ORIGINAL ARTICLE

Tension-band Plating for Leg-length Discrepancy Correction

Jaap J Tolk[1], Rajiv Merchant[2], Peter R Calder[3], Aresh Hashemi-Nejad[4], Deborah M Eastwood[5]

Abstract

Aim: Dual tension-band plates are used for temporary epiphysiodesis and longitudinal guided growth. The study aim was to assess rate of correction, to identify development of femoral and tibial intra-articular deformity during correction and to document resumption of growth after plate removal.

Materials and methods: A retrospective study of 34 consecutive patients treated with dual tension-band plates between 2012 and 2020 was performed. Twenty-four patients had surgery at the distal femur, six at the proximal tibia and four at both. Twenty-five female patients were treated at a mean age of 11.6 (±1.4) years and nine male patients at 13.5 (±1.5) years. Measurements were performed on standardised long-leg radiographs and included leg-length discrepancy (LLD), joint line congruency angle (JLCA), tibial roof angle, femoral floor angle and notch-intercondylar distance. Measurements were taken pre-operatively, at the end of discrepancy correction and at skeletal maturity.

Results: The LLD reduced by a mean of 12.9 mm (95% CI 10.2–15.5) with the mean residual difference 8.4 mm (95% CI 5.4–11.4). The mean correction rate for the proximal tibia was 0.40 (SD 0.33) mm/month and 0.68 (SD 0.36) mm/month for the distal femur. A significant mean change in residual LLD [−2.5 mm (95% CI −4.2 to −0.7)] was observed between plate removal and skeletal maturity at the femoral level only. After length discrepancy correction, the tibial roof angle showed a significant difference of 8.4° (95% CI 13.4–3.4) between legs. In femoral epiphysiodesis patients, no important differences were observed.

Conclusion: A significant reduction in LLD can be achieved using dual tension-band plating. A change in intra-articular morphology was observed only in the proximal tibia and not in the distal femur. In the authors' opinion, tension-band plating is a useful tool for leg-length equalisation but should be reserved for younger patients or when residual growth is difficult to predict. It is one of the management strategies for limb-length difference prior to skeletal maturity.

Keywords: Epiphysiodesis, Guided growth, Leg-length discrepancy, Tension-band plating.

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Introduction

Leg-length discrepancy (LLD) potentially induces gait disturbance, lower back pain and a reduced quality of life[1,2] but there is no reliable threshold that distinguishes a discrepancy that will cause symptoms from one that will not.[2] In clinical practice a predicted discrepancy of 2 cm or more at skeletal maturity is often used as an indication for surgical leg-length equalisation.[2] For length discrepancies between 2 and 5 cm, equalisation is achieved frequently with an epiphysiodesis of the longer leg at the distal femur, proximal tibia or both.[3]

Several surgical techniques for epiphysiodesis have been described and most produce an irreversible complete arrest. Dual tension-band plates are used as a means of temporary epiphysiodesis for longitudinal guided growth.[4–6] A growth modulating effect can be expected although the growth limiting effect is reported to be slower and less predictable as compared with definitive surgical physeal ablation.[4,6,7] When compared to other means of temporary epiphysiodesis (e.g. Blount staples), no difference in correction rate or residual LLD is reported.[8] When rigid staples are used in LLD correction, concerns have been raised regarding the reversibility of the epiphysiodesis. Potentially, a complete growth arrest is induced due to the rigid physeal compression.[9,10] LLD correction with tension-band plates aims for a growth deceleration rather than a complete growth stop with potentially less risk of complete physeal arrest.[9,11] To date, ongoing growth after tension-band plate removal has not yet been quantified.

In a combined group of angular and leg-length correction cases, Sinha et al. observed a 'volcano' type deformation of the proximal tibia and raised a concern that this might create an intra-articular deformity of the proximal tibia.[12] This observation was attributed to medial and lateral tethering by the tension-band plates, with ongoing central physeal growth and was most marked in the leg-length correction sub-group. Currently these findings have not

[1]Department of Orthopaedics and Sports Medicine, Erasmus MC–Sophia Children's Hospital, Rotterdam, South Holland, Netherlands; Catterall Unit, Royal National Orthopaedic Hospital, Stanmore, United Kingdom

[2]Catterall Unit, Royal National Orthopaedic Hospital, Stanmore, United Kingdom; Department of Trauma and Orthopaedics, Norfolk and Norwich University Hospitals NHS Foundation Trust, Norwich, United Kingdom

