Original Clinical Article

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Limb lengthening in the treatment of posteromedial bowing of the tibia

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Abstract

Purpose: Posteromedial bowing of the tibia is an uncommon but recognized congenital lower extremity deformity in children that can lead to limb length discrepancy (LLD) and residual angulatory deformity. The purpose of this study is to report a series of children at a single institution with posteromedial bowing treated by lengthening.

Methods: A retrospective review was carried out at our institution identifying 16 patients who were treated with limb lengthening for posteromedial bowing of the tibia and followed to skeletal maturity. Projected LLD was a mean of 7.7 cm (range 5.0 cm to 14.2 cm). Three patients were treated in a staged fashion with lengthening and deformity correction at age three to four years and subsequent definitive tibial lengthening. The remaining 13 patients were treated with limb lengthening approaching adolescence using circular external fixation.

Results: All patients were pain free and ambulated without a limp at final follow-up. The mean final LLD was 0.3 cm short. In spite of correction of distal tibial shaft valgus in 11 of the 16 patients, eight of the 16 (50%) required later correction of persistent, symptomatic ankle valgus by either hemiepiphyseodesis (seven patients) or osteotomy (one patient).

Conclusions: Children with posteromedial bowing of the tibial with projected LLD over 5cm can be effectively treated with lengthening. Patients with severe valgus of more than 30° of shaft valgus and difficulty ambulating at age three years can be successfully treated with a two-stage lengthening procedure. Attention should be paid in patients with posteromedial bowing to ankle valgus.

Level of Evidence: IV

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Keywords: posteromedial bowing; limb lengthening; tibia; pediatric; limb length discrepancy

Introduction

Posteromedial bowing of the tibia is a well recognized but uncommon congenital lower extremity deformity that presents in the newborn in association with a relatively severe appearing calcaneovalgus foot deformity[1–3] and variably severe bowing. This deformity improves as the child ages, often developing a progressive limb length discrepancy (LLD) with gradual resolution of the oblique plane distal tibial valgus and recurvatum deformity. This entity was first reported by Heyman and Herndon who distinguished this from anterolateral bowing.[4] Others since that time have discussed tibial bowing, combining posteromedial and anterolateral bowing in spite of the markedly different clinical courses.[5] Most of our patients presented for evaluation of the foot deformity and the parents were unaware of the associated tibial shortening and bowing. Tibial deformity can be diagnosed on prenatal ultrasound.[6,7] More severe angulatory deformities correlate with greater LLD and the LLD at maturity is usually less than 7 cm.[3,7–10] Spontaneous resolution of the bowing often occurs although some have advocated casting or bracing of the foot deformity.[5,11] Shah et al noted that the remodelling of bowing occurs rapidly in the first year of life but more slowly thereafter.[10] The LLD at maturity is most often less than 5 cm and is commonly treated with lifts or by contralateral epiphyseodesis. More recently, there are a few reports of tibial lengthening in this patient population and these are limited to small series or as a few cases in reports of tibial lengthening.[12–14]

At our institution, patients with projected limb length discrepancies of 5 cm or greater are offered the option of limb lengthening using a circular external fixator. Patients with substantial residual tibial bowing are also treated with limb realignment. The purpose of this article is to

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present the results and complications of our experience with tibial lengthening using circular external fixation.

Materials and methods

After obtaining approval from the Institutional Review Board, a review of the databases from our institutions was carried out. We sought to identify patients with posteromedial bowing of the tibia who had undergone limb lengthening or correction of an angulatory deformity using an external fixation device between 1 January 1990 and 31 December 2008, a 19-year time period. Patients were excluded if they had an associated genetic condition or less than two-year follow-up from the index procedure. A total of 52 patients with posteromedial bowing were identified after being seen at one of our institutions. In all, 18 of these 52 patients (35%) were treated by limb lengthening and 16 patients had greater than two years follow-up (two patients were lost to follow-up less than two years postoperatively and were excluded) and constitute the clinical material for the study.

