

Growth modulation in idiopathic angular knee deformities: is it predictable?

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Abstract

Purpose To evaluate the temporal and spatial sequence of events following temporal hemiepiphyodesis in idiopathic knee varus/valgus.

Methods This is a retrospective multicentre study on 372 physes in 206 patients. The average rate of correction (ROC) was calculated; univariate and multivariate analysis were performed.

Results In all, 92% of the femoral physes were followed for more than one year/reached skeletal maturity. Of those, 93% were corrected to a mechanical lateral distal femoral angle (mLDFA) of 85° to 89°; 2% did not, while 5% were over-corrected. A total of 92% of the tibial physes were followed for more than one year/reached skeletal maturity. Of those, 92% were corrected to a mechanical medial proximal tibial angle (mMPTA) of 85° to 89°; 2% did not, while 6% were over-corrected. Factors significantly influencing success and ROC were age, direction and magnitude of deformity. Femoral ROC was significantly faster than tibial ROC: 0.85° versus 0.78°/month, respectively ($p = 0.05$). Femoral valgus ROC

was significantly faster than varus ROC: 0.90° versus 0.77°/month, respectively ($p = 0.04$). A constant was derived to calculate the amount of correction. Significant correlation was found between calculated and actual mLDFA in valgus deformity during the first year ($r = 0.58$ to 0.87 , $p < 0.01$). Calculated mLDFA of varus deformity did not correlate with actual mLDFA. Significant correlation was found when calculating mMPTA correction in all deformities.

Conclusions Femur corrects faster than tibia; valgus femoral deformities are corrected faster than varus. Valgus correction in the distal femur/proximal tibia as well as varus correction in the tibia in idiopathic patients is highly predictable. The constant derived is the first tool which enables predicting and monitoring amount of correction in hemiepiphyodesis when correcting angular deformities around the knee.

Level of Evidence IV

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Introduction

Deviations of the axis of the knee in the coronal plane are very common during childhood and early adolescence, and most of them resolve spontaneously. Developmental (physiological) bowing is a common condition that causes exaggeration of normal age-related angulation changes at the knee joint. Neonates and infants normally have varus angulation of their legs and gradual correction of this angulation begins as a child starts walking. After that, there is usually a change to valgus angulation during the second and third years of life that reverts to the adult pattern around the age of six years.^{1,2}

Idiopathic frontal plane angular deformities around the knee are the most common lower limb deformities.^{3,4} Guided growth by tension band plating (TBP) is often used to correct coronal plane deformities around the knee. Since this method was introduced by Stevens in 2007⁵ many studies have demonstrated the efficacy, safety and advantages of TBP in the paediatric age group as an alternative to corrective osteotomy.^{6,7}

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This study presents insights from an international multicentre database analysis of idiopathic coronal knee deformity correction. Initial results regarding the entire study population have been previously published.⁸

The purpose of this study was to measure the effect, define parameters that influence success and define and validate a constant predicting amount of correction using temporary hemiepiphysiodesis around the knee in patients with idiopathic aetiology.

Materials and methods

This is a retrospective multicentre study conducted at five centres. In each centre approval was obtained from the local institutional review board.

Inclusion criteria were idiopathic knee angular deformities in the coronal plane. All other causes of angular deformity were excluded. All patients were treated by different types of TBP and had at least one preoperatively and two postoperatively digital-based full-length anteroposterior (AP) weight-bearing radiographs.

Deformity analysis of all radiographs was done using the TraumaCad software (product of Voyant Health, a Brainlab company, Munich, Germany) by a designated investigator in each centre.

This method has been proven as a reliable tool in terms of intra- and interobserver variability as shown by Segev et al.⁹

The mechanical lateral distal femoral angle (mLDFA) and the mechanical medial proximal tibial angle (mMPTA) were recorded and analyzed. Normal values for both were considered $87^\circ \pm 2^\circ$ degrees.¹⁰ Mean rate of correction (ROC) in $^\circ$ /month was calculated.

After calculating the mean ROC, the result was used as a constant, predicting the amount of correction at several time points throughout the follow-up period. Correlation between the actual and calculated amount of correction was then evaluated.

All medical records for each patient were reviewed, including surgical reports and radiographs. The underlying aetiology was recorded as well as the age at day of plate insertion. Remaining growth was estimated by subtracting the age at day of plate insertion from 17 years for male patients and from 15 years for female patients which are the ages considered for skeletal maturity in each.¹¹

Complications including screw breakage, postoperative infection and limited range of movement were recorded. Postoperative infection and limited range of movement were divided into early (within the first postoperative month) and late (after the first postoperative month).

