Introduction
A general understanding of angular deformities around the knee in the pediatric population, including the cause, diagnostic imaging techniques, consequences of such deformities in a growing child and treatment options, is essential knowledge for pediatricians and primary care providers. The present article is intended to provide an overview of these problems, as well as an update on recent innovations in treatment.

Knee angular deformities: consequences and natural history
Lower extremity angular alignment changes from bow legs (varus) to knock knees (valgus) in early childhood. Varus alignment at birth is usually about 15°, gradually starting to change to valgus at about 24 months. Valgus alignment reaches a maximum of 8–10° at approximately 3–4 years of age, subsequently decreasing to 6–7° of valgus at the age of 5–6 years [1–4]. These changes are schematically presented in the drawing in Figure 1.

Both angular and rotational deformities have biomechanical and functional consequences. Varus and valgus can cause shift of mechanical axis and joint load.

Genu valgum can significantly affect knee function, leading to patellar maltracking, overload of the lateral compartment of the knee and medial collateral ligament stress. These may further lead to pathological gait with sequential patellar instability and activity-related pain. Similarly, knee varus can cause medial compartment overload with lateral collateral ligament laxity with a lateral thrust, subsequent knee instability and eventually pain [5–9]. Varus deformity of the knee is typically associated with medial meniscal tears, whereas the valgus knee deformity is shown to have either side meniscal tear or both [10].

Longstanding deformity during early childhood (either varus or valgus) of knees can lead to growth plate damage. In the long term, knee malalignment may lead to degenerative changes of the knee. There is increasing evidence demonstrating the risk of progression of malaligned knees to osteoarthritis [11–16], but the exact threshold of varus or valgus magnitude leading to development of degenerative changes is not known.

In childhood, severe angular deformities have a tendency for progression according to the Hueter-Volkman law, which states that growth is retarded by increased mechanical compression, and accelerated by reduced loading [17].
Levine and Drennan [18] reported an association of a tibial metaphyseal–diaphyseal angle (MDA) of more than 11° with infantile Blount’s disease; this measurement has been used as a screening radiographic tool in the young child in whom the diagnosis of infantile Blount’s disease is in question.

Bowen suggested that significant progression is likely to occur in patients with more than 50% of tibial contribution to knee varus deformity as opposed to femoral component contribution of the knee joint [19].

Obesity, ligamentous instability or the presence of a lateral thrust may potentiate a varus deformity of the knees.

Angular deformities and gait

We believe that severe angular deformities of lower extremities can cause an awkward gait, difficulty with running and sport activities. However, there is a paucity of literature about angular deformities around knees and formal gait analysis.

It is well known that tibia vara can be associated with intoeing gait and lateral thrust of the knees, whereas genu valgum is associated with out-toeing and planovalgus feet.

Cause

Excessive varus or valgus deformities of lower extremities during childhood can develop following traumatic, dysplastic, metabolic, inflammatory, endocrine, neoplastic or developmental pathologies or be idiopathic. Interestingly, vitamin D deficiency rickets can cause either varus or valgus deformity of the knees [20]. Blount’s disease is the most common cause of pathologic knee varus in the pediatric population and can be infantile or adolescent at presentation. Typically, valgus knee deformity develops in late childhood; it often arises from asymmetric growth in the distal femur and does not spontaneously resolve in older children and adolescents [21]. In some cases, the proximal tibia is also abnormal [9].

Clinical evaluation

The child should be observed walking; attention should be paid to gait pattern, angular and rotational deformities of the knees. The presence and severity of dynamic varus or valgus should be assessed as well.

The degree of angular deformity of the lower extremity is measured with a goniometer with the knees extended and patellae facing forward. An intercondylar distance (the distance between the knees) is measured in the presence of bow legs, or an intermalleolar distance (the
distance between the ankles) in the presence of knock knees. Photographs and standing radiographs are helpful in documenting the deformity and progression. Angular and rotational alignment and joint range of motion and stability of the entire lower extremity are assessed. Typically, patients with longstanding angular deformities will suffer joint instability in the coronal plane, such as lateral side opening in varus or medial side opening with valgus deformities. Knee joint laxity typically is not present in physiologic bowing [9].

Clinical evaluation should also include assessment of legs’ length, deformities of other joints and the patient’s height.

Chronologic and bone age are of great importance while considering treatment options.

**Imaging**

A full-length standing anteroposterior radiograph of the entire lower extremity centered at the knee with the patella facing anteriorly has become the standard imaging modality for assessing lower limb alignment, joint orientation angles and length. This allows a comprehensive analysis of the magnitude and source of the deformities [22–24].

