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Prediction of loss of correction after hemiepiphysiodesis for the alignment of lower limb angular deformities

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Abstract

Guided growth by temporary hemiepiphysiodesis (HEPD) is established for the alignment of lower limb angular deformities. This retrospective cohort study was designed to assess the effect of HEPD in idiopathic coronal plane deformities around the knee and on the frontal knee joint line orientation, and to test the frontal knee joint line as predictive means for recurrence.

Fourty-four patients (78 deformities: valgus n = 64, varus n = 14) were enrolled in the retrospective observational study. Mechanical axis deviation, mechanical lateral distal femoral angle, and mechanical medial proximal tibial angle were assessed prior to surgery and during follow-up. The facultative frontal knee joint line angle (FKJLA) was used as predictive tool. Cases of remaining growth potential (n = 45/78) after implant removal were followed to assess rebound deformity.

Pre-operative angles of the mechanical axis were corrected average 9.0 months after HEPD. Pre-operative assessment of the frontal knee joint line revealed a mean of 3.9° in valgus, and –1.0° in varus deformities. At time of complete deformity correction, mean FKJLA was –0.2° in valgus, and –0.8° in varus deformities. Mean shift of FKJLA was significantly higher after singleHEPD compared to combiHEPD ($P < .001$). Patients having an unphysiological FKJLA (>/<0°–3°) after correction of mechanical axis had a significantly higher risk of rebound deformity ($P = .01$). Regression analysis showed a 60.5% higher risk of rebound deformity per each degree deviating from the FKJLA physiological range. Age, gender, or body mass index had no impact.

Temporary HEPD offers great potential for the correction of the mechanical axis and the frontal knee joint line. An unphysiological change of the frontal knee joint line is associated with a high risk of recurrent angular deformities. CombiHEPD instead of singleHEPD seems to be safer to prevent detrimental frontal knee joint line shift.

Level of Evidence: Retrospective comparative therapeutic study, Level III.

Abbreviations: FKJLA = frontal knee joint line angle, HEPD = hemiepiphysiodesis, JLCA = joint line convergence angle, MAD = mechanical axis deviation, mLDFA = mechanical lateral distal femoral angle, mMPTA = mechanical medial proximal tibial angle, ROC = rate of correction, SD = standard deviation, TFA = mechanical tibiofemoral angle.

Keywords: angular deformity, genu valgum, genu varum, growth modulation, hemiepiphysiodesis, pediatric orthopedics, prediction

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All data generated or analyzed during this study are included in this published article [and its supplementary information files].

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1. Introduction

Idiopathic angular deviations in the coronal plane of the knee are the prevailing deformities. To correct coronal plane deformities, Blount and Clarke[1] were the first to describe the principles of growth modulation using staples. In 2007, Stevens demonstrated the suitability of a tension band process for corrective guided growth in lower limb deformities.[2,3] At the present day, the technique of guided growth by temporary hemiepiphysiodesis (HEPD) is widely established. Literature available to date proofs this technique to be safe and effective as for correction of the mechanical leg axis (mechanical tibiofemoral angle [TFA], mechanical axis deviation [MAD]) and knee joint orientation angles (mechanical lateral distal femoral angle [mLDFA], mechanical medial proximal tibial angle [mMPTA]).[2,4,5]

The success rate of singular HEPD (singleHEPD: distal femoral or proximal tibial) and combined femorotibial approaches (combiHEPD) is high, and particularly the rate of correction (ROC) of valgus deformities is highly predictable.[6] Factors that significantly impact the outcome of HEPD such as age at index surgery or direction of deformity have been described previously.[7] Just as many studies available to date unveiled a rebound phenomenon with recurrent lower limb deformity after implant removal with patient age, time of correction, and pre-existing diseases being potential causes.[2,8–14] The underlying mechanisms remain unresolved yet.

Conceivably, non-physiological alterations of the mMPTA or the mLDFA upon therapy despite mechanical axis correction might lead to recurrence. However, measurement of mMPTA and mLDFA is dependent from the mechanical axis but does not respect the joint line convergence angle (JLCA), and mMPTA and mLDFA are deviating in valgus and varus deformities. This does not necessarily apply to the frontal knee joint line angle (FKJLA), which is an angle between the frontal center line of knee joints and the floor (depending on ankle position). According to Ashby and Eastwood,[12] the FKJL physiologically declines 0° to 3° medially (Fig. 1) corresponding to an *ideal* mLDFA of 88° and mMPTA of 87°. Non-physiological FKJLA is indicative of atypical load balancing and joint kinematics.

