Guided Growth for the Correction of Pediatric Lower Limb Angular Deformity

Neil Saran, MD
Karl E. Rathjen, MD

From the Division of Orthopaedic Surgery, Shriners Hospital, McGill University, Montreal, Quebec, Canada (Dr. Saran), and the Department of Orthopedics, Texas Scottish Rite Hospital for Children, Dallas, TX (Dr. Rathjen).

Dr. Saran or an immediate family member has received research or institutional support from Stryker. Dr. Rathjen or an immediate family member serves as an unpaid consultant to Orthopediatrics; has received royalties, financial, or material support from Saunders/Mosby-Elsevier; and serves as a board member, owner, officer, or committee member of Pediatric Orthopaedic Society of North America.


Copyright 2010 by the American Academy of Orthopaedic Surgeons.

Abstract

Guided growth is useful in correcting pediatric angular deformities. Although growth manipulation has been applied to various deformities, it is most commonly used to correct coronal plane deformity about the knee. Temporary hemiepiphysiodesis is performed using staples, percutaneous transphyseal screws, or a tension band plate. Permanent hemiepiphysiodesis can be done using either an open Phemister or a percutaneous approach. These techniques function by tethering one side of a growing physis, thereby allowing differential growth. Applied correctly, this can also result in angular deformity correction. Undercorrection and overcorrection are common problems with guided growth. However, careful preoperative planning and appropriate follow-up can minimize complications and allow for excellent deformity correction with minimal morbidity.

History of Growth Manipulation

Osteotomy is the most common technique for correction of angular deformity of a limb. However, growth manipulation or guided growth is a viable option in some skeletally immature patients. One of the earliest reports of growth manipulation to correct deformity is Phemister’s 1933 description of a technique that included hemiepiphysiodesis to correct angular deformity at the wrist.1 Bowen et al2 later developed a technique to aid in timing of permanent hemiepiphysiodesis; however, undercorrection or overcorrection of deformity may still occur. Because it has the potential to eliminate or reduce undercorrection or overcorrection, temporary hemiepiphysiodesis is an attractive alternative.

Temporary hemiepiphysiodesis appears to have begun with the work...
of Venable et al,3 who noted that electrical currents developed when different metals were placed in tissues. Based on these observations, Haas4,5 attempted to stimulate growth by placing various metals around the physis of skeletally immature animals. In one such experiment, a tensioned wire loop was placed around the physeal plate. Contrary to Haas’s expectations, there was less growth in the limb with the wire loop, leading him to hypothesize that compression created by the loop inhibited growth of the epiphyseal plate. Additional experiments were performed to verify this “temporary arrest,” and eventually he successfully performed the first temporary growth arrest in a human patient.4,5

Stimulated by Haas’s work, Blount began using rigid staples across the physis in skeletally immature patients. In their seminal paper published in 1949, Blount and Clarke6 described the use of three staples to minimize hardware failure and ensure temporary growth arrest. In 1954, Blount introduced a new staple.7 The Blount staple was engineered with reinforced corners to decrease breakage and extrusion, the two major problems seen with other staples. Until recently, use of this staple remained the most common technique for temporary hemiepiphysiodesis to correct angular deformity. In 1998, Métaizeau et al8 described the use of percutaneous transphyseal screws for angular correction. More recently, Stevens9 developed a tension band plate to facilitate temporary hemiepiphysiodesis.

**Etiology of Angular Deformity**

Common etiologies of angular limb deformity include extremes of physiologic variance, posttraumatic partial growth arrest, infantile and adolescent tibia vara, skeletal dysplasias, and metabolic bone disorders (Table 1).

