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ORIGINAL PAPER

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Magnetic resonance imaging of the growth plate in late-onset tibia vara

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Abstract We used Magnetic resonance imaging (MRI) in five patients (six knees), mean age 13.2 (12–15) years, with late-onset tibia vara (Blount's disease), to study the growth plate and its abnormalities. The MRI study was classified for severity of disease and compared with a radiographic classification. In severely involved knees, MRI indicated severe growth-plate changes on both sides of the knee joint. Widening in the entire proximal tibial growth plate, involvement of the distal femoral growth plate, as well as cartilage invaginations into the metaphyses, were constant findings. Three knees were treated operatively with oblique tibial osteotomy and three with lateral hemiepiphysiodesis. Two severely involved patients treated initially with hemiepiphysiodesis required additional surgery. The three patients with mild disease treated with tibial osteotomy had good clinical and functional results. This study suggests that extensive growth-plate changes in severe, late-onset tibia vara preclude successful treatment by tibial hemiepiphysiodesis. In addition, oblique osteotomy, which was successful in mild cases, was problematic in severe cases.

Résumé Nous avons utilisé la résonance magnétique nucléaire chez cinq malades (six genoux), d'âge moyen 13,2 (12–15) années présentant une maladie de Blount (Tibia Vara avec début tardif) pour étudier le cartilage de conjugaison et ses caractères anormaux. L'étude IRM a été classée selon la sévérité de la maladie et comparé avec une classification radiographique. Dans les genou altérés sévèrement l' IRM a montré des modifications sévéres du cartilage de conjugaison des deux côtés du genou. L'élargissement du cartilage de conjugaison tibial proximal, l'atteinte du cartilage distal fémoral, aussi bien que des invaginations du cartilage dans les métaphyses étaient des constatations constantes. Les malades ont été traités chirurgicalement par une ostéotomies tibiale oblique dans trois genoux ou une hémiépiphysiodèse pour trois genoux. Les deux malades sévèrement impliqués, initialement traités avec une hémiépiphysiodèse, ont nécessité une chirurgie supplémentaire. Trois patients avec une maladie peu évoluée traitée par ostéotomie tibiale avaient un bon résultat clinique et fonctionnel. Cette étude suggère que les modifications du cartilage de conjugaison dans le Tibia Vara sévère avec début tardif empêchent le traitement par hémiépiphysiodèse tibiale. De plus, l'ostéotomie oblique qui était utile dans les cas discrets était problématique dans les cas sévères.

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Introduction

Late-onset tibia vara (Blount's disease) has been widely reported in the literature as a condition resulting in progressive varus angulation below the knee. The term "late-onset tibia vara" was first introduced by Thompson et al. in 1984 [23]. Characteristics include African American, mostly males, moderate-to-heavy obesity, and a slow progression of varus deformity of the knee [16, 22, 23]. Disease etiology and pathogenesis remains obscure [16]. The radiologic appearance of Blount's disease is well known; the magnetic resonance imaging (MRI) changes in these patients have been reported recently [2, 4].

The optimal treatment for patients with late-onset tibia vara is still debated [2, 8]. Different types of proximal tibial or distal femoral osteotomy, hemiepiphysiodesis or asymmetric physeal distraction, have been proposed in the literature [1, 6, 20]. Tibial oblique osteotomy or hemiepiphysiodesis are the most frequent surgical procedures for correction of tibia vara [1, 2].

The purpose of this paper is to present preliminary observations on the nature of growth-plate changes in

Table 1 Blount's disease patient data. *MRI* magnetic resonance imaging, *BMI* body mass index kg/m^2 (BMI >27 = obesity), *L* left, *R* right, *Mo* moderate, *M* mild, *S* severe, *N* no, *Y* yes, *Y*^{a} yes after hemiepiphysiodesis, *Age* age at presentation

Patient	Age	Knee	X-ray	MRI	Hemiepiphysiodesis	Osteotomy	BMI	Outcome
1	13.8	L	M	M	N	Y	35	Good
2	12.2	L	S	S	Y	Y^a	47	Poor
		R	Mo	S	Y	Y^a	47	Poor
3	15.7	L	M	M	N	Y	33	Good
4	15.6	R	M	M	N	Y	39	Good
5	12.8	R	S	S	Y	Y^a	48	Poor

late-onset tibia vara as depicted by MRI and to determine if the findings can be of use in the management of this disorder. This might also be a basis for future use of MRI in evaluation of the anatomic course of tibia vara. This paper will also assess two surgical procedures used to correct tibia vara.