Charts were reviewed for demographic information, intraoperative information, complications and postoperative clinical information including joint range of motion, gait and pain. Both preoperative and postoperative radiographs were reviewed for alignment[15–19] and bony healing (defined as cortication of the regenerate on three cortices as evaluated by anteroposterior and lateral radiographs). Standard radiographic deformity measures were made on preoperative, post-correction and final lower extremity radiographs including the mechanical axis deviation, mechanical lateral distal femoral angle (mLDFA), mechanical medial proximal tibial angle (mMPTA) and mechanical lateral distal tibial angle (mLDTA).[16,17] In addition radiographs were measured for the anatomic medial proximal tibial angle (aMPTA),[16,17] measured through the centre of the proximal tibia, proximal to the midshaft bow. Shaft valgus and recurvatum were also measured with lines through the centre of the tibial shaft proximal and distal to the midshaft deformity. The final mechanical axis was also classified into a final zone within the knee.[20]

Preoperative planning

Preoperatively, all patients were evaluated with a standing anteroposterior radiograph of both lower extremities. These were assessed for LLD[21] as well as coronal alignment. A lateral of the affected tibia was also obtained to assess the sagittal plane deformity. Methods utilized to predict the LLD included the Green–Anderson (growth remaining) method,[22] the Mosley straight line graph[23,24] and the multiplier method.[25]

If correction of the tibial deformity was planned as a toddler, the external fixator was preconstructed to correct the shaft–shaft deformity present in the distal tibia while accomplishing a lengthening of 4 cm to 5 cm through the same site. This lengthening was planned as a preliminary to definitive lengthening with or without deformity correction at an older age. If lengthening as an older child or adolescent was planned, a circular external fixator was preconstructed to allow correction of the LLD as well as any deformity present. The circular external fixator was of an Ilizarov type (Smith-Nephew, Memphis, Tennessee, USA) early in the series. Later, a hexapod computer-controlled Taylor spatial frame circular external fixator (Smith-Nephew, Memphis, Tennessee, USA) was utilized. If lengthening alone was needed, a single osteotomy and correction site was planned with a neutral mechanical axis and equal limb lengths at skeletal maturity being the goal. If lengthening with a mid-tibial angulatory correction was planned, a three-ring external fixator was preconstructed with lengthening and correction of any proximal tibial varus accompanied by correction of distal tibial shaft and ankle valgus. Minimal lengthening of 1 cm to 2 cm was planned through the distal osteotomy. Lengthening was undertaken with the goal being equal limb lengths at skeletal maturity, a neutral mechanical axis and a neutral hindfoot. The amount of tibial valgus corrected was planned based on a combination of factors including the tibial shaft valgus and the amount of ankle valgus present radiographically. In addition, careful examination of the patient's hindfoot was carried out preoperatively. Some of the patients had compensatory varus deformity in the hindfoot with varying degrees of rigidity. Care was taken not to correct bony ankle deformity and leave the patient with clinical rigid hindfoot varus.

Surgical treatment – toddler

If a realignment and lengthening was planned as a three to four year old, following the induction of general anaesthesia, the fibula was approached at the level of the deformity under tourniquet control through a 2 cm to 3cm lateral incision. After carefully isolating the fibula subperiosteally with retractors at the junction of the proximal and middle thirds of the fibula, an oscillating saw was used to create an osteotomy. The fascia was left open and the lateral incision closed and the tourniquet deflated.

Following this, the preconstructed circular external fixator with two rings was suspended using suction tubing from the limb.[26] Transverse reference wires were placed from lateral to medial through the proximal and distal metaphysis. Additional wires and half pins were then placed to complete the fixation. After the tourniquet had once again been elevated, the external fixator was partially destabilized to allow motion at the proposed osteotomy site (typically by removing the anterior struts). A distal tibial corticotomy was then performed at the apex of the deformity using multiple drill holes and an osteotome.[27–29] The wound was then closed. After closure of the wounds and restabilization of the external fixator, dressings were applied.

Surgical treatment – older child or adolescent

Following the induction of general anaesthesia, the fibula was approached under tourniquet control through a 2 cm to 3 cm lateral incision at the junction of the proximal and middle thirds of the fibula. After carefully isolating the fibula subperiosteally with retractors, an oscillating saw was used to create an osteotomy. The fascia was left open and the lateral incision closed and the tourniquet deflated.