[3,4]Catterall Unit, Royal National Orthopaedic Hospital, Stanmore, United Kingdom

[5]Catterall Unit, Royal National Orthopaedic Hospital, Stanmore, United Kingdom; Department of Orthopaedics, Great Ormond Street Hospital for Children, London, United Kingdom

Corresponding Author: Jaap J Tolk, Department of Orthopaedics and Sports Medicine, Erasmus MC–Sophia Children's Hospital, Rotterdam, South Holland, Netherlands; Catterall Unit, Royal National Orthopaedic Hospital, Stanmore, United Kingdom, e-mail: j.tolk@erasmusmc.nl

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been confirmed and no previous analysis has reported on whether a similar articular change occurs on the femoral side of the joint. Reassuringly, Ballhause et al. reported that for patients treated with eight plates for angular deformities only, no such deformity of the joint surface was observed.[13]

The aim was to assess the rate of correction of LLD, the occurrence of intra-articular deformity during femoral and tibial dual tension-band plating, and the restoration of normal growth after plate removal. The results may define the role of dual tension-band plating in the strategies used for limb-length equalisation.

Materials and Methods

A retrospective study of consecutive patients treated with dual tension-band plates in our institution during the period 2012–2020 was performed. The Royal National Orthopaedic Hospital institutional ethical review board assessed and approved this study (registration number SE21.03).

Patients in whom dual tension-band plates were used for correction of a leg-length difference, on either the distal femur or proximal tibia or both, were included. Patients were excluded if appropriate long leg films were not available before and after leg-length correction or if they had undergone any other leg-length correction procedure during the guided growth period. Those that had had a previous or concomitant injury or intervention to the contralateral proximal tibia or distal femoral physes that would affect longitudinal growth were also excluded.

Surgical Technique

The medial and lateral sides of the distal femur or proximal tibia were approached through approximately 2 cm longitudinal skin incisions, taking care not to disturb the periosteum. The middle of the physis was visualised both in the coronal and sagittal plane with fluoroscopy and marked using a 1.6 mm smooth K-wire. A tension-band plate (8-plate, Orthofix, Inc, Lewisville, Texas) was then placed over the K-wire and a suitable sized plate was chosen to allow for appropriate screw position without disturbing the joint surface or the physis. In the sagittal plane we aimed for tension-band positioning central on the physis in antero-posterior direction and in line with the longitudinal anatomic axis of the affected bone. Guidewires were placed through the screw holes in the plate, aiming for slight divergence but without disturbing the physis. Theoretically the advantage of divergent screws is correction without a lag period; as such this position was deemed most suitable when tension-band plates are used for leg-length correction. This is in contrast to the use of tension-band plates in hemi-epiphysiodesis for angular correction, where parallel screw positioning is advocated.[9,11] Plate and guidewire positioning position was verified using fluoroscopy. The cortex was drilled over the guidewires with a cannulated drill. Screw sizes were measured and subsequently inserted over the guidewires. Care was taken to position the plate adjacent to the periosteal surface to minimise three-point screw bending and risk of screw breakage.[11] The guidewires were removed, and the screws were tightened further. Final fluoroscopic examination of the screw and plate position was performed followed by a layered wound closure and application of a sterile dressing. Postoperative instructions included weight-bearing as tolerated and radiographic follow-up with AP and lateral knee X-rays at 6 weeks postoperative, long leg films at 3 months and every 6 months thereafter, with individualised follow-up frequency depending on desired growth inhibition and correction speed observed.

Patient Demographics

Demographics regarding patient gender, body mass index (BMI), age at plate insertion and plate removal, underlying pathology leading to the LLD and complications during and after the guided growth period were obtained from the electronic patient files.

Radiographic measurements were performed on calibrated, standardized long-leg radiographs. Patients were positioned with knees fully extended and the patellae facing forward.

Radiological measurements were obtained at three time points. Pre-operatively (T0), at the end of length correction (T1, the last X-ray before plate removal) and at most recent review or skeletal maturity (T2). Skeletal maturity was defined as bilateral closure of both the distal femoral and proximal tibial physes on radiographic evaluation.