Materials and methods

Five male children (six knees) 12–15 (mean 13.2) years of age with late-onset tibia vara were evaluated in this study. All were obese. Three were American African and two Caucasian. Patients sought care because of pain and progressive knee deformity. The body mass index (BMI), which adjusts weight to stature, was employed to evaluate obesity.

Both knees were involved in one patient;in four, the involvement was unilateral. The degree of radiographic involvement in three patients (three knees) was mild, with the tibiofemoral angle below 20° of varus and the growth plate regular in shape. One patient (one knee) had moderate varus, with the angle between 20 and 39° and the growth place wide on the medial side of the tibia. Two patients (two knees) showed severe changes, with a tibiofemoral angle of 40° or more and the growth plate wide both medial and lateral of the tibia with flattening of the medial aspect of the tibial epiphysis. All patients had multiple anteroposterior radiographs and MRI. All patients were treated operatively—three knees by oblique tibial osteotomy (mean age at surgery 15 years) and three knees by percutaneous hemiepiphysiodesis as described by Bowen et al. [1]. Anticipated timing for the hemiepiphysiodesis was calculated by angular deformity versus the growth remaining chart. Mean age at percutaneous hemiepiphysiodesis was 12 years, 4 months (Table 1). All patients were followed clinically and radiographically until the end of growth for a minimum of 2 (range 2–7) years.

All MRI procedures were performed on a 0.5 T mobile unit (HP Vista; Picker International, Cleveland, OH. USA) by using a knee coil for a single knee and a body coil for both knees. Examination included the following two sequences: (1) coronal, T1-weighted, spin-echo imaging with a repetition time of 650 ms and an echo time of 20 ms (650/20); and (2) coronal, gradient echo imaging (TR 700, TE 20, with a 40° flip angle). The frequency-encoding gradient was perpendicular to the long axis of the femur to avoid chemical shift in the physis. No patient required sedation.

The MRI, obtained immediately before surgery, was reviewed to establish severity of disease based upon type and extent of cartilage changes in the growth plate. Findings in both the proximal tibia and distal femur of the involved limb were evaluated. The disease was considered mild if growth-plate changes (widening and irregularity) were limited to the medial half of the tibial growth plate. Severe disease was defined as involvement of the distal femoral growth plate in addition to the tibial changes. MRI grading was compared with radiographic classification (Table 1) [18]. It was not our intent to create a classification for MRI but to grade the severity for comparison with the radiographic classification. Serial radiographs were employed to evaluate the preoperative and postoperative extent of the disease.

Results

Three knees were classified by MRI as having mild changes. On the preoperative radiographs, all affected knees had medial proximal tibial metaphysis fragmentation with depression of the medial plateau (Fig. 1a). Radiographically, these cases were in the moderate category by tibiofemoral angle. Changes in the growth plates noted on MRI were found only in medial aspect of the proximal tibial growth plate. The plate was wide, irregular in shape, and with invaginations to the metaphysis. A small area of decreased signal at the medial tibial metaphysis was also noted (Fig. 1b and c). None of these knees had moderate involvement.

In three knees there were severe changes, observed on radiographs on both the medial and lateral part of the tibial growth plate and the distal femoral growth plate. All of these patients showed diminished height in the medial aspect of the proximal tibia epiphysis (Fig. 2a). By radiographic classification of tibiofemoral angle, all knees were in the severe category. MRI showed involvement of medial and lateral proximal tibial growth plate with significant widening and irregularity throughout the entire plate. A small area of decreased signal intensity was seen in the medial aspect of the tibial metaphyses (Fig. 2b). The widening was often accompanied by invaginations of growth-plate cartilage into the metaphyseal bone. Widening of the lateral and—to a lesser extent—the medial aspect of the distal femoral growth plate was also noted (Fig. 2c). The observed MRI changes correlated with severity of radiographic tibiofemoral angle measurements.

