, the greater potential for improvement in the NSA.<sup>22</sup> However, the best age at which to perform this procedure is not yet clear, and migration percentage of the femoral head may be the more appropriate indicator for the need to surgically intervene. This procedure has demonstrated success in all cerebral palsy patients classified via gross motor function classifications.<sup>22,23,24</sup> However, this procedure does not prevent further subluxation in all neuromuscular hips. Hsieh et al. concluded it was indicated and successful in patients with MP < 50%. In this study, approximately half the patients also underwent adductor tenotomy at the same procedure. Subsequent femoral and acetabular osteotomies may be needed in 5-21% of patients,<sup>22,23</sup> which is still a significant reduction in relatively large procedures performed on this patient population.

This procedure has also been used to treat coxa valga associated with developmental dysplasia of the hip (DDH), thought to be due to a growth disturbance of the lateral proximal femoral physis.<sup>25,26,27</sup> McGillion et al. first described this technique for this condition and demonstrated an improvement in proximal femoral alignment in 7/10



patients whose average age was 12 years.<sup>27</sup> Peng et al. demonstrated improvement in the center edge angle (CEA) in 10 children with hip dysplasia and an average age of 7 years after guided growth of the proximal medial femur for 2 years. It is thought that the varus changes in the proximal femur resulted in the change in CEA. Partial rebound growth did occur when the proximal femur grew off the screw, but the angle did not return to its preoperative measure, and the CEA continued to improve.<sup>25</sup> Torode et al. demonstrated an improvement in CEA and head-shaft angle in 13 hips with screw placement between 5-14 years of age. Indications for surgical intervention was increasing coxa valga in these DDH patients. Five patients did undergo screw revision as the proximal femur grew off the length of the screw 2+ years after it was placed. Screw revision for a longer screw was then performed.<sup>26</sup>

In order to mitigate the issues of required screw exchange, some have chosen to consider hip hemiepiphyseodesis without an implant. Agus et al. drilled the proximal medial physis in 11 children with DDH; however, no screw was used. An improvement in physeal inclination was demonstrated with growth.<sup>64</sup> The age at surgical intervention depended upon the age of diagnosis of the lateral proximal femoral growth abnormality, which may not occur in hip dysplasia patients until later in childhood.



**Figure 9.** A 15-year-old boy with distal ulna growth arrest after fracture and progressive deformity of wrist 3 years after fracture. A-B) Distal radius growth modulation with plate and screws and ulna lengthening with external fixator, C) Correction of distal radius alignment after treatment (Radiographs courtesy of Ken Noonan, MD, Madison, WI).

### Guided Growth at the Wrist

Very few indications for guided growth commonly exist in the upper extremity. At the proximal humerus there is a lot of growth potential which one could try to harness for correction of deformity; yet most deformities are not problematic and are well accommodated due to the large ranges of motion at this joint. At the elbow there are certainly deformities (post-traumatic cubitus varus or valgus) that may require osteotomy and where guided growth would be appealing. Unfortunately, there is minimal growth at this area such that it cannot be counted on to correct deformity. There are some post-traumatic, developmental, and genetic deformities (Madelung's, skeletal dysplasia) that could be amenable to guided growth at the distal radius.

Disorders such as multiple hereditary exostoses (MHE) can lead to radial deviation of the radius, perhaps as a result of the shortened ulna which tethers the radius. Kelly et al. performed distal radius stapling on the radial side of the distal radius physis in 18 patients with

MHE demonstrating an effective improvement in radial articular angle, deeming it a simple and effective treatment option for this distal radius deformity.<sup>65</sup>

Distal ulna physeal arrests after fracture can also occur, which can also lead to progressive apex radial inclination of the wrist joint and alteration in the alignment of the distal radius physis.

Guided growth of the radial side of the distal radius can correct this as the ulna is addressed separately with a lengthening procedure (Figure 9).