Following the fibular osteotomy, the preconstructed circular external fixator with two or three rings was suspended using suction tubing from the limb.[26] Transverse reference wires were placed from lateral to medial through the proximal and distal metaphysis. Additional wires and half pins were then placed to complete the fixation. After the tourniquet had once again been elevated, the external fixator was partially destabilized and a proximal corticotomy[27–29] was performed using multiple drill holes and an osteotome at the proximal metaphysis 0.5 cm to 1.0 cm distal to the proximal fixation. If a midshaft osteotomy was performed, the tibia was approached at the point of the diaphyseal deformity and a second tibial corticotomy was performed. After closure of the wounds, the external fixator was restabilized and dressings were applied.

Postoperative care

Postoperatively weight bearing was encouraged. An aggressive physical therapy for weight bearing and range of motion exercises at the knee and ankle was initiated on postoperative day one. Distraction was begun on postoperative day three. A pin site care regimen of daily showers without specific pin cleaning was begun as has been previously described.[30] The correction and regenerate bone was monitored with radiographs every one to two weeks until the end of correction and then monthly until complete consolidation. The external fixator was maintained until consolidation and cortication was complete and was then removed under general anaesthetic without subsequent immobilization.

Study group

There were nine boys and seven girls in the study group of 16 patients. There were seven right tibiae and nine left tibiae. The mean age of the patients at the index procedure was nine years and five months (range, three years and two months to 14 years). The mean projected LLD for this group of patients was 7.7 cm (range, 5.0 cm to 14.2 cm). Preoperative and final angulatory measurements are summarized in Table 1. The difference between the mMPTA and the aMPTA measurements for each patient measured 6.9° (range, 0° to 17°) and represented the proximal tibial compensatory varus. Little mechanical axis deviation was noted preoperatively (7.9 mm, range 0 mm to 30 mm) because of the compensatory proximal tibial varus and the distal nature of the deformity. Substantial ankle valgus was noted preoperatively with a mean LDTA of 76° (range, 41° to 89°). The three most severe patients (Table 2) had the most preoperative compensatory varus (15°, range 12° to 17°) and the most ankle valgus (LDTA 58°, range 41° to 73°).

Table 1 All patients

	Preoperative	Postoperative	Final
MAD (range) (Lateral dev.)	7.9 mm (0 mm to 30 mm)	8.2 mm (0° to 27°)	6.9 mm (0 mm to 38mm)
LDFA (range)	87.1° (85° to 90°)	86.1° (78° to 90°)	87.2° (85° to 90°)
mMPTA (range)	89.8° (87° to 101°)	89.8° (87° to 96°)	88.8° (86° to 91°)
aMPTA (range)	82.8° (73° to 90°)	87.6° (85° to 94°)	87.3° (84° to 90°)
Compensatory varus	6.9° (0° to 17°)	2.3° (1° to 5°)	1.8° (–1 to 4°)
LDTA (range)	76° (41° to 89°)	82.4° (69° to 93°)	81.3° (67° to 90°)
Shaft valgus (range)	14.5° (4° to 38°)	6.9° (0° to 20°)	6.7° (0° to 20°)
Shaft recurvatum (range)	11.8° (0° to 39°)	3.4° (0° to 11°)	2.2° (1° to 9°)

aMPTA, anatomic medial proximal tibial angle; LDFA, lateral distal femoral angle; LDTA, lateral distal tibial angle; MAD, mechanical axis deviation; mMPTA, mechanical medial proximal tibial angle