In the three mild cases, an oblique tibial osteotomy was performed. All patients after osteotomy obtained good clinical and functional results with satisfactory correction of varus deformity (Fig. 1d). In the two severe disease patients initially treated by lateral hemiepiphysiodesis (three knees), varus deformity of the tibia did not correct enough, and 1 year after the initial procedure, an oblique osteotomy was performed. While good varus correction was obtained after the osteotomy, over the course of time, the operated leg drifted into an overcorrected valgus state in two knees. It might be significant that only failed osteotomies occurred in patients who had

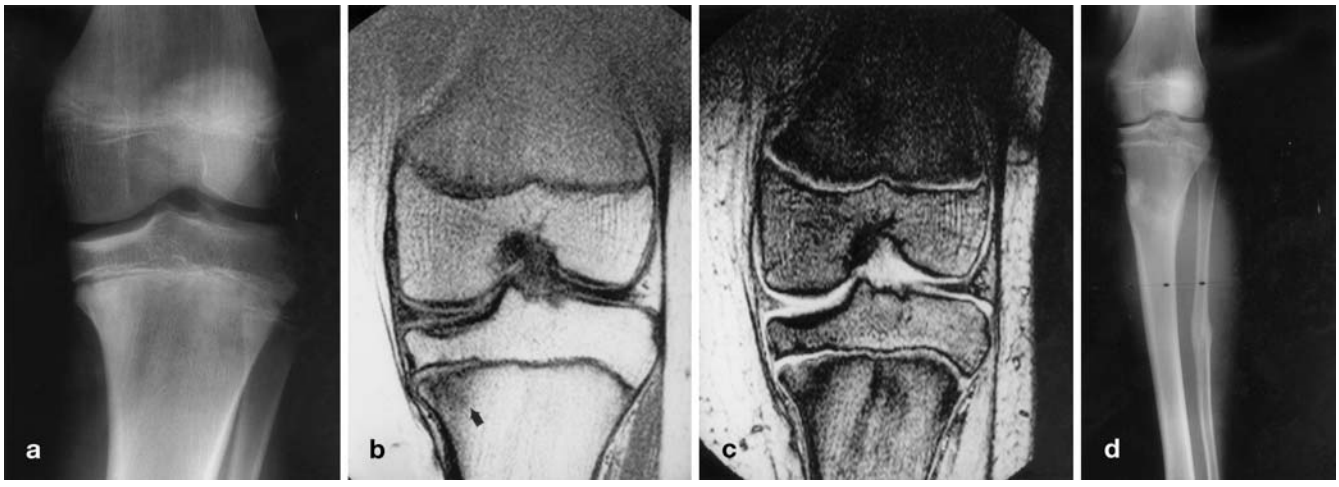


Fig. 1a–d Mild tibia vara (unilateral) in a 13-year-old boy. **a** Plain radiograph of the left knee shows mild tibia vara. The width of the tibial epiphysis is slightly diminished at its medial aspect while the growth plate is widened. No abnormalities are seen in the distal femur. **b** T1-weighted (650/20) MRI of the left knee. Flattening of the medial portion of the tibial epiphysis and widening of the growth-plate cartilage only in the medial side. Note small area of decreased signal at the tibial metaphysis (*arrow*). No MRI changes in femoral growth plate. **c** Gradient echo (700/20, 40°) sequence shows bright signal intensity at the medial part of the tibial growth plate. A mixed intensity signal area is shown at the tibial metaphysis surrounded by a rim of decreased signal. **d** Radiograph after 4 years of tibial oblique osteotomy; correction is maintained