**Table 1**

<table>
<thead>
<tr>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Idiopathic/physiologic</td>
<td>Resolving, persistent</td>
</tr>
<tr>
<td>Acquired</td>
<td>Trauma (physeal arrest, nonunion/malunion), infection, irradiation, iatrogenic, systemic inflammatory arthritis, neoplastic (enchondroma, osteochondroma)</td>
</tr>
<tr>
<td>Congenital</td>
<td>Skeletal dysplasia, syndrome, focal fibrocortilaginous dysplasia, bone disorder (fibrous dysplasia, osteogenesis imperfecta, hereditary multiple exostosis, Ollier disease, Maffucci syndrome), metabolic bone disease (rickets, renal osteodystrophy)</td>
</tr>
<tr>
<td>Other</td>
<td>Blount disease, neuromuscular conditions</td>
</tr>
</tbody>
</table>

**Indications for Correction of Deformity**

Although many studies have shown an association between varus and valgus malalignment of the knee and osteoarthritis (OA), there is no evidence that malalignment has a causal relationship with development of OA. However, there is evidence to suggest that malalignment may contribute to the development of knee OA. Biomechanical and gait studies have shown that varus alignment increases medial load during gait, that valgus alignment is associated with increases in lateral compartment peak pressures, and that varus and valgus malalignment increase medial and lateral load, respectively.10-13 Current evidence also shows that in patients with preexisting OA, the risk of progression is greater in those with malalignment.14 The risk of OA is often cited as a reason to consider management of angular lower extremity malalignment. However, because the natural history of varus and valgus malalignment is not well delineated, we believe that the primary indication for guided growth is a clinically unacceptable deformity in a patient with open physes.

Sagittal plane deformity, which may be more likely than coronal plane abnormality to produce functional impairment, can also be managed with guided growth. Indications include impairment producing deformity and a physis with adequate growth remaining (approximately 1 year) to allow correction.15 The literature describing the results of this application is sparse, and our anecdotal experience is underwhelming.

**Preoperative Assessment**

In most cases, the cause of the deformity can be diagnosed based on the patient history, physical examination, and radiographic imaging. Occasionally, further genetic or metabolic evaluation is required.

The physical examination should include careful assessment of limb length and coronal and sagittal alignment in the standing position as well as static and dynamic (ie, lateral thrust) knee stability. Some authors have advocated the use of intermalleolar and intercondylar distances to assess and follow coronal plane alignment, but we have not found these techniques to be clinically useful.

The preferred radiographic view for assessment of lower extremity deformity is a standing film that in-
includes the hip and the ankle. This view demonstrates functional alignment and allows assessment of the overall mechanical alignment as well as any focal or compensatory mal-alignment. The mechanical axis is defined as a line drawn from the center of the hip to the center of the ankle; this line normally passes through the center of the knee. The mechanical lateral distal femoral angle is formed at the intersection of a line extending from the center of the hip to the center of the knee and a line parallel to the distal femur (Figure 1). The mechanical medial proximal tibial angle is defined as the intersection of a line from the center of the knee to the center of the ankle and a line drawn parallel to the distal tibia. Each angle normally measures $87^\circ$.

Radiographs centered on the knee or ankle are also useful to ensure that the physeal plate is open and that the joints are congruent. In persons who may have intra-articular pathology or premature physeal arrest, CT scans and MRI can be useful in discovering minor physeal defects or bony physeal bars that may not be apparent on plain radiographs.

It is typically useful to determine skeletal age before performing hemiepiphysiodesis. This can be obtained by comparing a radiograph of the left hand to the standards published by Greulich and Pyle. Clinical parameters such as the Tanner stages and onset of menses, as well as radiographs of the elbow and pelvis, may also be helpful in determining the amount of growth remaining.

**Timing of Hemiepiphysiodesis**

Determining the appropriate timing of hemiepiphysiodesis is one of the most difficult aspects of using growth manipulation to correct angular deformity. Estimating remaining growth based on skeletal age is an inexact process. The health of the physis must be considered. Several conditions, including skeletal dysplasias, trauma, and irradiation, are associated with abnormal physeal growth, and persons with any of these will experience slower correction of angular deformity following hemiepiphysiodesis. Additionally, severe angular deformities may disturb normal physeal growth. The Heuter-Volkmann principle indicates that compression and tension forces at the physis can cause physeal growth inhibition and acceleration, respectively. Thus, more severe angular deformities produce greater compression on the “short” side of the physis, slowing growth. Subsequent correction after a hemiepiphysiodesis has been done to tether the “long” side.