Table 2 Patients treated by staged correction

	Preoperative	After first stage	Final
MAD (range) (Lateral dev.)	15 mm (1 mm to 25 mm)	9.7 mm (3 mm to 14 mm)	7 mm (4 mm to 9mm)
LDFA (range)	86.7° (85° to 89°)	86.7° (86° to 88°)	86.7° (86° to 87°)
mMPTA (range)	94.3° (89° to 101°)	91.3° (90° to 92°)	88.7° (88° to 89°)
aMPTA (range)	79.3° (73° to 89°)	85.0° (83° to 87°)	85.7° (85° to 87°)
Compensatory varus	15.0° (12° to 17°)	6.3° (5° to 9°)	3° (2° to 4°)
LDTA (range)	58.0° (41° to 73°)	78.7° (74° to 84°)	73.7° (70° to 77°)
Shaft valgus (range)	34° (31° to 38°)	9.3° (2° to 20°)	2.7° (2° to 3°)
Shaft recurvatum (range)	31° (22° to 39°)	0.7° (0° to 2°)	0.7° (0° to 2°)

aMPTA, anatomic medial proximal tibial angle; LDFA, lateral distal femoral angle; LDTA, lateral distal tibial angle; MAD, mechanical axis deviation; mMPTA, mechanical medial proximal tibial angle

Results

Circular external fixation was used in all patients. An Ilizarov type external fixator (Smith-Nephew, Memphis, Tennessee, USA) was used in seven patients earlier in the series. A computer-controlled hexapod external fixator (Smith-Nephew, Memphis, Tennessee, USA) was used for the last nine patients treated. Seven patients had residual apex posteromedial bowing with a substantial residual limb length discrepancy as they approached adolescence. In order to normalize the ankle, these patients required a distal tibial osteotomy in addition to the proximal corticotomy (Fig. 1a–d).

Patients were followed for a mean of 7.6 years following the index procedure (range, 3.2 years to 12.2 years). The mean overall length achieved was 7.3 cm (range, 4.4 cm to 15.2 cm) with three of these patients being treated with two limb lengthenings. The three patients treated with tibial lengthening between three and five years of age achieved a mean of 3.3 cm (range 2.0 cm to 4.4 cm) during the primary lengthening and angulatory correction. All patients, including the patients treated at a younger age, were treated by a lengthening as they approached adolescence and achieved a mean of 5.7 cm (range 3.4 cm to 8.6 cm) over a mean period of 27 weeks (range, 16 weeks to 41weeks) resulting in a mean lengthening index of 36 days/cm (range, 21 days/cm to 61 days/cm).

Alignment was substantially improved in this group of patients. The mechanical axis of the lower extremity passed a mean of 7.9 mm lateral (range, 0 mm to 30 mm lateral, normal 8 mm medial) to the centre of the knee. The mechanical axis of 15 of the 16 patients passed through the central third (zone I) of the knee.[20] In a single patient the mechanical axis passed through lateral zone II. This patient ultimately underwent tibial osteotomy to correct the alignment. The mMPTA and aMPTA improved somewhat with a decrease in the difference between these measures from 6.9° to 1.8° representing correction of the compensatory proximal tibial varus (Table 1). At last follow-up, a mean of 8.1 years postoperatively (range, 3.2 years to14.3 years), all patients had reached skeletal maturity and all patients were pain free. All patients regained full knee extension (0°) and flexion (140°). In total, 15 of the 16 patients regained full ankle dorsiflexion (20°) and all patients have regained full plantarflexion (40°), one patient had asymptomatic limited dorsiflexion to 10°. All of the 16 patients were able to ambulate without a limp. All patients had returned to activities of their choice and were not restricted. The final mean LLD was 0.3 cm short (range, 1.7 cm short to 1 cm long) and no patient was symptomatic. The two patients