According to a study by Sabharwal et al. [22] in children younger than 7 years old, the clinician should use age-specific values for limb alignment and joint orientation of the lower extremity, but for children older than 7 years of age alignment values of adults can be used.

Patients’ skeletal age is usually assessed according to the method of Greulich and Pyle [25] by comparing left hand radiograph with the atlas radiographs.

**Treatment**

Nonoperative treatment options of mild cases of infantile Blount’s disease and other angular deformities include observation, parent and patient education, counseling for weight reduction in obese kids and use of knee braces. Operative treatment includes acute correction by osteotomy, gradual correction by osteotomy with external fixator and hemiepiphysiodesis of growth plate for moderate to severe deformities.

**Bracing**

Satisfying results of treatment of infantile Blount’s disease were reported with early use of valgus producing knee-ankle-foot orthosis for mild cases with no risk factors for progression such as ligamentous laxity and obesity in kids younger than 3 years old [26,27].

Obviously, there are many cases for which conservative treatment is not sufficiently effective [28].

**Osteotomy**

Corrective osteotomy is the gold standard for severe angular deformity, but is a major surgical intervention with operative site morbidity, postoperative pain and prolonged therapy that requires internal or external fixation and restricted weight-bearing that are the main drawbacks of this surgery. Osteotomies, especially of the proximal tibia, are high-risk surgeries, with a small but significant incidence of compartment syndrome, neurovascular injury, overcorrection or undercorrection, delayed union or nonunion [29,30].

**Use of external fixators**

External fixator is a powerful tool for treating extremity deformities. It allows complex deformity correction with minimal soft tissue disruption and can be performed gradually, minimizing the risk of neurovascular injury and allowing exact deformity correction. Various types of external fixators have been used for deformity correction and lengthening [31–39]. In general, there are two types of fixators, ring-type fixators, such as classic or modified Ilizarov fixator or Taylor Spatial Frame (Smith&Nephew, Memphis, Tennessee, USA), that allow lengthening and deformity correction, and monolateral fixators, such as Limb Reconstruction System (Orthofix, Verona, Italy), that are excellent for lengthening and easier to apply but have limited deformity correction capabilities. Multiaxial correction system (MAC Biomet, Parsippany, New Jersey, USA) is the recently popularized option of monolateral fixator demonstrating satisfactory results [40].

**Temporary hemiepiphysiodesis/surgical growth plate manipulation**

Hemiepiphysiodesis, a relatively minor, usually outpatient surgical procedure after which weight-bearing need not be reduced, is an attractive alternative in the growing child and recently gained popularity among pediatric orthopedists. Historically, permanent hemiepiphysiodesis, using open or percutaneous techniques, was effective in treating angular deformities, but relies on careful preoperative evaluation and postoperative follow-up to avoid overcorrection, undercorrection or both. Temporary hemiepiphysiodesis has been shown to provide gradual deformity correction, yet may allow resumption of growth with implant removal [41–45].

Epiphyseal staples work primarily as a compression device, preventing growth on the index side of the physis. In the past, problems with staples have included implant failure, extrusion and physeal damage resulting in permanent closure of the growth plate.
Hemiepiphysiodesis must be done in skeletally immature patients with sufficient growth potential to correct angular deformity around the knee. Growth arrest or physeal bone bar are contraindications to hemiepiphysiodesis.

Recently, Stevens [28] reported good clinical results when using a two-hole tension band plate for temporary hemiepiphysiodesis. A number of implant companies have developed specialized plates for growth plate hemiepiphysiodesis, including the ‘8-plate’ of Orthofix, the ‘Peanut plate’ of Biomet, ‘PediPlates’ of OrthoPediatrics (Warsaw, Indiana, USA), and the ‘Hinge-Plate’ by Pega-Medical (Quebec, Canada).

Figure 2 demonstrates clinical pictures and images of an 11.5-year-old female patient displaying correction of knock knees from significant valgus to normal alignment.

Figure 3 shows clinical pictures and radiographs of a 13-year-old male patient with significant genu varum gradually corrected up to normal position.

In both cases the correction was achieved with tension band two-hole plates with screws.

In 2007, Stevens reported [28,46] use of nonlocking plate with two screws to perform temporary hemiepiphysiodesis in children. In his prospective case series he mentioned successful treatment in all but two patients with Blount’s disease in 34 patients with 65 different deformities around the knee due to various abnormalities including posttraumatic, metabolic, dysplastic or idiopathic conditions including Blount’s disease. The angular deformities were corrected faster than with staples and no growth arrest or hardware failure was noticed.