Therefore, the overall objective of this retrospective cohort study was to analyze the outcome of HEPD with respect to correction potential of both the TFA and the mechanical angles mMPTA and mLDFA. And to test the suitability of the facultative FKJLA for the assessment of the frontal knee joint line orientation at a glance. Moreover, we hypothesized that the FKJLA is a practical means to predict the follow-up and anticipate possible recurrence of deformity.

2. Materials and methods

2.1. Inclusion criteria

The present study was conceptualized in 2013. Patients who received guided growth by temporary HEPD at our department between 2006 and 2013 were identified. Idiopathic lower limb angular deformities in the coronal plane were retrospectively included as well as deformities secondary to different types of skeletal dysplasia or bone metabolism disorders such as multiple hereditary exostoses or phosphate diabetes. The use of eight-plates (Orthofix, Ottobrunn, Germany) and full medical history including physical examination and radiographs at individual

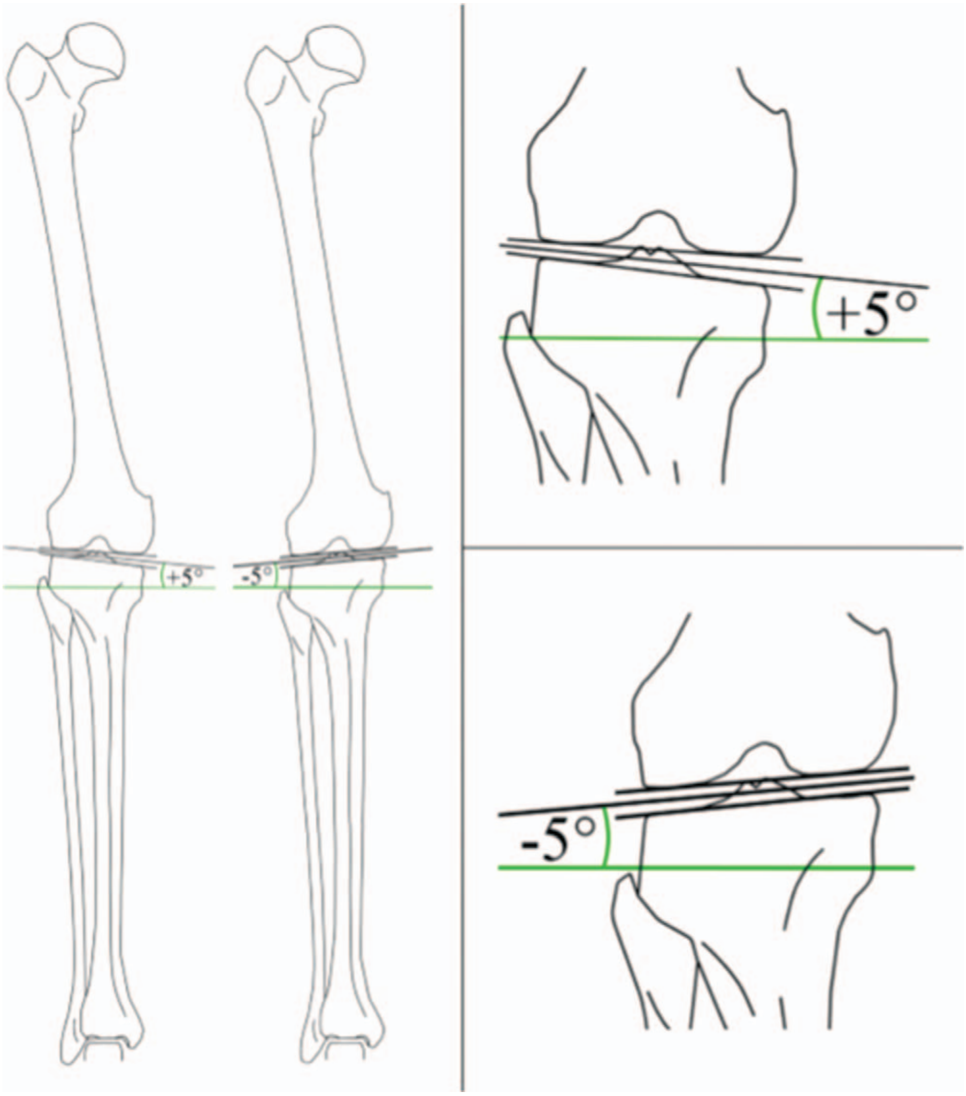

Figure 1. FKJLA is defined as angle between the frontal center line of knee joints (FKJL) and the horizontal respectively the floor. Physiologically, the FKJLA is medially descending corresponding to a value of 0° to 3°, whereas a laterally descending FKJLA is pathological expressed as negative values. Graphics represent examples of + and −5° FKJLA.

follow-up were mandatory. Exclusion criteria were multiplanar and rotatory deformities, and poor compliance.