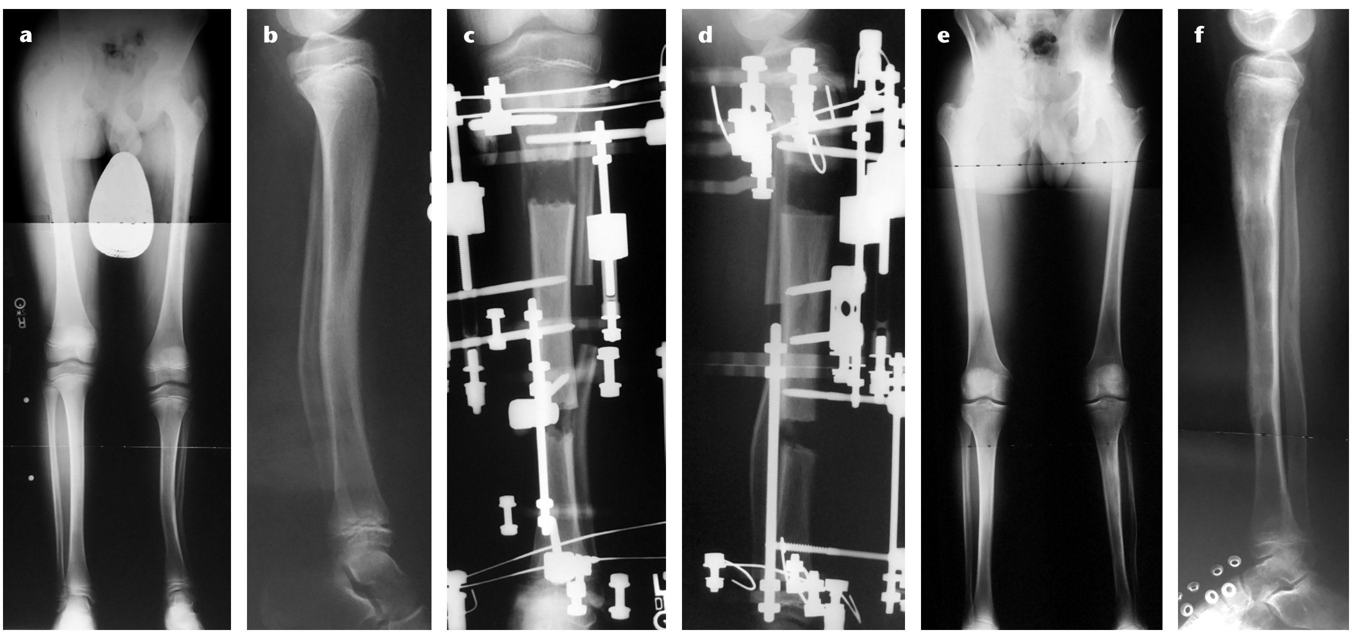

Fig. 1 **(a)** Standing anteroposterior radiograph of both lower extremities showing a nine-year-old male with a projected 5.8 cm LLD and distal tibial valgus. **(b)** Lateral radiograph of the tibia in the same patient showing mild recurvatum of the distal tibia. **(c)** Anteroposterior radiograph of the tibia in the same patient six weeks postoperatively showing an Ilizarov external fixator in place with a bipolar lengthening and distal tibial angulatory correction. **(d)** Lateral radiograph of the tibia in the same patient six weeks postoperatively showing an Ilizarov external fixator in place with a bipolar lengthening and distal tibial angulatory correction and early regenerate bone. **(e)** Standing anteroposterior radiograph of both lower extremities in the same patient five years postoperatively showing solid healing of the regenerate and equal limb lengths. **(f)** Lateral radiograph of the tibia in the same patient five years postoperatively showing solid healing of the regenerate.

lost to follow-up less than two years postoperatively, excluded from the study, were doing well when last seen after removal of the external fixator.

Six of the 16 patients (38%) were treated by lengthening of the tibia without correction of any remaining distal tibial valgus. Seven of the 16 patients (44%) were treated with a bipolar lengthening including proximal lengthening and a mid to distal tibial lengthening combined with correction of a valgus recurvatum oblique plane deformity (Fig 1a–f). Three of the 16 patients (19%) had significant valgus deformities that did not remodel and interfered with walking after age three years. These three