Growth of the distal ulna physis at the wrist can also be permanently stopped in cases of positive ulna variance due to radial growth arrest from trauma. Some have tried temporarily slowing the physis with a plate and screws.<sup>66</sup> Scheider et al.<sup>67</sup> demonstrated the utility of performing this guided growth procedure in the distal ulna to treat painful ulnar positive variance in seven pediatric wrists. Average ulna variance decreased from +3.9mm preoperatively to +0.1mm over 2 years after the initial surgery with six of the seven wrists not requiring further surgical treatment. Their conclusion was that this procedure would be indicated in young adolescents (10-13 years old) with mild to moderate differences in positive ulnar variances and an open distal radius physis.

### Complications from Guided Growth

Undercorrection of the angular deformity being treated with guided growth is a risk, potentially increased with older age of the patient at the time of the procedure. If there is insufficient growth remaining, then guiding the growth of the bone may not fully correct the deformity. In general, guided growth procedures should be considered when a girl is approximately 10 years of age and a boy 10-12 years of age. Patients should have 2+ years of growth remaining, so it may be pertinent to obtain a family history to assess familial growth tendencies.

Potential implant issues are ubiquitous at all locations and for all indications. Hardware backing out of the bone



**Figure 10.** A 9-year-old boy with cerebral palsy underwent anterior distal femoral stapling to address fixed knee flexion deformity. Correction obtained with growth but late follow-up resulted in hyperextension of the knee (Radiographs courtesy of Haluk Altiok, MD, Chicago, IL).

would decrease the success of the guided growth procedure and warrant hardware revision or removal. This can occur with staples and is one reason that use of plate and screws may be preferred over staples.<sup>68</sup> This has been demonstrated repeatedly in guided growth of the proximal femur<sup>24,25</sup> and has been addressed by revision of the screw for a longer length.<sup>22,23,26</sup>

Implant breakage is a concern with guided growth in general, especially around the knee. A questionnaire to the Pediatric Orthopaedic Society of North America (POSNA) published in 2010 demonstrated that overweight and obese patients with Blount disease being treated with plate and screws for genu varum sustained implant breakage more commonly than normal weight patients.<sup>69</sup> With the use of cannulated screws and a plate in this patient population, the metaphyseal screw has

**Table 1. Accepted Indications for Guided Growth in the Lower and Upper Extremities**

Deformity	Location	Diagnoses	Pearls
Genu Vara and Valgus	Distal Femur Proximal Tibia	Multiple Indications	The gold standard for guided growth provided enough growth remains
Hallux Valgus	1 <sup>st</sup> metatarsal base	Idiopathic, CP	Treat younger symptomatic patients
Calcaneus Deformity	Distal tibia posterior	Clubfoot, CP, Post-traumatic	Newer treatment option with positive early results
Ankle Equinus	Distal tibia anterior	Clubfoot Residual	Lower risk than osteotomy with benefit potential
Ankle Valgus	Distal tibia medial	Idiopathic, MHE, MM, Other	Reliable and effective method of correction
Knee Flexion Contracture	Distal femur anterior	CP, Syndromes, Arthrogryposis	Lower risk than osteotomy and effective in moderate deformity
Coxa valga	Proximal femur medial	CP, DDH	Prevent and potentially improve hip subluxation; less invasive and lower risk than osteotomy
Deformity of the Wrist	Distal Radius	Post-traumatic, MHE, Other	Less invasive than osteotomy Consider correction of short ulna

CP (cerebral palsy), MHE (multiple hereditary exostoses), MM (myelomeningocele), DDH (developmental dysplasia of the hip)

been shown to break.<sup>30,70</sup> If the patient is obese, it is recommended to consider using solid screws to decrease the possibility of breakage with time.<sup>71</sup> One report demonstrated a screw that was placed in the proximal femur to decrease coxa valga broke upon attempt at revision, leading the authors to place a second screw parallel to the first one in subsequent procedures needed for the physis growing off the screw.<sup>22</sup>

Overcorrection can occur if the guided growth implant is left in place longer than needed which can be due to late follow-up<sup>72,73</sup> (Figure 10).