2.2. Clinical assessment

Age, sex, and height were documented initially, at individual follow-up and prior to implant removal in order to determine correction potential in terms of time also. As for age, radiographs of the non-dominant hand were conducted and were analyzed according to Greulich and Pyle in cases of bone metabolism disorders. Physical examination including assessment of angular deformity and range of motion was done pre-operatively, post-HEPD at least quarterly, and prior implant removal. Postimplant removal, we followed patients with open physes at least for 6 months to assess rebound deformity eventually. Loss of correction relative to the correction measured prior to implant removal was defined as recurrent intercondylar or intermalleolar distance of 2 to 5 cm (mild) and ≥5 cm (requiring therapy). Only in the latter cases radiographs were taken for the sake of radiation protection.

2.3. Radiographs

Digital-based full-length anteroposterior weight-bearing radiographs of both limbs were taken immediately prior to surgery *and* implant removal. Therefore, patients were positioned truly anteroposterior with the ankles hip-width. Radiographs were assembled using the Ysio system and Syngo Workplace (Siemens Healthcare, Erlangen, Germany). The applied reference guide was 25 mm in diameter. Radiographs were evaluated using the IMPAX EE R20 Release XIII software (Agfa Healthcare, Düsseldorf, Germany). The Z620 Workstations (Hewlett Packard, Böblingen, Germany) and 2 EIZO Radioforce RX 340 monitors (Mönchengladbach, Germany) were used.

2.4. Radiological assessment

The MAD relative to the tibial plateau width, the mechanical TFA (valgus: positive values, varus: negative values), the JLCA, the FKJLA, the mLDFA, and the mMPTA were determined according to Paley and Herzenberg.[14] Shift over time and ROC per months and cm longitudinal growth were calculated. Differences (delta) during follow-up were calculated.

2.5. Surgical procedures

In this study, temporary HEPD was executed using eight-plates. Implants were placed either distal femoral medial or lateral, or proximal tibial medial or lateral (singleHEPD) always at the site of largest angular deformity (Fig. 2). Indications for combined femorotibial combiHEPD were pathological mechanical angles both distal femoral *and* proximal tibial. Another indication for combiHEPD were cases of advanced age and thus limited remaining growth potential. Implants were removed when deformity correction was accomplished.

2.6. Ethical statement

The study was approved by the institutional Ethical Committee (13-260A, 2013-12-13) and 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 was not required for this study.