Data was collected using the same central web-based database in all centres.

Statistical analysis

Univariate and multivariate analysis was performed to determine parameters that influence the rate and amount of correction.

Correlation between calculated and actual amount of correction was evaluated by Pearson correlation coefficient.

Results

In total, 372 physes of 206 patients were included: 110 male and 96 female; their mean age at surgery was 12.5 years (SD 2.3).

In all, 257 physes were followed up to 18 months and 115 physes were followed over 18 months. Mean follow-up was 16 months (SD 2.2).

Data included 178 femoral physes and of those, 157/178 (88.2%) were in valgus and were operated on with a medial hemiepiphysiodesis while 21/178 (11.8%) were in varus and were operated on with a lateral hemiepiphysiodesis.

A total of 128 tibial physes were analysed and of those, 98/128 (76.5%) were in valgus and were operated on with a medial hemiepiphysiodesis while 30/128 (23.5%) were in varus and underwent a lateral hemiepiphysiodesis.

In all, 66 were combined femoral and tibial physes and of those 52/66 (78.8%) were in valgus and operated on with a medial hemiepiphysiodesis while 14/66 (21.2%) were in varus and underwent a lateral hemiepiphysiodesis (Table 1).

Femoral correction

In all, 92% (199/216) of the patients were followed more than one year/reached skeletal maturity and of these 93% (185/199) were corrected to standard alignment (mLDFA between 85° to 89°); 2% (four patients) did not achieve correction to standard alignment while in 5% (ten patients) there was over-correction. A total of 8% (17 patients) did not achieve correction at the time of the study but were still growing.

Tibial correction

In all, 92% (143/156) of the patients were followed for more than one year/reached skeletal maturity. Of these, 92% (131/143) achieved correction to standard alignment (mMPTA between 85° to 89°); 2% (three patients) did not achieve correction to standard alignment while in 6% (nine patients) there was over-correction. In all, 7% (13 patients) did not achieve correction but were still growing at the time of the study.

ROC of the femur was significantly faster than that of the tibia: 0.85° compared with 0.78° /month, respectively ($p = 0.05$).

Table 1 Operation site

Bone	Number of physes (%)	Medial aspect hemiepiphysiodesis (%)	Lateral aspect hemiepiphysiodesis (%)
Femur	178 (48)	157 (88.2)	21 (11.8)
Tibia	128 (34)	98 (76.5)	30 (23.5)
Femur and Tibia	66 (18)	52 (78.8)	14 (21.2)
Total	372 (100)	307 (82.5)	65 (17.5)

Table 2 Rate of correction (ROC) (°/month)

Bone	Minimum ROC	Maximum ROC	Mean ROC (SD)	Significance
Femur	0.04	3.72	0.85135 (0.837)	p = 0.05
Tibia	0.06	4.76	0.7806 (0.825)	
Femur varus	0.04	2.81	0.7722 (0.811)	p = 0.04
Femur valgus	0.06	3.72	0.9031 (0.835)	
Tibia varus	0.07	3.17	0.8224 (0.798)	p = 0.57
Tibia valgus	0.06	4.76	0.8412 (0.763)	

ROC in valgus deformity of the femur was significantly faster than in varus deformity: 0.90° compared with 0.77°/month, respectively (p = 0.04). This difference has not been found in the tibia (Table 2). In order to predict the amount of correction, average ROC was tested as a constant which was multiplied by the number of months from initial surgery.

Statistically significant correlation was found between calculated and actual femoral angle (mLDFA) in valgus deformity during the first year of correction (r = 0.58 to 0.87, p < 0.01). Calculating the mLDFA after 12 months was not reliably predictable.

Calculated femoral angle (mLDFA) of varus deformity did not correlate to the actual mLDFA.

Correlation was also found between calculated and actual tibial angle (mMPTA) in valgus deformity during the first eight months of correction.

Calculating the mMPTA after eight months was not reliably predictable.

Statistically significant correlation was also found between calculated and actual tibial angle (mMPTA) in varus deformity correction during the entire follow-up period (see Table 3 for all correlations).

The age of the patient represented by remaining months of growth (skeletal maturity being defined as 15 years for girls, 17 for boys)¹¹ was found to significantly influence the amount of femoral and tibial correction.

The younger the child the better the chance to achieve correction; as seen with multivariable analysis, patients with more than 38 remaining months of growth (range 12 to 59.3, ± 20.2) i.e. girls less than 12 years and boys less than 14 years, had a statistically significant better chance at achieving full correction for the femur (factor 1.3, p = 0.02) and the tibia (factor 1.17, p = 0.025).