Once correction of the deformity is obtained, implant removal is commonly performed. Rebound of the deformity has been shown in ankle valgus<sup>4,74,75,76</sup> and presumably could occur with other areas of guided growth. Close

follow-up until skeletal maturity is recommended to remove the implant promptly when overcorrection could occur and to assess for rebound deformity.

## Conclusion

Guiding the growth of children to correct deformity is the symbol of our profession. Over the last decade, studies have been performed exploring the expanded utility and success of guided growth procedures in skeletally immature patients beyond its uses in treating genu varum and genu valgum (Table 1). The expanded clinical uses of guided growth would benefit from future larger studies, including longer-term follow-up and patient-reported outcomes. Guiding the growth of bones is a concept that will stay with us and will continue to translate into improved function in children with less morbidity.

## References

1. Phemister DB. Operative arrestment of longitudinal growth of the bones in the treatment of deformities. *J Bone Joint Surg*. 1933;15(1):1-15.
2. Blount WP, Clarke GR. Control of bone growth by epiphyseal stapling: a preliminary report. *J Bone Joint Surg Am*. 1949;31(3):464-478.
3. Métaizeau JP, Wong-Chung J, Bertrand H, et al. Percutaneous epiphysiodesis using transphyseal screws (PETS). *J Pediatr Orthop*. 1998;18(3):363-369.
4. Stevens PM. Guided growth: 1933 to the present. *Strategies Trauma Limb Reconstr*. 2006;1:29-35.
5. Klatt, J, Stevens, PM. Guide growth for fixed knee flexion deformity, *J Pediatr Orthop*. 2008;28(6):626-631.
6. Burghardt RD, Herzenberg JE, Standard SC, Paley D. Temporary hemiepiphysal arrest using a screw and plate device to treat knee and ankle deformities in children: a preliminary report. *J Child Orthop*. 2008;2(3):187-197.
7. Eastwood DM, Sanghrajka AP. Guided growth: recent advances in a deep-rooted concept. *J Bone Joint Surg Br*. 2011;93(1):12-18.
8. Sevil-Kilimci F, Cobanoglu M, Ocal MK, et al. Effects of tibial rotational-guided growth of the geometries of tibial plateaus and menisci in rabbits. *J Pediatric Orthop*. 2019;39(6):289-294.
9. Arami A, Bar-On E, Herman A, et al. Guiding femoral rotational growth in an animal model. *J Bone Joint Surg Am*. 2013;95:2022-2027.
10. Wiemann JM, Tryon C, Szalay EA. Physeal stapling versus 8-plate hemiepiphysiodesis for guided correction of angular deformity about the knee. *J Pediatr Orthop*. 2009;29(5):481-485.
11. Mielke CH, Stevens PM. Hemiepiphysal stapling for knee deformities in children younger than 10 years: a preliminary report. *J Pediatr Orthop*. 1996;16(4):423-429.
12. Stevens PM. Guided growth for angular correction: a preliminary series using a tension band plate. *J Pediatr Orthop*. 2007;27(3):253-259.
13. Sanpera I, Raluy-Collado D, Frontera-Juan G, et al. Guided growth: the importance of a single tether. An experimental study. *J Pediatr Orthop*. 2012;32(8):815-820.
14. Wesberry DE, Carpenter AM, Thomas JT et al. Guided growth for ankle valgus deformity: the challenges of hardware removal. *J Pediatric Orthop*. 2020;40(9):e883-e888.
15. Rupprecht M, Spiro AS, Rueger JM, et al. Temporary screw epiphysodesis of the distal tibia a therapeutic option for ankle valgus in patient with hereditary multiple exostosis. *J Pediatric Orthop*. 2011;31(1):89-94.
16. Chang FM, Ma J, Pan Z, et al. Rate of correction and recurrence of ankle valgus in children using a transphyseal medial malleolar screw. *J Pediatric Orthop*. 2015;35(6):589-592.
17. Yilmaz, G, Oto M, Thabet AM, et al. Correction of lower extremity angular deformities in skeletal dysplasia with hemiepiphysiodesis: a preliminary report. *J Pediatric Orthop*. 2014;34(3):336-345.
18. Bayhan IA, Yildirim T, Beng K, et al. Medial malleolar screw hemiepiphysiodesis for ankle valgus in children with spina bifida. *Acta Orthop Belg*. 2014;80:414-418.
19. Driscoll MD, Linton J, Sullivan E, et al. Medial malleolar screw versus tension-band plate hemiepiphysiodesis for ankle valgus in the skeletally immature. *J Pediatric Orthop*. 2014;34(4):441-446.
20. Nouh F, Kuo LA. Percutaneous epiphysiodesis using transphyseal screws (PETS): a prospective case study and review. *J Pediatr Orthop*. 2004;24(6):721-725.
21. Stevens PM, Belle RM. Screw epiphysiodesis for ankle valgus. *J Pediatric Orthop*. 1997;17(1):9-12.
22. Portinaro N, Turati M, Cometto M, et al. guided growth of the proximal femur for the management of hip dysplasia in children with cerebral palsy. *J Pediatr Orthop*. 2019;39(8):e622-e628.
23. Hsieh HC, Wang TM, Kuo KN, et al. Guided growth improves coxa valga and hip subluxation in children with cerebral palsy. *Clin Orthop Relat Res*. 2019;477:2568-2576.