Leg-length Measurements

Both the affected and the contralateral sides were evaluated. Leg length and mechanical axis measurements were performed using TraumaCad software (version 2.5, Brainlab Ltd. Petach-Tikva, Israel) and reported in millimetres (mm).[14] Total leg length was measured between the most proximal part of the femoral head and centre of the distal tibial surface. Tibial length was measured between a point between the tibial eminences and the centre of the distal tibial surface. Femoral length was measured between the most proximal part of the femoral head and the intercondylar notch.[14]

Articular Morphology Measurements

For the assessment of the proximal tibial articular surface, the medial and lateral slope angles were measured as the angle between the plateau surface and the line between the ends of the physis.[12,13] From these measurements the tibial roof angle is calculated by deducting the sum of tibial slope angles from 180° (Fig. 1).[12,13]

To quantify distal femoral articular changes, the notch intercondylar distance and the femoral floor angle were obtained. The notch intercondylar distance is defined as the distance between the most proximal point of the femoral notch to a line through the most distal part of the femoral condyles (Fig. 2A).[15] In analogy with measurement of the tibial roof angle,[12] we quantified the shape of the distal femur on standing AP radiographs using the 'femoral floor angle'. This consists of measurements of 'medial and lateral femur condyle slope angle', defined as the angle between a line through the ends of the distal femoral physis and

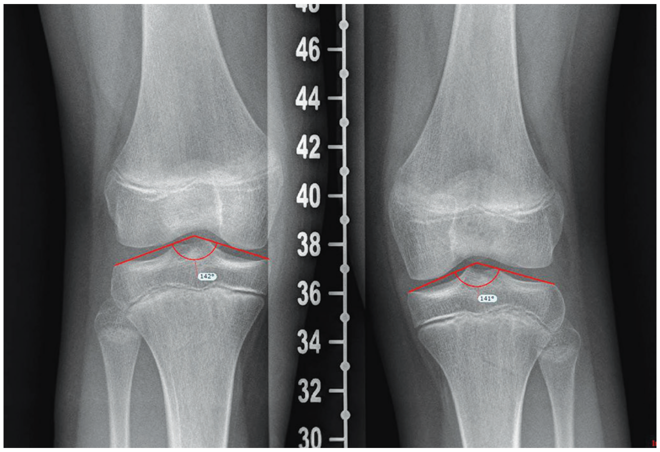
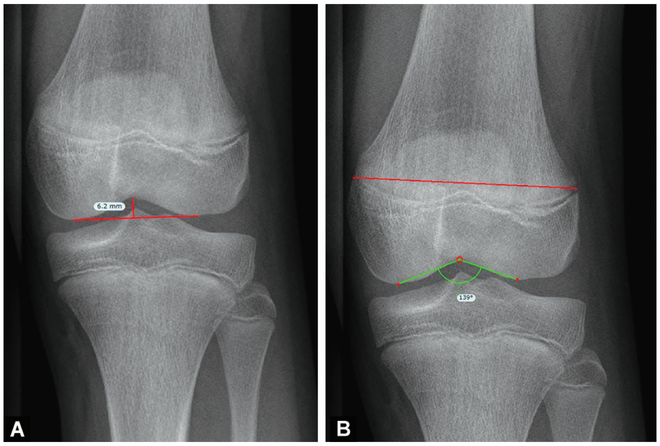


Fig. 1: Radiograph of the knee showing the tibia roof angle



Figs 2A and B: (A) Radiograph of the knee showing the notch-intercondylar distance; (B) Radiograph of the knee showing the femoral floor angle

Table 1: Reliability analysis of non-standardised radiographic measures

	ICC	*95% CI*
Tibial roof angle	0.852	(0.779–0.900)
Femoral floor angle	0.546	(0.325–0.695)
Notch intercondylar distance	0.886	(0.831–0.923)
Screw divergence angle	0.951	(0.916–0.971)

ICC two-way random effects model for absolute agreement. ICC, intra-class correlation coefficient; 95% CI, 95% confidence interval

the line through the most distal surface of the femoral condyle and the top of the femoral notch. The femoral roof angle is then calculated by deducting the sum of femoral slope angles from 180° (Fig. 2B).

The inter-screw divergence angles were measured for medial and lateral screws for each plate implanted.[12] Positive values reflected diverging screws.[12] For analysis, the combined tibial screw and combined femoral screw angles were calculated as (medial + lateral screw angle) for tibia and femur, respectively.