Patient sex did not influence the success of the treatment.

The amount of deformity represented by the calculated difference from normal value preoperatively, was found to have a significant negative influence on treatment success: for each degree of difference from 87° mLDFA or mMPTA the chance of achieving normal alignment (87° ± 2°) was reduced by a factor of 0.245 for the femur and 0.259 for the tibia (p = 0.021 and p = 0.09, respectively).

Complications

Two patients (1%) experienced early postoperative infection (within the first postoperative month). The first patient was operated on both tibia with lateral plates the second underwent surgery on both tibia and femur with medial plates.

Two patients (1%) experienced early limited range of movement (within the first postoperative month). The first patient had both tibiae operated on with lateral plates while the second underwent surgery on both tibia and femur with medial plates.

No hardware failure was recorded during this study.

Discussion

In 1949 Blount and Clarke¹² first described the use of a staple for hemiepiphysal arrest and since then many other procedures attempting to guide epiphysal growth have been discussed and published.¹³⁻¹⁵ The uniqueness of this study is its extent; it includes data on 372 physes in 206 patients and the findings regarding different ROC in valgus and varus deformity.

In all, 93% of the femoral deformities and 92% of the tibial deformities were corrected to standard alignment (mLDFA and mMPTA between 85° to 89°, respectively) within 16 months from plate insertion. These findings correlate with previous studies: Burghardt and Herzenberg⁶ demonstrated in their study of 43 patients (54 physes, various aetiologies) around 90% treatment success. In this series, success was defined as reaching either full deformity correction or avoiding the need for realignment osteotomy in the treated limb segment. Shabtai and Herzenberg⁷ in their review article also mention that the most predictable outcome for TBP's occurs in the idiopathic group. Boero et al¹⁶ studied 58 patients with knee angular deformities managed with eight-Plate guided growth. In all, 30 were idiopathic while the rest were due to pathological aetiology. In the idiopathic group 100% experienced complete correction of deformities (mean tibial femoral angle after correction was 5° ± 1.2°). In this study there was no differentiation between distal femoral angle and tibial femoral angle because only one tibial-femoral angle was measured.

Furthermore, some of the over-corrected cases can also be referred to as 'corrected' because over-correction may

Table 3 Pearson correlation coefficients between calculated and actual amount of correction

	Valgus				Varus	
	< 4 mths	4 to 8 mths	8 to 12 mths	> 12 mths	< 7 mths	> 7 mths
Right femur	r = 0.79 p < 0.01	r = 0.75 p < 0.01	r = 0.58 p < 0.01	r = 0.22 p = 0.31	r = 0.48 p = 0.4	r = 0.64 p = 0.03
Left femur	r = 0.73 p < 0.01	r = 0.87 p < 0.01	r = 0.75 p < 0.01	r = 0 p = 1	r = 0.48 p = 0.26	r = -0.66 p = 0.1
Right tibia	r = 0.94 p < 0.01	r = 0.81 p < 0.01	r = 0.30 p = 0.3	r = 0.34 p = 0.09	r = 0.92 p < 0.01	r = 0.81 p < 0.01
Left tibia	r = 0.74 p < 0.01	r = 0.77 p < 0.01	r = 0.46 p = 0.1	r = 0.29 p = 0.14	r = 0.74 p = 0.07	r = -0.82 p < 0.01

be desirable in some cases, taking into consideration the rebound phenomenon.

ROC of the femur was found to be significantly faster than that of the tibia; 0.85° compared with 0.78°/month, respectively. Previous data¹⁷ shows that growth rate of the distal femoral growth plate is 9 mm per year while the growth rate of the proximal tibial growth plate is 6 mm per year. Our findings correlate with previous studies; Ballal et al¹⁸ found in their study of 25 children (51 idiopathic physes) a mean ROC of 0.7° per month in the distal femur and of 0.5° per month in the proximal tibia.

To the best of our knowledge, our study presents the first evidence for higher ROC of valgus compared with varus femoral deformity. Success rate was similar in varus and valgus deformity.

We found that the younger the child, the better the chance to achieve correction: girls under the age of 12 years and boys under the age of 14 years had a statistically significant better chance at achieving full correction for both the femur and tibia. These findings correlate with previous data from Guzman et al¹⁹ who found in their study of 47 idiopathic physes, that girls under the age of 11 years and boys under the age of 13 years achieved correction at a rate of 4.5° per year, while older children achieved correction at a rate of 3.4° per year.