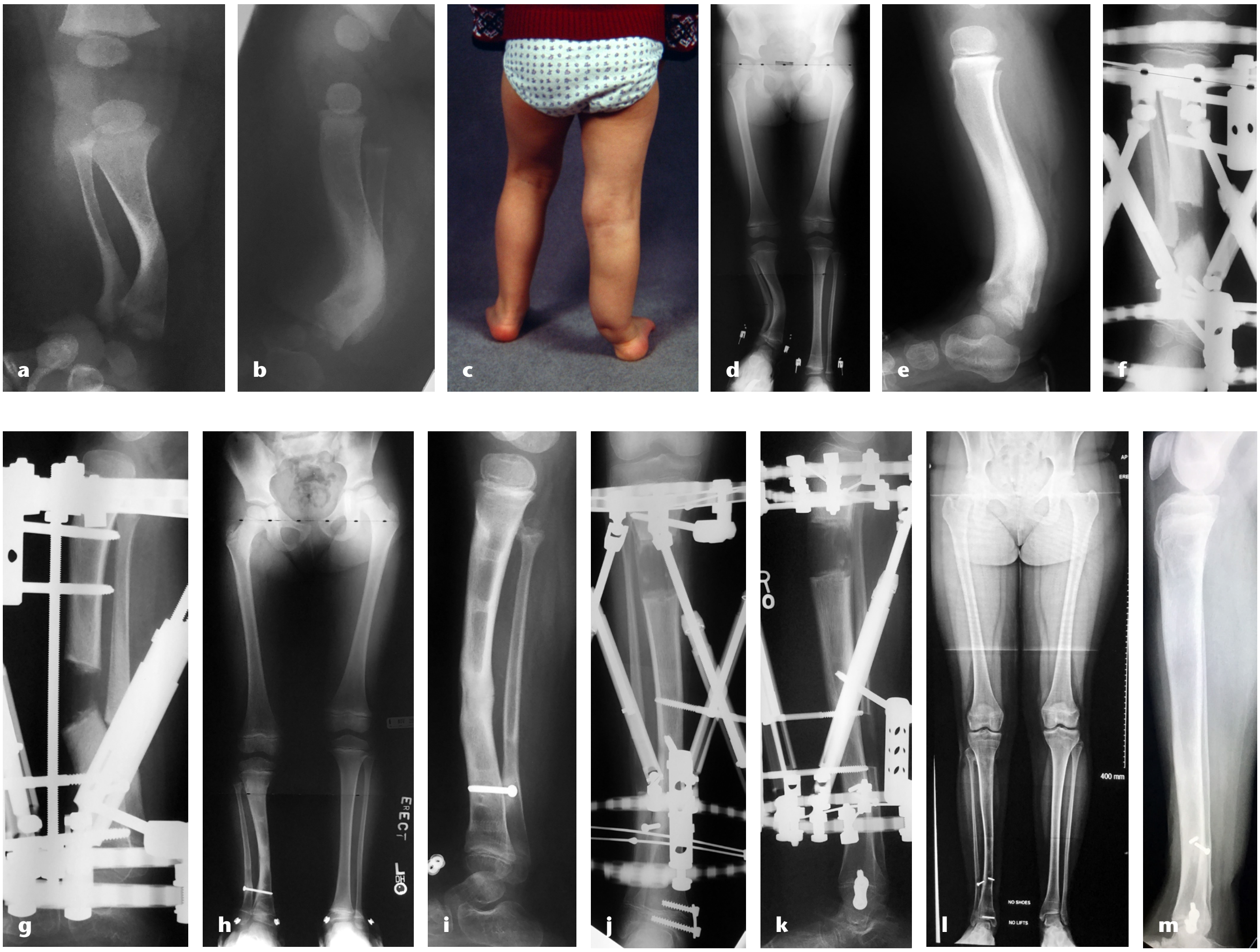

Fig. 2 **(a)** Anteroposterior radiograph of the right tibia in a five-month-old female showing marked distal tibial valgus. **(b)** Lateral radiograph of the right tibia in the same patient showing marked distal tibial recurvatum. **(c)** Clinical image of the same patient showing the lower extremities from the back with marked ankle valgus. **(d)** Standing anteroposterior radiograph of both lower extremities in the same patient showing marked distal tibial valgus and a limb length discrepancy. Note the marked residual deformity. **(e)** Lateral radiograph of the tibia in the same patient with marked distal tibial recurvatum. Note the marked residual deformity. **(f)** Anteroposterior radiograph of the right tibia in the same patient at age three years now four weeks postoperatively during lengthening and valgus correction with a hexapod external fixator. **(g)** Lateral radiograph of the right tibia in the same patient at age three years now four weeks postoperatively during lengthening and recurvatum correction with a hexapod external fixator. **(h)** Standing anteroposterior radiograph of the lower extremities one year postoperatively showing healing of the lengthening with a syndesmosis screw in place. **(i)** Lateral radiograph of the lower extremities one year postoperatively showing healing of the lengthening with a syndesmosis screw in place. **(j)** Anteroposterior radiograph of the right tibia in the same patient at age nine years now five weeks postoperatively during lengthening of the tibia with a hexapod external fixator. Note the medial distal tibial plate hemiepiphyseodesis placed to correct residual ankle valgus. **(k)** Lateral radiograph of the right tibia in the same patient at age nine years now five weeks postoperatively during lengthening of the tibia with a hexapod external fixator. Note the medial distal tibial plate hemiepiphyseodesis placed to correct residual ankle valgus. **(l)** Standing anteroposterior radiograph of both lower extremities in the same patient five years postoperatively showing solid healing of the regenerate and equal limb lengths. **(m)** Lateral radiograph of both lower extremities in the same patient five years postoperatively showing solid healing of the regenerate.

patients also had a larger projected LLD of 11.5 cm (range, 9.2 cm to 14.2 cm). These three patients were treated with correction of a severe valgus recurvatum deformity with lengthening between age three and four years. These three patients required a second lengthening as they approached adolescence that included lengthening in all three patients (Fig. 2a–m). In one of these patients this was a bipolar lengthening with combined proximal lengthening and a mid to distal correction of a residual valgus recurvatum oblique plane deformity.

Complications

All but three patients (13 of 16 patients) developed superficial pin tract infections which resolved after oral antibiotics. No patient required intravenous antibiotics, no patient developed osteomyelitis. No patients developed ankle or knee contractures requiring surgical intervention.