24. Lee W, Hsuan-Kai K, Yang WE, et al. Guided growth of the proximal femur for hip displacement in children with cerebral palsy. *J Pediatr Orthop*. 2016;36(5):511-515.
25. Peng SH, Lee WC, Kao HK, et al. Guided growth for caput valgum in developmental dysplasia of the hip. *J Pediatr Orthop B*. 2018;27(6):485-490.
26. Torode IP, Young JL. Caput valgum associated with developmental dysplasia of the hip: management by transphyseal screw fixation. *J Child Orthop*. 2015;9:371-379.
27. McGillion S, Clarke NMP. Lateral growth arrest of the proximal femoral physis: a new technique for serial radiological observation. *J Child Orthop*. 2011;5:201-207.
28. Stevens PM, Kennedy JM, Hung M. Guided growth for ankle valgus. *J Pediatric Orthop*. 2011;31(8):878-883.
29. Noonan KJ, Halanski MA, Leiferman E, Wilsman N. Growth Retardation (Hemiepiphyseal Stapling) and Growth Acceleration (Periosteal Resection) as a Method to Improve Guided Growth in a Lamb Model. *J Pediatr Orthop*. 2016 Jun;36(4):362-9.
30. Scott AC. Treatment of infantile Blount disease with lateral tension band plating. *J Pediatr Orthop*. 2012;32(1):29-34.
31. Danino B, Rodl R, Herzenberg JE, et al. Guided growth: preliminary results of a multinational study of 967 physes in 537 patients. *J Child Orthop*. 2018;12:91-96.
32. Sanpera I, Raluy-Collado D, Frontera-Juan, et al. Guided growth: the importance of a single tether. An experimental study. *J Pediatr Orthop*. 2012;32(8):815-820.
33. Fox IM, Smith SD. Juvenile bunion correction by epiphysiodesis of the first metatarsal, *J Am Podiatr Med Assoc*. 1983;73(9):448-455.
34. Sheridan LE. Correction of juvenile hallux valgus deformity associated with metatarsus primus adductus using epiphysiodesis technique. *Clin Podiatr Med Surg*. 1987;4(1):63-74.
35. Wertheimer SJ. Role of epiphysiodesis in the management of deformities of the foot and ankle. *J Foot Surg*. 1990;29(5):459-462.
36. Ellis VH. A method of correcting metatarsus primus varus: a preliminary report. *J Bone Joint Surg*. 1951;33B(3):415-417.
37. Seiberg M, Green R, Green D. Epiphysiodesis in juvenile hallux abducto valgus: a preliminary retrospective study. *J Am Podiatr Med Assoc*. 1984;84(5):225-236.
38. Sabah Y, Rosello O, Clement JL, et al. Lateral hemiepiphysiodesis of the first metatarsal for juvenile hallux valgus. *J Orthop Surg*. 2018;26(3):1-5.
39. Davids JR, McBrayer D, MD, Blackhurst DW. Juvenile hallux valgus deformity surgical management by lateral hemiepiphysiodesis of the great toe metatarsal. *J Pediatric Orthop*. 2007;27(7):826-830.
40. Chiang MH, Wang TM, Kuo KN, et al. Management of juvenile hallux valgus deformity: the role of combined hemiepiphysiodesis. *BMC Musculoskelet Disord*. 2019;20(472):1-8.
41. Schlickewei C, Ridderbusch K, Breyer S, et al. Temporary screw epiphysiodesis of the first metatarsal for correction of juvenile hallux valgus. *J Child Orthop*. 2018;12:375-382.
42. Sinha A, Selvan D, Sinha A, et al. Guided growth of the distal posterior tibial physis and short term results: a potential treatment option for children with calcaneus deformity. *J Pediatric Orthop*. 2016;36(1):84-88.
43. Burghardt RD, Tettenborn LP, Stucker R. Growth disturbance of the distal tibia in patients with idiopathic clubfeet: ankle valgus and anteflexion of the distal tibia. *J Pediatric Orthop*. 2016;36(4):343-348.
44. Al-Aubaidi Z, Lungaard B, Pedersen NW. Anterior distal tibial epiphysiodesis for the treatment of recurrent equinus deformity after surgical treatment of clubfeet. *J Pediatric Orthop*. 2011;31(6):716-720.
45. Ebert N, Ballhause TM, Babin K, et al. Correction of recurrent equinus deformity in surgically treated clubfeet by anterior distal tibial hemiepiphysiodesis. *J Pediatric Orthop*. 2020;40(9):520-525.
46. Giertych, BF, Heintzman SE, Lang PJ, et al. Anterior hemi-epiphysiodesis of the distal tibia for residual equinus