Temporary (ie, reversible) hemiepiphysiodesis is an attractive option in younger patients. Theoretically, once angular correction has been achieved, the tethering device (ie, staple, screw, plate) may be removed, and normal linear growth will resume. However, the response of the physis is unpredictable following removal of the tethering device, and recurrence of deformity as a result of the so-called rebound effect (ie, accelerated growth on the side of the physis that was temporarily restrained) is so common that most authors favor delaying removal of the tethering implants until a small amount ($\approx 5^\circ$) of overcorrection has occurred. It has also been noted that the tethered side of the physis may close before the untethered side. If this occurs with significant growth remaining, a contralateral hemiepiphysiodesis on the untethered side may be required to prevent permanent overcorrection.

For patients who are near skeletal maturity, permanent hemiepiphysiodesis is an attractive option because it eliminates the possibility of implant-related complications and the unpredictability associated with the rebound effect. Correct timing of permanent hemiepiphysiodesis is imperative to limit the possibility of over- or undercorrection.
Bowen et al² reported on a technique to determine the timing of hemiepiphysiodesis. They incorporated data from the Green-Anderson growth-remaining chart,²⁴ skeletal age, and physeal width to develop their own chart on angular deformity versus growth remaining for coronal plane deformities about the knee (Figure 2). Based on their data, Bowen et al² estimated correction of 7° per year following distal femoral hemiepiphysiodesis and 5° per year in the proximal tibia. In their series of 13 patients, average correction was 30% less than predicted, primarily because 2 patients did not achieve any correction. Two patients required completion epiphysiodesis to prevent overcorrection.

The unpredictability associated with guided growth makes it imperative that parents be well-educated regarding the importance of routine postoperative follow-up (approximately every 4 months) as well as the likelihood of additional procedures, potentially on the contralateral extremity, to fine-tune the angular alignment and limb length (Figure 3).

**Surgical Techniques**

There is considerable debate regarding the physiologic advantages of each surgical technique used to achieve angular correction with growth modulation. Proponents of staples and plates theorize that a lateralized fulcrum increases the moment arm, thereby producing more efficient correction. However, those who favor permanent hemiepiphysiodesis argue that instrumented hemiepiphysiodesis cannot produce angular correction until growth on the tethered side has occurred to allow a "threshold" compression to be reached such that further growth is inhibited. To date, there is no conclusive scientific evidence to support one method over another. Recent reviews have failed to demonstrate a difference between staples and tension band plates.²⁵

**Temporary Hemiepiphysiodesis**

**Staples**

The surgical technique for using staples to achieve angular correction has changed little since the original description by Blount and Clarke⁶ in 1949. Under fluoroscopic guidance, three staples are used to span the physeis. Attention should be paid to placement in the sagittal and coronal planes (Figure 4). The entire procedure is extraperiosteal, and care must be taken to avoid damaging the physis or the zone of Ranvier; doing so could create a permanent hemiepiphysiodesis. As reported by Zuege et al,¹ surgical insult to the physis can also be associated with rebound growth. The authors reported an average of 5° (range, 2° to 11°) of rebound in 22 patients with 35 deformities who un-
derwent staple removal. Overcorrection of approximately 5° was recommended for patients with significant growth remaining.

**Screws**

In 1998, Métairie et al described a new technique for percutaneous epiphysiodesis using transphyseal screws. In an effort to avoid leaving unaesthetic scars in cosmetic deformities, they developed a technique in which screws are placed across the
physis through stab incisions. In their original study, they presented nine patients with an average of 7° of genu valgum (range, 4° to 12°) undergoing angular deformity correction using this technique. All had correction to within 3° of anatomic mechanical alignment; one patient required removal of the screw to prevent overcorrection. A major criticism of this study was the mild initial deformity. However, other studies have since confirmed the validity of this technique in patients with greater deformity.