Two patients had residual knee valgus and were treated with medial proximal tibial hemiepiphyseodesis in order to achieve normal alignment. A single patient developed late valgus due to a partial proximal tibial physeal arrest and required repeat proximal tibial osteotomy to achieve normal alignment. Eight patients, in spite of correction of the tibial shaft valgus, had symptoms associated with residual ankle valgus with a decreased LDTA. Seven of these patients were treated with medial distal tibial hemiepiphyseodesis with good correction. The eighth patient developed ankle pain associated with valgus and because she was close to skeletal maturity was treated by distal tibial osteotomy with good correction. All patients ultimately were pain free at the ankle.

Discussion

Congenital posteromedial bowing of the tibia is generally recognized as a cause of mild limb length inequality and teaching about the deformity emphasizes that the valgus and recurvatum typically resolves without treatment.[31] While this is true of most patients with posteromedial bowing, clearly there is a spectrum of disease, ranging from patients who spontaneously resolve the deformity and are left with a mild LLD to those who have a substantial residual LLD with associated persistent angulation that interferes with the ability to ambulate. When limb lengthening is reported, many authors have performed a single proximal osteotomy with subsequent lengthening with the presumption that the residual deformity is minimal and can be ignored.[12,13] Only four of the patients that we have described here were adequately treated by simple tibial lengthening. We agree with Wright et al[14] that a significant minority of the patients with posteromedial bowing of the tibia can benefit from an approach that emphasizes deformity correction.

Limb lengthening in this group of patients with more severe projected LLD was successful with a minimum of complications. This group was unusual in that most of these patients had residual valgus in the distal tibia and were therefore treated definitively with either bipolar osteotomies or early osteotomy correcting the distal valgus. Typically, the distal osteotomy was performed to correct valgus and minimal length was achieved through this osteotomy. Although this study does not include patients that were treated with epiphyseodesis, other authors have noted that the severity of the bowing and LLD are roughly correlated,[3,8] these patients had more severe deformities and larger discrepancies than many patients with posteromedial bowing. Further, more severely bowed patients also seemed to have increased amounts of compensatory proximal tibial varus (Fig. 2c). This compensatory varus has been noted by Franzone et al[32] and as they had noted, the varus is present in the earliest radiographs of these patients (Fig. 2b) and seems to be a congenital part of the deformity rather than an acquired compensation.