Mechanical axis deviation (MAD) was measured as the distance in mm between the centre of the knee and the mechanical axis.[16] JLCA was measured as the angle between the line through the most distal points of each femoral condyle and the line through the medial and lateral tibial plateau.[17]

To assess reliability of the outcome parameters that are not standardized in TraumaCad (tibial roof angle, femoral floor angle, notch intercondylar distance and screw divergence angle) these measures were obtained independently by two of the authors (RM and JT) for all patients. Intra-rater reliability was calculated on 136 measurements (bilateral measurements on radiographs before and after length correction for each of the 34 patients), using two-way random effects models for absolute agreement and presented as intra-class correlation coefficients (ICC) (Table 1). For outcome analysis the average score of the two assessors for each parameter was used.

Statistical Analysis

For descriptive statistics of continuous variables, means with standard deviation were reported. For discrete variables counts and percentages are presented.

Mean leg-length differences were calculated for each of the leg segments measured (total leg length, femoral length and tibial length) and reported as mean differences with 95% confidence intervals for each time point. Length differences were compared between T0 and T1 and between T1 and T2 using the paired samples *t*-test. The rate of correction was calculated for each segment as the change in segment length divided by correction time and presented as mm/month.

Measures of changes in intra-articular morphology between the affected and unaffected leg were compared using the paired samples *t*-test on radiographs taken before (T0) and at the end of leg-length correction (T1). For analysis of tibial measurements, only patients who had proximal tibial temporary epiphysiodesis were included and, for the analysis of femoral changes, only data from distal femoral temporary epiphysiodesis patients were used.

Growth after tension-band plate removal was assessed in the subgroup of patients that were not skeletally mature at T1 and who had X-rays available at skeletal maturity. The LLD at T1 and T2 was compared using a paired samples *t*-test.

The relationship of screw length and screw divergence at implantation with leg-length correction rate was analysed and assessed by calculating Pearson's correlation coefficients.

Results

Forty-two patients were identified who had undergone dual tension-band plating for management of their LLD of which 34 were eligible for analysis as outlined in Flowchart 1. In total 24 patients had temporary epiphysiodesis of the distal femur, 6 of the proximal tibia and 4 of distal femur and proximal tibia. The demographics are presented in Table 2; most patients are female and the mean age at plate insertion was 12.1 (±1.7) years. A range of pathological conditions were responsible for the LLD but developmental dysplasia of the hip was most common in this cohort (Fig. 3).

The LLD before plate insertion and at the end of the correction period are presented in Table 3. The mean total reduction was 12.9 mm (95% CI 10.2–15.5), and the mean residual LLD was 8.4 mm (95% CI 5.4–11.4). The mean correction rate for proximal tibial temporary epiphysiodesis was 0.40 (SD 0.33) mm/month and 0.68 (SD 0.36) mm/month for temporary epiphysiodesis of the distal femur.

Measurements of tibial articular morphology are presented in Table 4. At baseline none of the parameters showed a significant between-leg difference. At the end of length correction, the tibial roof angle did show a significant difference of 8.4° (95% CI 13.4–3.4, $p = 0.004$) between the operated and non-operated legs.

For the measurements of articular changes in patients with femoral epiphysiodesis, only the notch-intercondylar distance was significantly different at the end of length correction; 0.5 mm (95% CI 0.06–0.9) greater on the operated leg compared to the non-operated side (Table 5). The other measures did not show a significant difference at baseline or at plate removal.

For the analysis of growth after tension-band plate removal, we reviewed the cohort of 19 patients who were not skeletally mature at T1 and who had a further assessment (T2). The total residual LLD and tibial length difference in the tibial dual plating group increased slightly between T1 and T2 over a median period of 16.3 (IQR 7.9–33.0) months (Table 6). This change was not significant. On the femoral side, a significant change in LLD was observed between plate removal (T1) and most recent review (T2); there was a mean