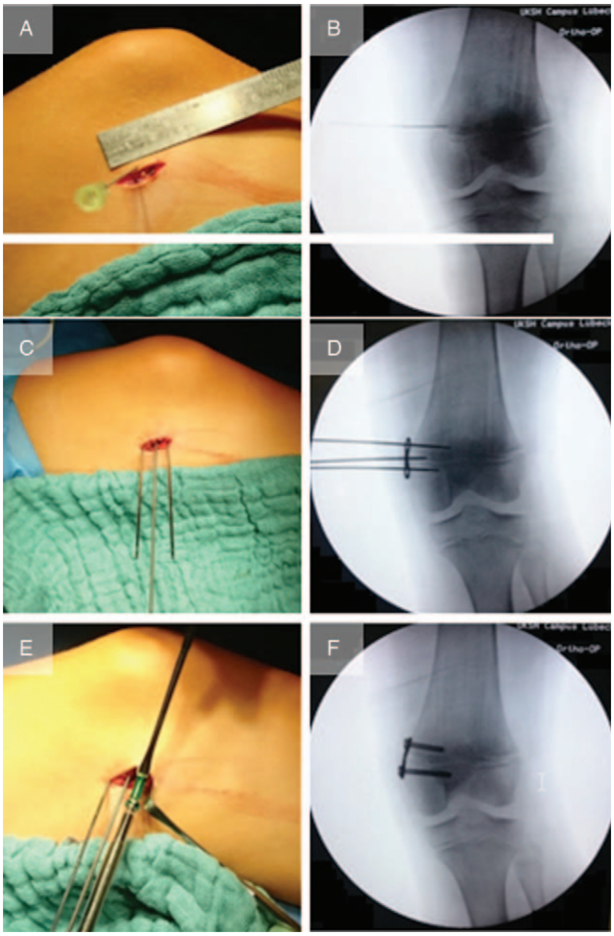

Figure 2. Case of a 12 year old female with idiopathic genu valgum due to a pathologic mLDFA. The physis was located under an image intensifier (A, B). Skin incision was followed by dissection down to the periosteum. The physis was located again using a first guide wire. The appropriate plate size was selected and the plate was placed over the guide wire down to the bone. Prior plate bending was optional. Using the drill guide, both the epiphyseal and the metaphyseal guide wire was inserted (C). Correct positioning of the wires was checked using fluoroscopy (D). Cannulated screws were consecutively inserted as the growth plate must not be penetrated (E). Correct screw and plate positioning was finally checked using fluoroscopy (F). Guide wires were removed followed by wound closure. mLDFA = mechanical lateral distal femoral angle.

2.7. Statistical analysis

Data were collected using a central web-based database. Statistical analysis was conducted using SPSS Vs. 2 (IBM, Hamburg, Germany). The data shown present mean ± standard deviation (SD). Box-and-whisker plots indicate variable outside the upper and lower quartiles. Binary regression analysis was conducted to estimate the relationship of various angles and loss of correction. Odds ratio, *P* values, and 95% confidence interval were calculated. The level of significance was set at $P < .05$.

3. Results

3.1. Demographics

Fourty-four patients (20 male, 24 female) with overall 78 angular deformities met the inclusion criteria and were enrolled in the retrospective cohort study. Thirty-eight patients respectively 69

Table 1

Fourty-four patients (20 male, 24 female) with overall 78 angular deformities met the inclusion criteria and were enrolled in the retrospective observational study. Deformities were predominantly idiopathic (88.5%).

	Patients		Deformities	
	n	%	n	%
Idiopathic & secondary	44	100	78	100
Male	20			
Female	24			
Idiopathic	38	86.4	69	88.5
Male	17			
Female	21			
Secondary	6	13.6	9	11.5
Male	3			
Female	3			

deformities were idiopathic, 6 patients respectively 9 deformities were secondary due to multiple hereditary exostoses (n=1) or phosphate diabetes (n=5). This summed up to overall 64 valgus and 14 varus angular deformities (Table 1). Mean age at time of surgery was 12.3±2.5 SD years (range: 2.6–15.8; male: mean 13.7±1.8 SD, range: 9.7–15.8; female: 11.2±2.4, range: 2.6–14.1). No significant differences were found for age ($P=.36$) and gender ($P=.94$). SingleHEPD was undertaken in 57 cases (distal femoral: n=44, proximal tibial: n=13). Combined femorotibial combiHEPD was undertaken in 21 cases (Table 2). Postimplant removal, we found n=45/78 deformities with open physes indicating remaining growth potential. These cases were followed at least 6 months to assess rebound deformity eventually.

3.2. Correction interval

Mean time until correction respectively implant removal was 9.0±5.6 months (range: 3–29 months). Mean time until correction in males was 10.8±6.6 months (range: 3–29 months) and in females 7.6±4.3 months (range: 3–22 months).

3.3. Mechanical axis

Complete ROC of mechanical axis was found in 71/78 of treated extremities. In 7/78 cases we found an improved mechanical axis yet no complete correction due to end of growth. In 5/78 cases overcorrection was observed that had to be addressed by contralateral HEPD. This resulted in a complete correction of the mechanical axis finally. Another 4/78 cases had a mild overcorrection that resolved spontaneously however.

Table 2

82% of all included deformities were genua valga. 73% of all deformities were treated with singleHEPD and mainly distal femoral (56% of all cases). CombiHEPD was indicated in 27% of all cases and necessary in 25% of all genua valga and in 36% of all genua vara.

	All deformities	Genu valgum	Genu varum
Total	78	64	14
Combihepd	21	16	5
SingleHEPD femoral	44	40	4
SingleHEPD tibial	13	8	5

HEPD = hemiepiphysiodesis.