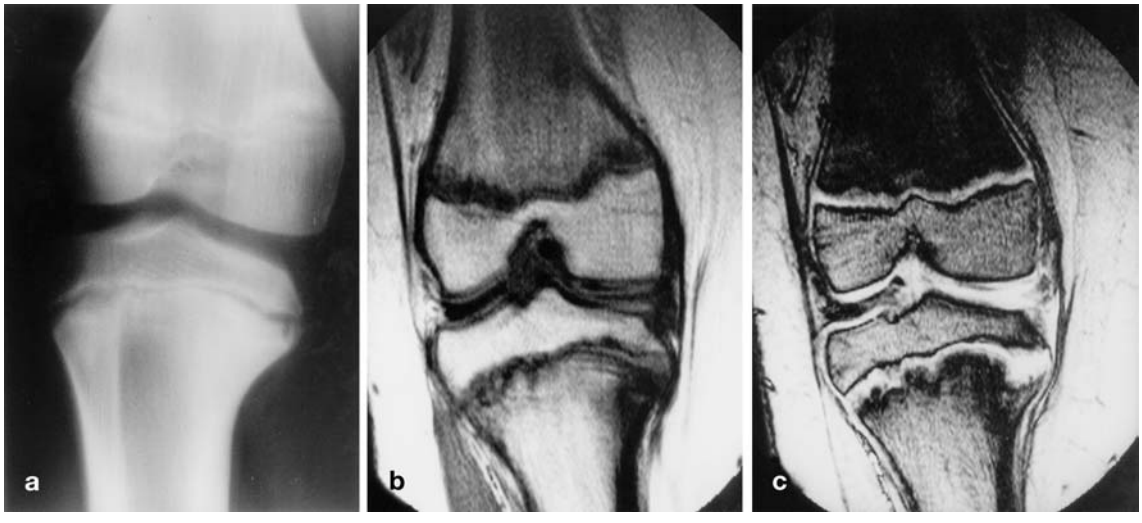


Fig. 2a–c Severe tibia vara (bilateral) in a 12-year-old boy. **a** Varus angulation of the right tibia is seen on conventional anteroposterior tomogram. The tibial growth plate is widened and irregular in the medial and lateral metaphysis. To a lesser extent, similar findings are present in the femoral growth plate. **b** T1-weighted images (650/20) of the right knee show severe flattening of the medial tibial epiphysis. The tibial growth plates are wide, irregular, and show mixed signal intensity. The same signal intensity is observed in the lateral femoral growth plate. Decreased signal is noted in the deformed medial tibial metaphysis. **c** Gradient echo images (700/20, 40°) better demonstrate the abnormality at the tibial epiphysis. Note the invaginations of cartilage into the tibial metaphysis that account for part of the decreased signal on the T1-weighted sequences. The wide tibial physeal involvement is clearly visible in both the medial and lateral half, while the femoral involvement affects mostly the lateral aspect of the physis

an earlier epiphysiodesis on the lateral growth plate. In the third knee after failing hemiepiphysiodesis, progressive varus deformity recurred. These three knees were found in two extremely obese African American children with BMI over 45. They were more obese (by BMI) than the patients with mild disease.

Discussion

Blount's disease includes infantile, juvenile and adolescent, and late-onset types [2, 11, 22, 23]. This classification is based on age and clinical onset of the disease. Although many studies on Blount's disease have been well known in the literature, the characteristics of late-onset tibia vara has been less-well documented. Recommendation for treatment, which is still controversial, in

late-onset tibia vara includes many surgical procedures; however, techniques commonly used for correction of the varus deformity are oblique tibial osteotomy and lateral hemiepiphysiodesis.

In three knees (two patients) in our study where lateral hemiepiphysiodesis was performed, none of the tibias showed arrest of progressive varus deformity and both patients required an additional proximal tibial osteotomy. The good results in the three mild cases demonstrate that oblique osteotomy could be successful in those cases. We do not know about the potential use of hemiepiphysiodesis in such cases because no knee in the mild MRI category was treated in this way.

Epiphysiodesis does not alter forces on the tibial growth plate. Osteotomy, however, results in realignment to a more favorable distribution of forces over the growth plate. Our results with hemiepiphysiodesis concur with published reports that hemiepiphysiodesis is not the best solution for correcting tibial bowing in late-onset Blount's disease [12, 22].

Arthrography has been used to depict lesions in the articular cartilage in Blount's disease, but this technique is of no use in the evaluation of the growth plate [4, 21]. During the last few years, MRI has shown to be an effective and accurate method for evaluating cartilaginous structures to include the growth plates in pathologic conditions [9, 13, 14, 15]. Normal growth-plate cartilage has an intermediate signal in T1-weighted sequences and a bright signal in gradient echo sequences, the latter having proven to provide optimal plate visualization. These are the sequences used in this paper and are our standard protocols for evaluation of the growth plate.