Flowchart 1: Flow diagram of included and excluded patients

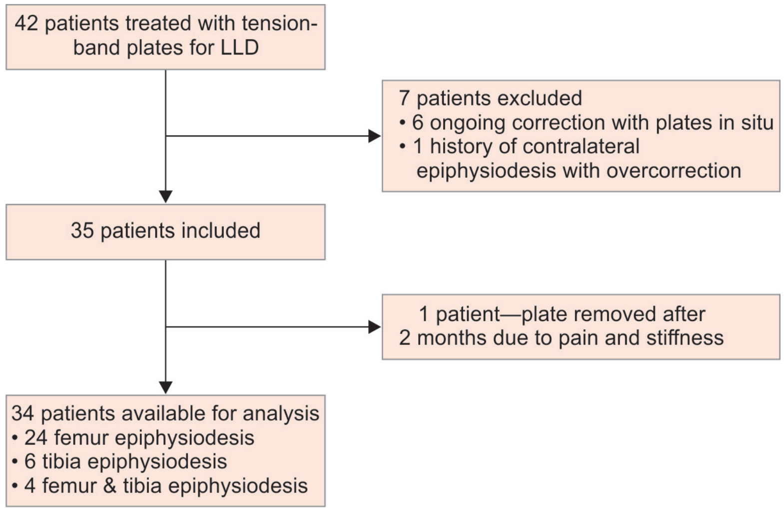


Table 2: Patient characteristics

Gender, female [*n* (%)]	25	(73.5%)
BMI	20.2	(±4.5)
Side, right [*n* (%)]	15	(44.1%)
Age at implantation (years)	12.1	(±1.7)
• Male	13.5	(±1.3)
• Female	11.6	(±1.5)
Plates removed	29	(85.3%)
Correction time (months)		
• Femur	17.6	(±5.6)
• Tibia	22.0	(±6.5)
Underlying pathology		
• DDH	14	(41.2%)
• Legg-Calvé-Perthes disease	7	(20.6%)
• Hemi-hypertrophy	4	(11.8%)
• CTEV	4	(11.8%)
• Cerebral palsy	2	(5.9%)
• HME	1	(2.9%)
• Mosaic Turner syndrome	1	(2.9%)
• SUFE	1	(2.9%)

Data presented as mean and standard deviation between brackets or as number of cases and percentage between brackets as specified. Correction time; mean time between tension-band plate insertion and removal. BMI, body mass index; DDH, developmental dysplasia of the hip; CTEV, congenital talipes equinovarus; HME, hereditary multiple exostosis; SUFE, slipped upper femoral epiphysis

decrease of 2.5 mm (95% CI 0.7–4.2). This change in the residual LLD suggests the distal femoral physis in the longer leg has not resumed a normal rate of growth (Table 6). Overall, after plate removal an average longitudinal growth up to skeletal maturity of 12.8 (SD 12.0) mm for the femur and 11.0 (SD 9.0) mm of the tibia was observed (Table 6).

The mean screw divergence at implantation was 2.0° (SD 9.1) for the medial tibial screws, 3.5° (SD 8.8) for the lateral tibial screws, 6.4° (7.6) for the medial femoral screws and 3.8° (6.1) for the lateral femoral screws. Mean screw length was 22.2 mm (SD 2.9) for the tibia and 25.8 mm (SD 4.0) for the femur. Screw divergence and screw length showed no significant correlation with the leg-length correction rate in either the tibia or the femur (Table 7).

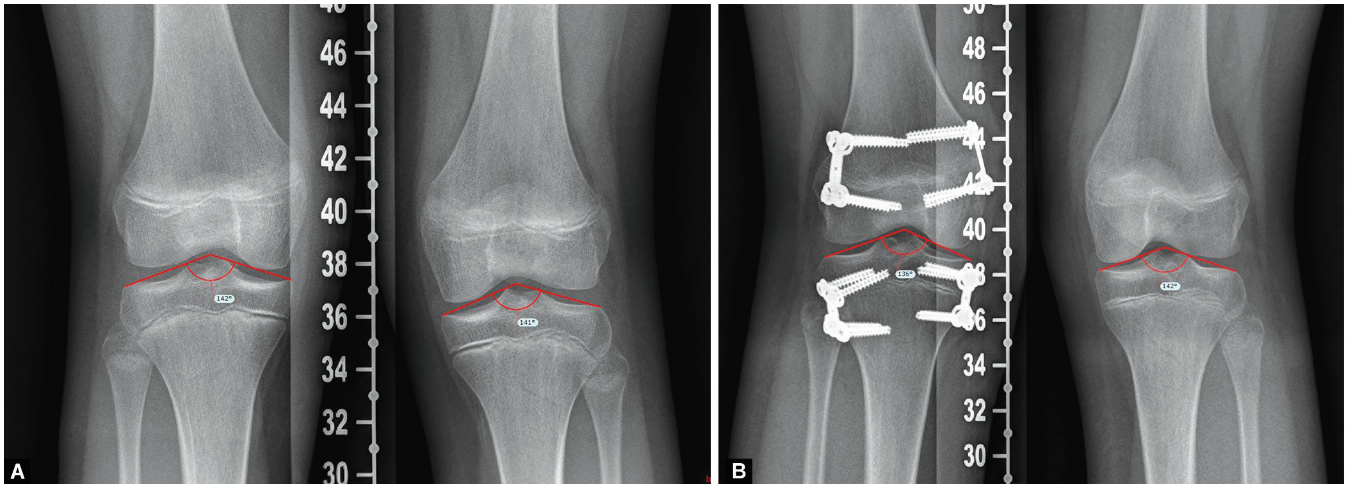
Complications were reported in 12 patients (35.3%). Seven patients reported knee pain and limitation in range of motion. In six patients this resolved with time and physiotherapy but in one patient severe pain and stiffness led to plate removal and manipulation under anaesthesia to regain knee joint movement at 2 months after plate insertion. In five cases there was evidence of screw bending but this did not create problems at screw removal. In one patient a screw migrated through the medial proximal tibia physis during correction; at removal, a definitive physeal ablation was performed to prevent secondary angular deformity.