The pre-operative TFA in valgus knees was 6.9±3.3° (MAD 22.6±9.3 mm). The pre-operative TFA in varus knees was –7.2±4.0° (MAD –23.3±10.9 mm). The TFA in valgus knees at time of implant removal was –0.2±2.9° (MAD 0.3±9.3 mm). The TFA in varus knees at time of implant removal was –1.2±2.6° (MAD –3.8±7.8 mm; Fig. 3, Table 3). Overall, the pre-operatively measured TFA was finally corrected 7.1±4.0° (MAD 23.0±11.4 mm) in valgus deformities and 6.0±2.7° (MAD 19.5±8.4 mm) in varus deformities.

3.4. Rate of correction: mechanical axis

We found a ROC of the TFA of 1.6±1.3°/cm longitudinal growth in valgus and 1.4±0.6°/cm longitudinal growth in varus deformities (overall mean: 1.6±1.2°/cm). When looking at singleHEPD procedures, we found a ROC of the TFA of 1.23±0.52°/cm longitudinal growth (MAD 4.3±1.86 mm/cm longitudinal growth). For combiHEPD procedures, we found a higher ROC of the TFA of 2.64±1.89°/cm (MAD 7.66±4.85 mm/cm; Table 4).

This corresponds to a ROC of the TFA of 0.99°/month and of the MAD of 3.2 mm/month in valgus and of the TFA of 0.87°/month and of the MAD of 2.9 mm/month in varus deformities (overall mean TFA: 0.97°/month; overall mean MAD: 3.2 mm/month). SingleHEPD procedures resulted in a ROC of the TFA of 0.8±0.4°/month (MAD 2.7±1.5 mm/month). CombiHEPD procedures led to a higher ROC of the TFA of 1.4±1.0°/month (MAD 4.1±2.6 mm/month; Table 4).

3.5. Mechanical angles

In valgus knees, the pre-operative mLDFA was 83.1±3.1°. The pre-operative mLDFA in varus knees was 93.2±3.8°. Immediately prior to implant removal, the mLDFA was 89.5±2.8° in valgus deformities and 89.7±3.5° in varus deformities. This corresponds to a correction of the mLDFA of 6.4±2.9° in valgus deformities and of 3.6±2.1° in varus deformities (Fig. 3, Table 3).

Pre-operatively, the mMPTA was 92.3±3.0° in valgus knees and 84.6±2.4° in varus knees. At time of implant removal, the mMPTA was 88.0±2.2° in valgus deformities and 88.4±1.8° in varus deformities (Fig. 3, Table 3). This reflects a correction of the mMPTA upon HEPD of 4.3±3.9° in valgus knees and of 4.2±2.5° in varus knees.

3.6. Correction rate: mechanical angles

Correction of knee joint orientation angles upon treatment was as follows: mLDFA 0.87°/month in valgus and 0.58°/month in varus deformities (overall mean: 0.84°/month); mMPTA 0.6°/month in valgus and 0.51°/month in varus deformities (overall mean: 0.57°/month).

When subdividing into singleHEPD procedures, we found a shift of the mLDFA of 1.37±0.51°/cm longitudinal growth and 0.9±0.4°/month whereas combiHEPD led to a shift of the mLDFA of 1.4±1.04°/cm longitudinal growth and 0.7±0.5°/month (Table 4).

The mMPTA after singleHEPD shifted 0.81±0.47°/cm longitudinal growth and 0.4±0.3°/month, after combiHEPD 1.26±1.07°/cm longitudinal growth and 0.7 longitudinal growth and 0.6°/month (Table 4).

Table 3

Mechanical axis (TFA), mechanical axis deviation (MAD), and mechanical angles mLDFA and mMPTA, and frontal knee joint line angle (FKJLA) pre-operative and immediately prior implant removal (and delta) subdivided into genua valga and vara.