Wiemann et al. [47**] conducted a retrospective comparative study focusing on hemiepiphysiodesis for angular knee deformities using either stapling or tension band eight-plates. Sixty-three hemiepiphysiodesis procedures performed on 38 patients were included in the study. They concluded that the eight-plate is as effective as staple hemiepiphysiodesis for guided correction of angular deformity with respect to rate of correction and complications, even in somewhat younger patients. Higher complication rates were observed in patients with pathologic physes (Blount’s disease, skeletal dysplasias).

Figure 2 Bilateral idiopathic genu valgum treated with application of eight-plates on the medial sides of the distal femur

(a, b) Clinical pictures of 11.5-year-old female patient presented with significant bilateral knocked knees. (c) Preoperative full-length standing film. (d) Postoperative full-length standing film. Correction of genu valgum 11 months after placement of plates for ‘guided growth’ is shown. The plates were subsequently removed to prevent too much correction. (e, f) Clinical pictures at the end of treatment showing normal alignment of the knees.
The ‘two holes plate with screws’ device was applied in patients with previous temporary hemiepiphysiodesis failure in a safe manner with satisfactory results [46].

The later reported results of the use of the two-hole plate with physeal and metaphyseal screws device were encouraging. Burghardt et al. [48] reported good or excellent results in 10 of the 11 (17 eight-plates) patients treated with this tool for various angular deformities, mostly around knees. No hardware-related problem or growth arrest was reported.

Stevens [49] published another retrospective series of 14 children with ‘sick physes’ such as rickets, endocrinopathies and skeletal dysplasias, altogether 68 hemiepiphysiodesis procedures performed. Deformities treated by stapling experienced rebound in 41% and staple migration in 54%, whereas no hardware failure was reported in the tension band plate technique, although it was too early to judge about rebound of deformities. The main conclusion of this study was the overall correction of angular deformities in sick physes conditions.

Recently, a retrospective case series was published describing stapling treatment for angular deformities around the knees in patients with multiple epiphyseal dysplasia (MED). Hemiepiphysal stapling is effective for angular correction in MED with minimal surgical insult. However, as physeal behavior after staple removal is rather unpredictable, including rebound, insufficient correction and premature physeal closure, close monitoring is mandatory until skeletal maturity [50].

Guided growth can prevent the need for more extensive surgery for angular deformities correction around the knee, such as osteotomy. Temporary hemiepiphysiodesis with tension band plate provides minimally invasive surgery, with apparently acceptable results compared with the traditional physeal stapling. Tension band plate use for treatment of adolescent Blount’s disease appears to be less successful than in other conditions due to a certain rebound rate that was reported recently [51].

Angular correction usually achieved by temporary hemiepiphysiodesis of distal femur is about 1° a month, so tension band requires a sufficient growth potential. The complication rate of tension band plate with physeal and

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**Figure 3** Bilateral genu varum treated with application of eight-plates on the lateral sides of the distal femora and proximal tibiae

(a) (b)

(c) (d)

(e) (f)

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**Figure 3**

(a, b) Clinical pictures of 13-year-old male patient presented with significant bilateral knocked knees. (c) Preoperative full-length standing film. (d) Postoperative full-length standing film. Correction of genu varum 9 months after placement of plates for ‘guided growth’ is shown. The plates were subsequently removed to prevent overcorrection. (e, f) Clinical pictures at the end of treatment showing normal alignment of the knees.
metaphyseal screws listed in the recent studies is minimal, but can include unilateral physis closure, screw breakage and rebound after device removal [28,46,47**, 48*,49*,50,51].

Conclusion
Angular deformities of the knees are of great interest and challenge for pediatricians. The latest development of the efficient minimally invasive surgical option makes the treatment of knee varus and valgus readily available in order to achieve satisfactory lower limb alignment and improve lower extremity function.

Acknowledgement
The authors did not receive any financial support for the present study. There is no conflict of interest. Dr Green is a project designer for a Pediatric Hinge Plate developed by Pega Medical to help correct lower extremity malalignment problems in children.

References and recommended reading
Papers of particular interest, published within the annual period of review, have been highlighted as:
• of special interest
•• of outstanding interest
Additional references related to this topic can also be found in the Current World Literature section in this issue (p. 120).


This is the first comparative study for use of tension band plate versus staples for hemiepiphysiodesis in patients with angular deformities of the knees, showing that tension band plates are as good as staples in terms of correction and complication rate.


This series outlined low complication rate of tension band plate when used to correct bow legs or knock knees in the pediatric population.


This study demonstrated efficacy of the tension band plate treating angular knee deformities in children with sick growth plates. The overall correction of angular deformities in sick physes condition was achieved.


Advances in growth plate modulation Goldman and Green