deformity in children with clubfeet. Submitted for Publication. Presented at 2019 POSNA Meeting.

47. Davids JR, MD, Valadie AL, Ferguson RL, et al. Surgical management of ankle valgus in children: use of a transphyseal medial malleolar screw. *J Pediatric Orthop.* 1997;17(1):3-8.

48. van Oosterbos M, van der Zwan AL, van der Woude HJ, et al. Correction of ankle valgus by hemiepiphysiodesis using the tension band principle in patients with multiple hereditary exostosis. *J Child Orthop.* 2016;10:267-273.

49. Cobanoglu M, Collu E, Kilimci FS, et al. Rotational deformities of the long bones can be corrected with rotationally guided growth during the growth phase. *Acta Orthop.* 2016;87(3):301-305.

50. Cullu E, Cobanoglu M, Peker MK. The effect of guided growth on rotational deformities of the long bones: a biomechanical study on sawbone. *Intl J Paediatr Orthop.* 2015;1(1):44-47.

51. Lazarus DE, Farnsworth CL, Jeffords ME, et al. Torsional growth modulation of long bones by oblique plating in a rabbit model. *J Pediatric Orthop.* 2018;38(2):e97-e103.

52. Métaizeau JP, Wong LD, Denis D, et al. New femoral derotation technique based on guided growth in children. *Orthop & Traumatol Surg Res.* 2019;105:1175-1179.

53. Kramer A, Stevens PM. Anterior femoral stapling. *J Pediatric Orthop.* 2001;21(6):804-807.

54. Palocaren T, Thabet AM, Rogers K, et al. Anterior distal femoral stapling for correcting knee flexion contracture in children with arthrogryposis – preliminary results, *J Pediatric Orthop.* 2010;30(2):169-173.

55. 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(5): 555-559.

56. 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 Pediatric Orthop.* 2019;39(5):e360-ee365.

57. Spiro, AS, Babin K, Lipovac S, et al. Anterior femoral epiphysiodesis for the treatment of fixed knee flexion deformity in spina bifida patients. *J Pediatr Orthop.* 2010;30(8):858-862.