		Pre-operative				Prior to implant removal				Δ			
		Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max
TFA (°)	Genu valgum	6.9	3.3	3.0	23	−0.2	2.9	−7.0	7.0	7.1	4.0	1.0	17.0
	Genu varum	−7.2	4.0	−19.0	−3.0	−1.2	2.6	−9.0	2.0	6.0	2.7	2.0	12.0
MAD (mm)	Genu valgum	22.6	9.3	10.0	66.0	−0.3	9.7	−25.0	23.0	23.0	11.4	2.0	49.0
	Genu varum	−23.3	10.9	−54.0	−9.0	−3.8	7.8	−25.0	7.0	19.5	8.4	7.0	38.0
mLDFA (°)	Genu valgum	83.1	3.1	70.0	88.0	89.5	2.8	82.0	96.0	6.4	2.9	1.0	13.0
	Genu varum	93.2	3.8	89.0	102.0	89.7	3.5	83.0	96.0	3.6	2.1	1.0	6.0
mMPTA (°)	Genu valgum	92.3	3.0	88.0	102.0	88.0	2.2	83.0	92.0	4.3	3.9	1.0	19.0
	Genu varum	84.6	2.4	80.0	87.0	88.4	1.8	85.0	91.0	4.2	2.5	1.0	9.0
FKJLA (°)	Genu valgum	3.9	3.5	−4.0	10.0	−0.2	3.0	−7.0	6.0	5.0	3.4	0.0	15.0
	Genu varum	−1.0	2.1	−4.0	3.0	−0.8	1.8	−4.0	3.0	2.8	1.7	1.0	6.0

mLDFA = mechanical lateral distal femoral angle, mMPTA = mechanical medial proximal tibial angle, SD = standard deviation, TFA = mechanical tibiofemoral angle.