In the recent literature, there are three papers evaluating the usefulness of MRI in Blount's disease. Stanitski et al. presented the use of MRI to demonstrate that there is no true bony deficiency of the tibia plateau in early-onset tibia vara. They concluded that medial plateau defect does not exist [21]. On the other hand, Ducou le Pointe et al. reported the presence of depression on the tibial proximal articular surface, with medial epiphyseal fragmentation on MR images in patients with Blount's disease [7]. These authors showed posterolateral and medial collapse of the tibial plateau [7]. In both papers, the authors did not describe changes occurring within the growth plates around the knee joint. Growth plates should be assessed as a part of the MRI evaluation of the knee joint in Blount's disease patients. In the third paper, Mukai et al. presented data on the use of MRI to evaluate bowleg deformity in infants. They described MRI changes, like depression in the medial tibial growth plate and an abnormal signal in the metaphysis in addition to epiphyseal lesions. The authors suggest that changes occurring around the tibial growth plate might be an early prediction of Blount's disease [19].

From our observations, the main lesion found in Blount's disease patients consists of an irregular widening at the medial proximal tibial growth plate, which is more prominent in the severe cases. This widening is probably due to the response of the growth plate to focal injury. The ultimate cause for this injury remains obscure, although compression is the most widely accepted theory [10, 11].

In the three severely affected knees in our study, the abnormality went across the entire growth plate but was more prominent in the medial half. Besides the widening, significant invaginations of the tibial growth-plate cartilage were noted on the MRI. They appeared as contiguous extensions of the plate into the adjacent metaphyseal marrow. Kleinman et al. described in detail, based on radiographic and histopathologic study, the mechanism of extension of the growth-plate cartilage into the metaphysis as a sign of healing fracture [17]. Invaginations may be a response to any focal disruption of the plate's cellular organization.

Widening of the epiphyseal plate of the distal femur in late-onset tibia vara has been reported as a conventional plain film observation [3]. In the same report, a case of bowing with involvement of only the lateral aspect of the femoral physis was attributed to chronic stress secondary to genu varum. Our three knees with severe disease, however, illustrate that MRI can show growth-plate involvement concurrently at multiple locations. In the proximal tibial growth plate, both medial and lateral involvement can develop, and at the same time, pathologic changes in the lateral distal femoral physis were observed. We did not study this. A biomechanical distraction seems to be the mechanism of changes in the lateral aspect of the femur. In our opinion, diastasis and other changes, both of the femoral and tibial growth-plate cartilage, were the result of low-grade chronic growth plate stress resulting from genu varum and excessive weight. The effect of compressive forces medially and tension forces laterally appears to disrupt growth-plate function similarly, leading to widening across the tibial plate. This implies that both tensile and compressive stress produce a similar disruption of growth-plate function. Those forces that make the growth plate abnormal can also cause vascular injury in metaphyseal areas [3, 5]. Osteotomy of the tibia is designed to change the loading at the growth plate and remove these tension stresses.

A slightly decreased signal in the T1-weighted images was noted in the medial aspect of the tibial metaphysis, the area that shows the classic "beaking" on conventional plain films. Gradient echo images reveal that plate widening and invaginations of cartilage occur adjacent to this abnormal signal area. In our opinion, the decreased signal is secondary to thickening and fusion of the trabeculae in the metaphyseal cancellous bone. Changes like this are seen in healing metaphyseal fractures and represent a healing response in the area adjacent to the most severe plate disruption [17].

The three knees treated with hemiepiphysiodesis showed no evidence of growth-plate arrest or bridging in response to the surgery (Fig. 3). It is our belief that the abnormal growth plate cannot respond to the surgery