Nouh and Kuo reported an average of 12.5° of correction by 2.6 years using percutaneous epiphysiodesis with transphyseal screws in 18 knees with an average initial angular deformity of 18° (nine patients). The only failure was in a patient with hypophosphatemic rickets. Khoury et al reported on 30 patients, with an average correction of 6.9° in the femur and 3.9° in the tibia. Based on a corrective rate of 0.8° per month in four patients with Blount disease and 0.2° per month in those with idiopathic genu valgum, the authors suggested that proximal tibial varus corrected at a faster rate than did proximal tibial valgus. Thirteen screw removals were performed in skeletally immature patients. Six of the 13 had recurrence of deformity ranging from 2° to 15°, and 1 had a persistent progression of correction of 2°. No permanent physeal arrests were reported. De Brauwer and Moens reported more modest results, with 6 of 48 knees having no angular correction. In patients undergoing screw removal to prevent overcorrection, one third had an average of 2° of rebound and another one third had 2° of continued correction after removal of the percutaneous screws.

**Tension Band Plate**

Concerns regarding implant breakage and migration as well as the potential for physeal arrest associated with the use of staples led to the advent of the tension band plate. Stevens used this plate in 34 patients with 65 deformities of the femur and tibia. A 30% higher rate of correction was reported with plating than with staples. Apart from two patients with adolescent Blount disease, all patients achieved full correction. No premature physeal arrests were reported. The only complications in this series included screw loosening in one patient with Blount disease, which required revision of the screws, and one stitch abscess that resolved with oral antibiotics. The recommended screw size has since been changed from 4.0 to 4.5 mm.

Four patients aged <11 years with bilateral idiopathic genu valgum developed bilateral rebound growth and recurrence of deformity after removal of the device.

Ease of application and the excellent results to date have led to widespread use of tension band plating for guided growth. However, studies with longer-term follow-up are required to further define its indications. Schroerlucke et al showed a high rate of implant failure with tension band plating in patients with Blount disease, with eight hardware failures in 18 extremities. Although all of these patients had above average weight and body mass indices, the authors found no significant difference with regard to these parameters between those with hardware failure and those without hardware failure. The average correction rate was 5° per year at the proximal tibia in patients without Blount disease. This result is similar to that proposed by Bowen et al and that seen by Castañeda et al. Recent implant failures of the tension band plate, such as those reported by Schroerlucke et al, have led to implant modifications, including the availability of solid screws and plates with multiple screw holes.

**Permanent Hemiepiphysiodesis**

Permanent hemiepiphysiodesis has also been used successfully to treat angular deformities. The drawback with this technique is that it must be done near skeletal maturity as determined by...
growth charts. This is not a viable option when deformity is present at an early age and requires treatment, unless the surgeon plans to perform a completion hemiepiphysiodesis (ie, stop growth of the entire physis) when angular correction is achieved. Permanent hemiepiphysiodesis can be done open or percutaneously.

Open Hemiepiphysiodesis
Open hemiepiphysiodesis is based primarily on the method described by Phemister, in which a window of cortical bone was removed to a depth of 1 cm at the level of the physis and a second bone block from the distal metaphysis was advanced across the physis to promote fusion. Modifications of this technique involve eccentrically placed rectangular cortical windows that are rotated 180°, and central-square or diamond-shaped windows that are rotated 90°. Although many surgeons now favor the percutaneous technique, the open method remains the gold standard for achieving permanent epiphysiosis, mainly because it offers visual confirmation of appropriate physeal ablation at the time of surgery. Physeal arrest is seen consistently with this technique; however, some studies have shown significant rates of failure. Bowen et al reported a 6% failure of arrest secondary to dislodgement of the bone plug. Scott et al reported a 17% rate of failure of epiphysiodesis in 24 patients treated for limb-length discrepancy.