Discussion

The present study shows a significant reduction in LLD can be achieved using temporary epiphysiodesis with dual tension-band plating. Measures of intra-articular morphology showed a significant change only in the proximal tibial epiphysiodesis group, whereas no important changes were observed in those undergoing distal femoral epiphysiodesis. No significant rebound overgrowth effect was observed following plate removal. On the contrary, growth at the distal femoral physis remained reduced as compared to the contralateral side.

Previous studies showed that the rate of correction after temporary epiphysiodesis is slower than after surgical physeal ablation.[4–6] This is confirmed here, with a correction rate of 0.40 mm/month (4.8 mm/year) for proximal tibial and 0.68 mm/month (8.2 mm/year) for distal femoral temporary epiphysiodesis. This is slightly less than the average growth of 6 and 10 mm/year of the proximal tibia and distal femur, respectively, that could be expected without any intervention.[18] Suggested explanations for an incomplete growth inhibition are that growth is inhibited but not completely stopped or that there is a lag period before growth inhibition occurs.[9]

On the basis of this lower efficacy as compared to other methods, some authors have discarded the use of tension-band plates for length correction completely.[4–6] Nevertheless, the speed of inhibition of longitudinal growth by itself might not be the most important benefit with this technique; the timing of the procedure is considered too. As stated by Stevens, the goal is to produce growth deceleration and not growth arrest.[9] When used appropriately, dual tension-band plating relies less on the precise determination of skeletal age and growth remaining[9] especially as growth can be



Figs 3A and B: Example of a patient treated with dual tension-band plating of both the distal femur and the proximal tibia. Pre-operative tibial roof angles were similar between the operated and the non-operated leg, whereas after leg-length correction the tibia roof angle was considerably lower on the operated side compared to the contralateral side. This resembles a 'volcano'-type deformity

Table 3: LLD before and after leg-length correction

	T0		*T1*		*Change*		*p value*
Total LLD*	21.3	(8.7)	8.4	(8.5)	−12.9	(−10.2 to −15.5)	<0.001
Tibial difference†	13.8	(4.8)	6.0	(6.0)	−7.8	(−4.1 to −11.5)	0.001
Femoral difference‡	17.1	(7.6)	5.5	(9.4)	−11.6	(−9.1 to −14.1)	<0.001

All differences in millimetres, positive values reflect a longer operated leg. Comparisons using paired samples *t* test. LLD, leg-length difference. *Data for complete cohort, $n = 34$. †Data for tibia epiphysiodesis patients only, $n = 10$. ‡Data for femur epiphysiodesis group only $n = 28$

Table 4: Change in intra-articular morphology in the tibial group with temporary epiphysiodesis ($n = 10$)

	Long leg (operated)		*Shorter leg (non-operated)*		*Between leg difference*		*p value*
Tibial roof angle (°)							
Plate insertion – T0	143.8	(3.8)	144.6	(4.7)	0.8	(−1.9 to 3.5)	0.519
Plate removal – T1	138.5	(7.3)	146.9	(4.2)	8.4	(3.4 to 13.4)	0.004
JLCA (°)							
Plate insertion – T0	1.4	(0.8)	0.7	(1.1)	−0.7	(−1.7 to 0.3)	0.132
Plate removal – T1	1.7	(0.7)	1.2	(0.4)	−0.5	(−1.0 to 0.1)	0.052
MAD (mm)							
Plate insertion – T0	5.6	(9.9)	6.9	(3.1)	1.3	(−3.6 to 6.2)	0.562
Plate removal – T1	8.5	(11.8)	9.6	(8.1)	1.1	(−4.2 to 6.4)	0.653