Three of our patients had severe bowing with difficulty ambulating even with an ankle–foot orthotic (AFO) at age three years and required early treatment (Fig 2a–g). Operative treatment was indicated in these patients because of the combination of functional disability and a decrease in the rate of spontaneous remodelling noted by Shah et al[10] after age one year. A similar approach to this severely affected group has been described by Napiontek and Shadi.[33] The length provided decreased the amount of lift required by the children as they grew and lengthening seems to be relatively well tolerated in this age group.[34] We agree with Johari et al[35] that early surgery does not seem to positively influence the ultimate LLD or deformity, but there are clinical situations where early surgery is functionally indicated. Because of the large projected LLD in this group (11.5 cm) a staged approach was utilized in this group initially lengthening and correcting the tibial shaft deformity with plans for a subsequent definitive lengthening procedure when the patient approached adolescence. This approach proved successful in correcting the alignment (Table 2) as well as equalizing the limb length discrepancy.

We believe that patients with residual distal tibial valgus should be treated with a comprehensive approach that addresses both the LLD and the angulatory component. Failure to address the distal tibial valgus in our patients led to later problems and procedures to correct residual valgus. One complicating factor in correcting distal tibial valgus is the presence of compensatory hindfoot varus. If this varus is rigid, attempts to correct the distal tibial valgus can potentially lead to unmasking the varus deformity. All our patients were ultimately ambulating with a neutral hindfoot alignment in spite of the the final LDTA remaining in valgus. Careful preoperative examination of the foot is essential during the correction planning process.

Eight of the 16 patients required either medial distal tibial hemiepiphyseodesis (seven patients) or distal tibial osteotomy (one patient) following the index procedure.[36] Shah et al[10] noted a 'wedge shaped epiphysis' in the distal tibia in patients with posteromedial bowing which seemed to increase the amount of ankle valgus above the valgus caused by the diaphyseal bowing. During correction of valgus deformity, the shaft deformity was nearly completely corrected, yet a number of patients continued to have substantial ankle valgus. The compensatory proximal tibial varus was also nearly completely corrected and was not a source of persistent ankle valgus in these patients.

Weaknesses in this study include the limited number of patients. As in any unusual condition, the limited volume of patients can lead to unusual cases skewing the data. In addition, as a tertiary referral centre, our patient population may be skewed towards more severe disease and 16 of the 52 patients (29%) identified in our search had a LLD or deformity that was treated with limb lengthening. A number of patients in our referral area most likely had posteromedial bowing but because of the mild nature of their disease were not seen at our centre. This would lead to an overestimation of the frequency of larger limb length discrepancies.

Conclusion

In all, 16 of the 52 children identified at our institution with congenital posteromedial bowing of the tibia had a projected LLD at maturity of 5 cm or more and elected to equalize the limb lengths by tibial lengthening. Half of these children also had residual distal tibial deformity and benefited from correction of the deformity. Limb lengthening procedures alone were effective in patients with a LLD of 5 cm or more without residual distal tibial valgus. Limb lengthening with associated deformity correction was carried out in patients with residual distal tibial deformity. A subgroup of children were severely involved and benefited from a staged approach with intervention prior to the age of four years with limb lengthening and deformity correction followed by definitive limb lengthening and correction of residual deformities as the patient approached adolescence. The most significant problem encountered was that of persistent distal tibial valgus in spite of initial correction. These patients should be carefully followed for persistent ankle deformity.

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COMPLIANCE WITH ETHICAL STANDARDS

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ETHICAL STATEMENT

Ethical approval: All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent: Informed consent was waived by the Institutional Review Board and no patient identifiable information is contained in the manuscript.

ICMJE CONFLICT OF INTEREST STATEMENT

JEG has received an honorarium for teaching Spatial frame courses from Smith-Nephew.

All other authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

JEG: All phases of manuscript including design, Data collection, Data analysis, Primary author, Editing.

PLS: Design, Data analysis, Coauthor, Editing.

TRL: Data collection, Data analysis, Coauthor, Editing.

MLM: Data collection, Data analysis, Coauthor, Editing.

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