Percutaneous Hemiepiphysiodesis
In a technique first described by Bowen and Johnson, a large-diameter drill is used to open the cortex, and the physis is curetted percutaneously under fluoroscopic guidance. Several authors have published series demonstrating excellent results with this technique. Inan et al recently reported three incomplete arrests in a series of 97 patients treated with percutaneous epiphysiodesis to manage limb-length discrepancies. Others have reported failure rates as high as 15%.

Despite the attractiveness of smaller incisions and the potential for shorter hospital stays with percutaneous hemiepiphysiodesis, as well as reduced need for formal physical therapy, we believe that open hemiepiphysiodesis is more reliable, given the complex three-dimensional undulating anatomy of the physis. We prefer permanent hemiepiphysiodesis for angular correction with the Phemister open technique.

Fibular Epiphysiodesis
McCarthy et al showed that the proximal fibula overgrows approximately 3 mm per year when the proximal tibia undergoes epiphysiodesis. In that study, fibular overgrowth >1 cm resulted in a prominent fibular head. One patient with 25 mm of overgrowth was symptomatic, and two patients with Symes prostheses were symptomatic as a result of 1 to 2 cm overgrowth. The authors recommended fibular epiphysiodesis when overgrowth is expected to exceed 1 to 2 cm. However, proximal fibular epiphysiodesis can usually be done through the same incision with minimal added surgical time or morbidity. We use this technique whenever we perform permanent lateral proximal tibial epiphysiodesis.

Complications
Complications associated with guided growth can be classified as physiologic (eg, infection, swelling, stiffness), hardware-related (eg, implant extrusion, breakage, prominence), or growth-related (eg, undercorrection, overcorrection, permanent physeal injury). Hemarthrosis and knee effusion have been reported in 2% to 6% of cases; these conditions tend to resolve by 3 weeks. Liotta et al reported that 40% of patients who underwent open Phemister epiphysiodesis required formal physiotherapy compared with only 8% of those who underwent percutaneous epiphysiodesis to aid with range of motion and strength. Infection has been reported in ≤6% of patients, with no difference between those treated with or without implants. The infections tend to be superficial and resolve with oral antibiotics. Although the incidence of migration and extrusion of staples is relatively high, rates of extrusion that require reinsertion have been reported to range from 2% to 8%. Growth-related complications, such as undercorrection and overcorrection, can be minimized with close follow-up. Permanent physeal arrest has become uncommon in this era of extraperiosteal placement of temporary hemiepiphysiodesis devices and with special attention paid at the time of implant removal.

Future Directions
Current experimental work related to guided growth includes efforts to stimulate a physis as well as to achieve hemiepiphysiodesis with minimally invasive techniques. Haas’s initial growth modulation studies were based on the idea that the physis could be stimulated into hyperactivity by electrical currents. One experimental animal study has shown encouraging results using this concept, but others have failed to reproduce the results. Although growth stimulation is still theoretical, minimally invasive techniques using high-current electricity and growth factors such as stromal cell–derived factor-1 have been shown to cause physeal disruption (ie, epiphysiodesis) in animal models.
Summary

Guided growth is an attractive surgical option for correction of angular deformity in skeletally immature patients. Although guided growth is technically feasible for deformity in any plane or extremity, it is used most commonly and most predictably for coronal plane deformities about the knee. Permanent hemiepiphysiodesis can be performed in patients within 2 years of skeletal maturity. Although temporary hemiepiphysiodesis has been described as being more effective than permanent epiphysiodesis, there are currently few scientific data to support this. However, temporary hemiepiphysiodesis is an attractive alternative for patients younger than 10 years: A preliminary report. J Pediatr Orthop 1996;16(4):423-429.

References

Evidence-based Medicine: Levels of evidence are described in the table of contents. In this article, no level I studies are cited. Level II studies include references 14 and 17. References 25, 27, 31, and 33 are level III studies. References 1, 2, 4, 6-10, 15, 18-23, 26, 28-30, 32, 34, 35, and 37-40 are level IV studies. Reference 12 is level V expert opinion. References 3, 5, 11, 13, 36, and 41-44 are basic science and biomechanical studies.

Citation numbers printed in bold type indicate references published within the past 5 years.