Values presented as mean with standard deviation for absolute values and mean with 95% confidence interval for between leg differences. T0, baseline measurement; T1, time of tension-band plate removal. Comparisons using paired samples *t* test. JLCA, joint line congruency angle; MAD, mechanical axis deviation

expected to resume after plate removal.[7] In our opinion this makes the technique especially useful in pathologies where calculating remaining growth is difficult and in young children with a significant and increasing LLD. Overall this cohort had an LLD that was under-corrected, highlighting the recognition that the rate of correction is slow with the dual tension-band plating technique. Thus the timing of the procedure is crucial if the aim is limb-length equalisation rather than simply a reduction in the discrepancy and when the contralateral limb may be the pathological leg with a lower than average growth potential.

The analysis of morphological changes in the proximal tibia showed the tibial roof angle was significantly different between the operated and non-operated leg after tension-band plating for a temporary epiphysiodesis. This measured a mean 8.4° lower on the operated leg which would be consistent with the 'volcano type' change observed in an earlier report.[12] This supports the theory that whilst the tension-band plates result in a medial and lateral tether, they do not prevent ongoing central physeal growth. It has been suggested that these changes might lead to instability or joint incongruency[12] but the clinical implications of this change are not clear. None of our patients reported long-term knee complaints or instability. Further research on the clinical interpretation and long-term effects, if any, of this finding is warranted.

An analysis on potential articular changes on the femoral side after dual tension-band plating has not been reported before. Somewhat surprisingly, the changes observed on the tibial side were not replicated in our analysis of femoral morphology where the physis has a faster growth rate. Central overgrowth leading to a decrease of notch height was not observed. On the contrary, a significant but small [0.5 mm (95% CI 0.06–0.9)] increase in notch intercondylar

Table 5: Change in intra-articular morphology in the femoral group with temporary epiphysiodesis ($n = 28$)

	Long leg (operated)		*Shorter leg (non-operated)*		*Between legs difference*		*p value*
Femoral floor angle (°)							
Plate insertion – T0	142.7	(3.9)	143.7	(3.9)	1.0	(–0.2 to 2.2)	0.088
Plate removal – T1	140.3	(5.8)	140.9	(5.3)	0.6	(–1.7 to 2.6)	0.604
Notch intercondylar distance (mm)							
Plate insertion – T0	6.6	(1.4)	6.6	(1.2)	0.0	(–0.3 to 0.3)	1.000
Plate removal – T1	7.7	(1.6)	7.2	(1.4)	–0.5	(–0.9 to 0.06)	0.023
JLCA (°)							
Plate insertion – T0	1.4	(1.3)	1.2	(0.9)	–0.2	(–0.8 to 0.4)	0.456
Plate removal – T1	1.4	(1.3)	0.9	(0.9)	–0.5	(–1.1 to 0.1)	0.075
MAD (mm)							
Plate insertion – T0	4.1	(8.7)	3.1	(8.4)	–0.9	(–3.9 to 2.1)	0.530
Plate removal – T1	2.6	(13.6)	2.3	(10.8)	–0.3	(–3.3 to 2.7)	0.845

Values presented as mean with standard deviation for absolute values and mean with 95% confidence interval for between leg differences. Comparisons using paired samples *t* test. T0, baseline measurement; T1, time of tension-band plate removal; JLCA, joint line congruency angle; MAD, mechanical axis deviation

Table 6: LLD after leg-length correction (at plate removal) and at most recent review

	Plate removal – T1		*Skeletal maturity – T2*		*Change*		*p value*
Total LLD*	4.2	(6.6)	3.2	(5.7)	–1.1	(–2.7 to 0.6)	0.179
Tibial difference†	2.2	(3.0)	5.2	(3.1)	3.0	(–0.6 to 6.6)	0.083
Femoral difference‡	3.4	(8.6)	0.9	(8.3)	–2.5	(–4.2 to –0.7)	0.010

All differences in millimetres. Values presented as mean with standard deviation for absolute values and mean with 95% confidence interval for between leg differences. Comparisons using paired samples *t* test. T1, time of tension-band plate removal; T2, skeletal maturity; LLD, leg-length difference. *Data for complete cohort, $n = 19$; †Data for tibia epiphysiodesis patients only, $n = 8$; ‡Data for femur epiphysiodesis group only $n = 15$

Table 7: Analysis of relationship between screw divergence and leg-length correction rate