No hardware failure was observed in this study, most probably due to the homogenic characteristics of the group. Previous studies report on hardware failure mainly when using the hemiepiphyodesis for pathological physes.²⁰ Complication rate for idiopathic patients is usually low; in a recent review by Shabtai and Herzenberg⁷ the complication rate was 4% (ten accumulated cases in 250 knees).

We were able to calculate and validate a constant which appears to predict the amount of correction over time and enable more precise follow-up. This constant is based on average ROC multiplied by the number of months from initial surgery.

A statistically significant correlation was found between calculated and actual mL DFA in valgus deformity during the first year of correction. Calculated mL DFA of varus

deformity did not correlate with the actual mL DFA. The reason for this difference may be the small number of patients with varus deformity (21 patients with varus compared with 157 patients with valgus). Correlation was also found between calculated and actual mMPTA in valgus deformity during the first eight months of correction and in varus deformity correction during the entire follow-up period.

This validated constant can be used when evaluating patients before surgical intervention to determine the timing of the surgery. It is limited in its accuracy for the first year post-surgery in the case of distal femur, and to about eight months in the proximal tibia.

The multiplier method (MM) described by Aguilar et al²¹ is a simple and accurate method for discrepancy predictions and outcome of full epiphyodesis to correct leg-length discrepancy. Recently, Eltayeb et al²² published a study that aims to validate the MM in predicting the timing of angular correction with hemiepiphyodesis in patients with coronal plane deformities. They found that the MM has a tendency to under predict. The constant described in our study is another tool which appears to predict the amount of correction of angular deformities around the knee by hemiepiphyodesis and enable more precise follow-up.

There are few limitations in our study that should be acknowledged: deformity analysis of all radiographs was done in each centre by a designated investigator using the TraumaCad software. The investigators included paediatric orthopaedic surgeons as well as residents in orthopaedic surgery. This method has been proven as a reliable tool in terms of intra- and interobserver variability as shown in Segev et al.⁹ In their study, five paediatric orthopaedic surgeons measured 50 digital radiographs on three separate days using the TraumaCad system and found that there were no clinically significant biases, and that the variability between specialists and residents was non-significant. As a retrospective study, follow-up meetings and radiograph frequency differed according to the physician preference.

Data collected did not include measurement of mechanical axis deviation which primarily affects the knee but also has an effect on the hip, ankle and subtalar joints.²³ This

study is focused on coronal plain deformities around the knee – distal femur and proximal tibia – and those are better represented by the mL DFA and the mMPTA, respectively. We were unable to assess rebound growth due to insufficient follow-up data in some of the patients. The rebound phenomenon requires further study, but since it is a simple and well tolerated procedure, it does not preclude repeating the treatment if it occurs.⁵

Conclusions

This study confirms that success rate using guided growth by TBP in idiopathic coronal plane deformity around the knee is high. It gives the first evidence for higher ROC of valgus compared with varus femoral deformity. Valgus correction in the distal femur and proximal tibia in idiopathic patients is highly predictable. Varus correction in the tibia was found to be highly predictable too. A constant derived for calculating ROC may be useful in the clinical setting. Patients with more than three years of growth had a better chance to achieve full correction.

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COMPLIANCE WITH ETHICAL STANDARDS

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OA LICENCE TEXT

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ETHICAL STATEMENT

Ethical approval: This is a retrospective multicentre study conducted at five centres. In each centre, approval was obtained from the local institutional review board. 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 not required for this study.

ICMJE CONFLICT OF INTEREST STATEMENT

RR has received royalties from Merete Medical and has a patent PCT/DE2014/100115 with royalties paid.

JEH is a consultant for the following companies: Orthofix, Orthopediatrics, Smith Nephew, Nuvasive, Wish Bone Medical. The following organizations supported his institution: Avitus Orthopaedics, CyMedica Orthopedics, DePuy Synthes, Johnson Controls, MHE Coalition, NuVasive Specialized Orthopedics, Orthofix, OrthoPediatrics, Paragon 28, Smith & Nephew, Stryker, Vilex and Zimmer Biomet.

UN is a member of the AO Foundation-Pediatric Expert Group.

All other authors have no conflict of interest to declare.

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AUTHOR CONTRIBUTIONS

BD: Study design, Measurements, Statistical analysis, Manuscript preparation.

RR: Measurements.

JEH: Measurements.

LS: Measurements.

FG: Measurements.

UN: Study design.

ES: Study design.

SW: Study design, Manuscript preparation.

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