58. Al-Aubaidi Z, Lundgaard B, Pedersen NW. Anterior distal femoral hemiepiphysiodesis in the treatment of fixed knee flexion contracture in neuromuscular patients. *J Child Orthop.* 2012;6:313-318.

59. 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(9): e873-e879.

60. Cobb L, McCarthy JJ. Simple technique for anterior hemi-epiphysiodesis with cannulated screws does not violate knee cartilage. *Ortho Today.* 2016;June.

61. Kay RM, Rethlefsen SA. Anterior percutaneous hemiepiphysiodesis of the distal aspect of the femur: a new technique: a case report. *J Bone Joint Surg Case Connect.* 2015;5(4):1-5.

62. Nazareth A, Gyorji MJ, Rethlefsen SA, et al. Comparison of plate and screw constructs versus screws only for anterior distal femoral hemiepiphysiodesis in children. *J Pediatric Orthop B.* 2020;29(1):53-61.

63. Oleas-Santillán G, Bowen JR. Tension band plate-guided growth of knee-flexion deformity in arthrogryposis multiplex congenital in which metaphyseal funnelization induce screw encroachment upon the neurovascular bundle. *J Pediatr Orthop B.* 2020;29(1): 62-64.

64. Agus H, Onvural B, Kazimoglu C, et al. Medial percutaneous hemi-epiphysiodesis improves the valgus tilt of the femoral head in developmental dysplasia of the hip (DDH) type-2 avascular necrosis. *Acta Orthopaedica.* 2015;86(4):506-510.

65. Kelly JP, James MA. Radiographic outcomes of hemiepiphysiodesis for distal radius deformity due to multiple hereditary exostoses. *J Pediatr Orthop.* 2016;36(1):42-47.

66. Farr S. A unique case of temporary epiphysiodesis in an adolescent patient with ulnocarpal impaction syndrome. *J Hand Surg Eur.* 2013;38(8):1003-1004.

67. Scheider P, Ganger R, Farr S. Temporary epiphysiodesis in adolescent patients with ulnocarpal impaction syndrome: a preliminary case series of seven wrists. *J Pediatr Orthop B*. 2020;11:1-4.
68. Kumar A, Gaba S, Sud A, et al. Comparative study between staples and eight plate in the management of coronal plane deformities of the knee in skeletally immature children. *J Child Orthop*. 2016;10:429-437.
69. Burghardt RD, Specht SC, Herzenberg JE. Mechanical failures of eight-plate guided growth system for temporary hemiepiphysiodesis. *J Pediatr Orthop*. 2010;30(6):594-597.
70. Schroerlucke S, Bertrand S, Clapp J, et al. Failure of Orthofix eight-plate for the treatment of Blount disease. *J Pediatr Orthop*. 2009;29(1):57-60.
71. Shin YW, Trehan SK, Uppstrom TJ, et al. Radiographic results and complications of 3 guided growth implants. *J Pediatr Orthop*. 2018;38(7):360-364.
72. Lawing C, Margalit A, Ukwuani G, et al. Predicting late follow-up and understanding its consequences in growth modulation for pediatric lower limb deformities. *J Pediatr Orthop*. 2019;39(6):295-301.
73. Kemppainen JW, Hood KA, Roocroft JH, et al. Incomplete follow-up after growth modulation surgery: incidence and associated complications. *J Pediatr Orthop*. 2016;36(5):516-520.
74. Rupprecht M, Spiro AS, Schlickewei C, et al. Rebound of ankle valgus deformity in patients with hereditary multiple exostosis. *J Pediatr Orthop*. 2015;35(1):94-99.
75. Farr S, Alrabai HM, Meizer E, et al. Rebound of frontal plane malalignment after tension band plating. *J Pediatr Orthop*. 2018;38(7):365-369.
76. Leveille LA, Razi O, Johnston CE. Rebound deformity after growth modulation in patients with coronal plane angular deformities about the knee: who gets it and how much? *J Pediatr Orthop*. 2019;39(7):353-358.