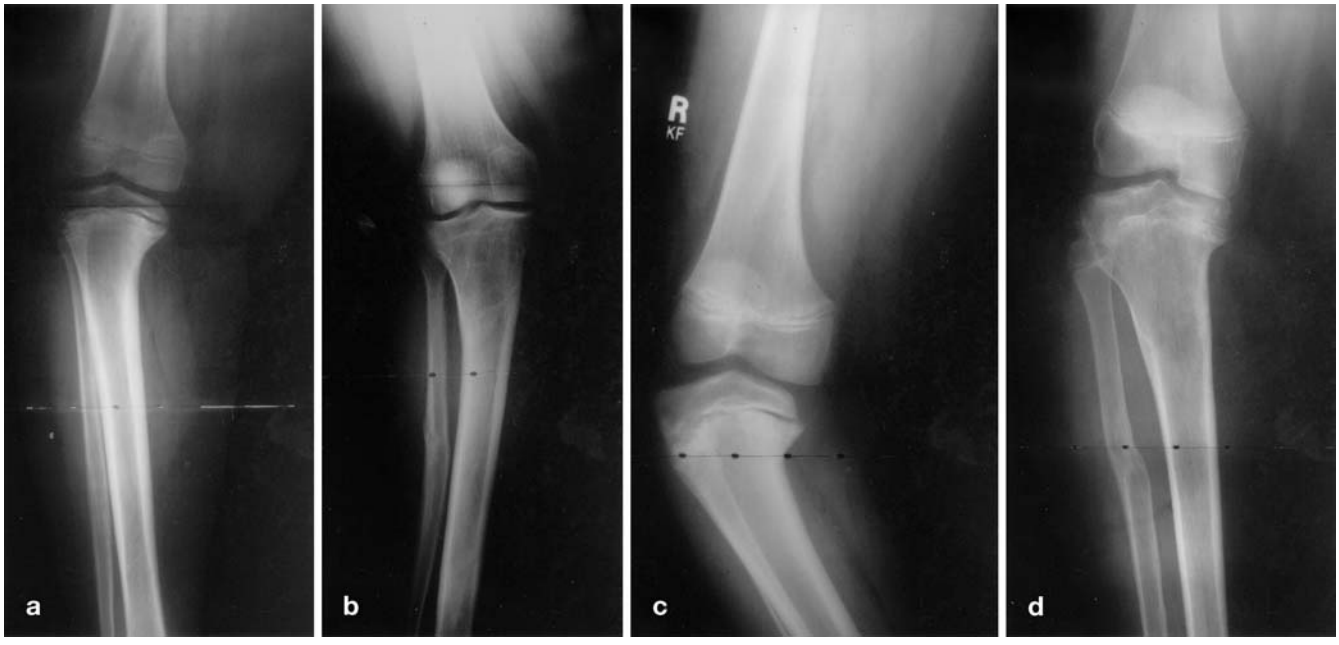
and form a bony bridge. Histopathologic changes have been described in the growth plate and the metaphysis in patients with Blount's disease [8, 19]. These changes lead to deformity and growth impairment due to disorientation and disorganization of the columnar pattern of the chondrocytes. They are accompanied by an excess of acellular or hypocellular matrix and abnormal large capillary vessels in the metaphysis. We postulate that response to epiphysiodesis is influenced by these changes.

Fig. 3 Bilateral late-onset tibia vara in a 12-year-old boy was initially treated by hemiepiphysiodesis. Note the wide lateral part of the proximal tibial growth plate 6 months after surgery. No signs of bone bridging or plate arrest are present

Fig. 4a–d Long-term (5-year) follow-up in two patients with severe Blount's disease following failed hemiepiphysiodesis and oblique tibial osteotomy. A 12-year-old boy developed valgus deformity. Preoperative standing radiograph at age 12 years (**a**) and follow-up at age 17 years (**b**). An 11-year-old boy developed recurrent varus. Preoperative standing radiograph at age 11 years (**c**) and follow-up at age 16 years (**d**)

The patients with severe knee involvement not only failed to respond to hemiepiphysiodesis, they also had a poor response to tibial osteotomy. With two knees developing progressive valgus (Fig. 4a and b) and one knee developing recurrent varus (Fig. 4c and d), there is indication that surgery alone in late disease is problematic. It is our feeling that the extent of growth-plate involvement and severe obesity contribute to the poor outcome. The advanced changes across the tibial growth plate possibly inhibit formation of the bony bridge. Our data showing good outcome with tibial osteotomy at the mild stage of disease, although limited, suggest early intervention should be considered.

The severity of the late-onset tibia vara is based mainly on tibiofemoral angle measurements. In our opinion, the severity of this disease can be further refined on the basis of growth-plate changes found on the MRI. In our mild cases, these changes are observed only at the medial part of the proximal tibial growth plate. The severe cases showed the changes through the whole tibial plate and in the lateral distal femoral growth plate. We think that both angle measurements and MRI have potential use in management of this disorder. MRI provides detailed information regarding the extent of growth-plate involvement. In severe cases, hemiepiphysiodesis appears of no value. Oblique tibial osteotomy produced equally poor long-term outcome in severely involved knees. This may relate to the extreme obesity in our patients with severe Blount's disease.



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