	Pearson correlation coefficient	*p value*
Medial tibial screw divergence	–0.369	0.294
Lateral tibia screw divergence	–0.381	0.278
Combined tibial screw divergence	–0.203	0.574
Screw length tibia	0.176	0.627
Medial femoral screw divergence	0.043	0.828
Lateral femoral screw divergence	0.137	0.488
Combined femoral screw divergence	0.103	0.601
Screw length femur	0.101	0.609

Pearson correlation coefficients of specified measurements with tibia correction rate for tibia screw measurement and femur correction rate with femur screw measurements

distance was seen in the distal femoral epiphysiodesis group. The other measures of femoral articular morphology (femoral floor angle and JLCA) did not show a between leg difference after length correction. The reasons for this discrepancy between tibial and femoral morphological changes are not clear.

The results on the distal femoral morphology might have been influenced by the reliability of the measurement methods used. The femoral floor angle, developed for this analysis in the present study, showed only moderate reliability. This could have had a negative influence on the sensitivity to measured change. Therefore, in the study design, all measures of articular morphology were assessed by two independent observers and multiple parameters of articular change were used for the femoral analysis. The other two outcome parameters used for distal femoral morphology changes (notch-intercondylar distance and JLCA) do have good reliability. As the results here did not support development of central physeal overgrowth, we concluded that a volcano type overgrowth does not occur on the femoral side.

Our results indicate growth resumed at both the proximal tibial physis and distal femoral physis after plate removal. Previous authors have suggested the potential for rebound growth after plate removal as identified as a significant change in LLD at later follow-up.[19,20] This rebound effect is known to occur after plate removal in hemi-epiphysiodesis for varus or valgus.[21,22] In line with previous animal studies,[7] we observed return of growth after implant removal. Nevertheless, after plate removal the distal femoral physis showed slightly slower growth on the affected side, compared to contralateral. Thus, with a residual LLD where the treated leg was long, the LLD continued to reduce over time following plate removal. Therefore, we do not recommend routinely overcorrecting leg-length difference when using tension-band plates.

It has been suggested that screw position and screw length might influence the rate of leg-length correction.[9,23] Parallel screw placement has been suggested to cause a lag time, and therefore divergent screw placement is advocated.[9,11,23] Our results do not reflect such an association; no relationship between screw divergence and rate of leg-length correction could be identified. Based on these findings the surgical technique can be considered quite forgiving with regards to meticulous divergent screw positioning; however, disturbing the physis or joint surface should obviously be avoided. We did not observe a relationship between screw length with correction rate. The use of smaller screws might increase the risk of migration through the physis during growth. This was an observed complication in one case but the 24 mm screw used in this patient was not shorter than average and probably not responsible for the occurrence of this complication.

Limitations

The limitations of this study include its retrospective nature, the relatively small numbers of mainly older children and the multiple underlying pathological reasons for the LLD. A limitation in the assessment of articular changes is we performed a two-dimensional analysis on changes in the coronal plane. Reassuringly, Balhause et al. reported no sagittal plane changes in a hemi-epiphysiodesis group,[13] although no femoral analysis was made in their study. As we did not routinely obtain lateral X-rays after implantation or removal, we could not analyse whether sagittal plane changes or changes to other dimensions of distal femur or proximal tibia occurred. Further analysis of potential three-dimensional changes would warrant further study with MRI or CT imaging modalities.

Conclusion

The present study does show that tension-band plating can be used successfully as one of the strategies for leg-length equalisation. It should be noted that the growth inhibiting effect is not complete. Therefore, when timing this procedure, we would recommend performing the operation earlier then would be indicated through the calculations used for permanent physeal ablation. The finding that continued growth can be expected after plate removal and that no rebound effect was observed supports this recommendation.

This technique poses the risk of a small but significant change in articular morphology of, as yet, uncertain clinical importance on the tibial side. In line with previous reports, we found complications especially postoperative pain and knee stiffness. This was more common than with other epiphysiodesis techniques and plate removal is common.[24] Tension-band plating is not our preferred technique for leg-length equalisation but may be part of the strategy for modifying an increasing discrepancy in the younger patient with an overgrowth syndrome or when residual growth is difficult to predict.

Orcid

Jaap J Tolk https://orcid.org/0000-0003-1685-7490
Rajiv Merchant https://orcid.org/0000-0002-7766-1953
Deborah M Eastwood https://orcid.org/0000-0002-6191-4768

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