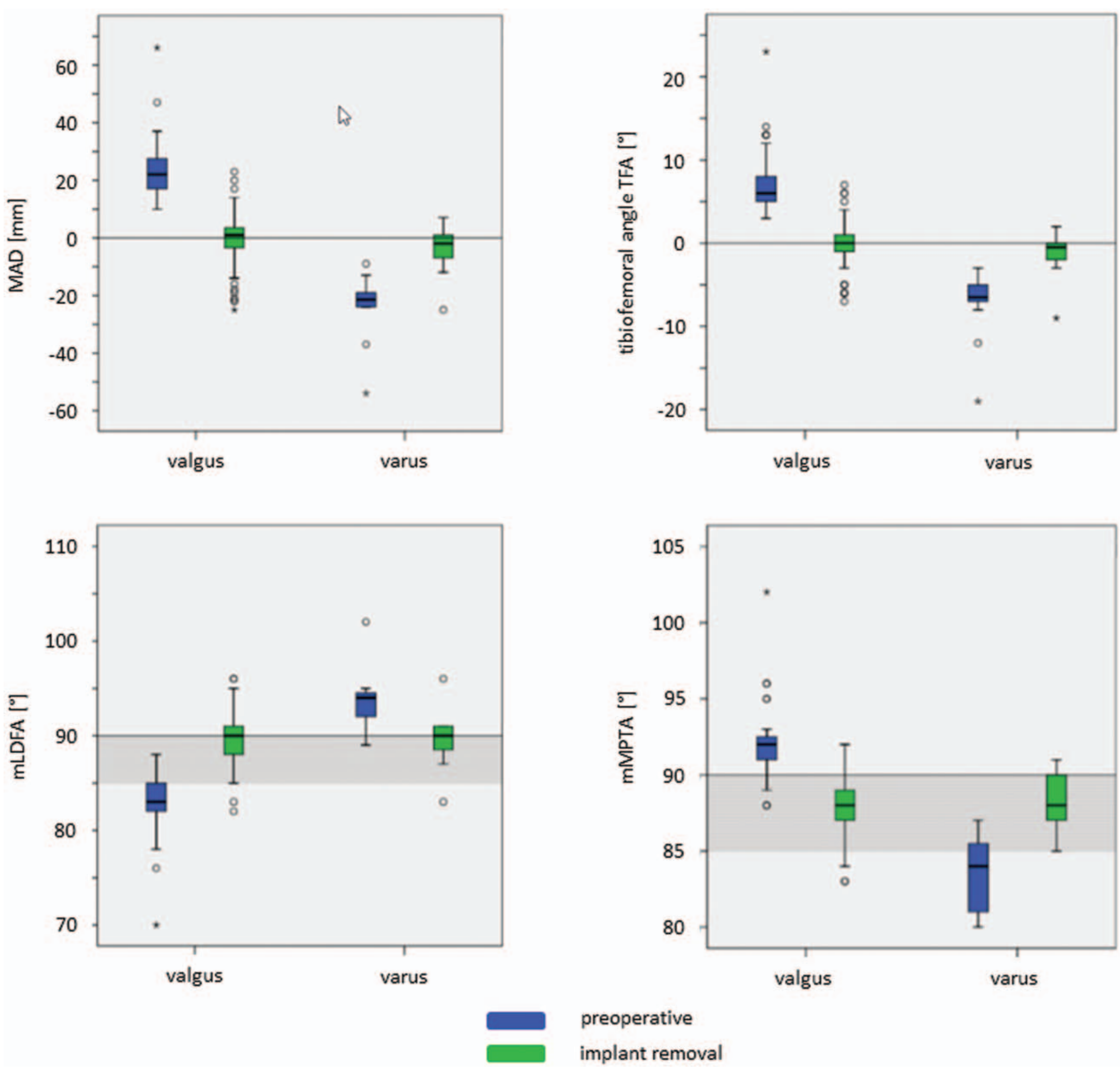

Figure 3. Box-and-whisker plots depict shift of mechanical axis deviation (MAD [mm]), tibiofemoral angle (TFA), mLDFA, and mMPTA (°) upon HEPD (pre-operative [blue] and prior to implant removal [green]) comparing valgus and varus deformities. Plots indicate variables outside the upper and lower quartiles, and outliers (*$P < .05$). Hatching displays anticipated physiological range of the mLDFA and the mMPTA. HEPD = hemiepiphysiodesis, mLDFA = mechanical lateral distal femoral angle, mMPTA = mechanical medial proximal tibial angle.

Table 4

Shift of mechanical axis deviation (MAD [mm]), mechanical axis (TFA), and mechanical angles mLDFA and mMPTA (°) per time (month) and longitudinal growth (cm). Data show a higher correction rate for combiHEPD compared to singleHEPD procedures (except for mLDFA shift/time).

		Correction/time (month)				Correction/growth (cm)			
		Mean	SD	Min	Max	Mean	SD	Min	Max
TFA (°)	SingleHEPD	0.8	0.4	0.1	1.8	1.23	0.52	0.13	2.67
	CombiHEPD	1.4	1.0	0.2	3.5	2.64	1.89	0.43	6.50
MAD (mm)	SingleHEPD	2.7	1.5	0.2	6.3	4.3	1.86	0.29	9.33
	CombiHEPD	4.1	2.6	0.8	10.0	7.66	4.85	1.71	20.00
mLDFA (°)	SingleHEPD	0.9	0.4	0.1	1.8	1.37	0.51	0.5	2.57
	CombiHEPD	0.7	0.5	0.3	2.0	1.4	1.04	0.4	4.0
mMPTA (°)	SingleHEPD	0.4	0.3	0.1	1.0	0.81	0.47	0.14	1.81
	CombiHEPD	0.7	0.6	0.0	2.3	1.26	1.07	0.2	4.0

HEPD = hemiepiphysiodesis, mLDFA = mechanical lateral distal femoral angle, mMPTA = mechanical medial proximal tibial angle, SD = standard deviation, TFA = mechanical tibiofemoral angle.

3.7. Frontal knee joint line angle

Pre-operative assessment of the FKJLA revealed a mean of 3.9 ± 3.5° in valgus, and –1.0 ± 2.1 in varus deformities. At time of implant removal, the FKJLA was –0.2 ± 3.0° in valgus, and –0.8 ± 1.8° in varus deformities. Therefore, deltaFKJLA was 5.0 ± 3.4° in valgus, and 2.8 ± 1.7° in varus knees (Table 3). Mean shift of FKJLA (deltaFKJLA) was significantly ($P < .001$) higher in the singleHEPD treatment group (5.4 ± 3.4°) compared to combiHEPD (2.2 ± 1.5°; Fig. 4).

3.8. Shift: FKJLA

In order to analyze the impact of HEPD on the FKJLA, patients with secondary deformities (n = 9) and those with unintentional overcorrection of mechanical axis (n = 5) were excluded. 64/78 deformities remained for further evaluation: 40/64 deformities had a non-physiological (>/<0°–3°) FKJLA pre-operatively. At time of mechanical axis correction, 57.5% of these cases had a physiological FKJLA, 42.5% had a non-physiological FKJLA still. 23/64 deformities had a physiological FKJLA pre-operatively. At time of mechanical axis correction, 45.8% of these cases had a physiological FKJLA still, whereas 54.2% revealed a shift from physiological to non-physiological FKJLA.

3.9. Loss of correction

For this analysis, secondary deformities, and cases with overcorrections and completed growth during follow-up were excluded; 45/78 deformities remained for further evaluation. A follow-up of at least 6 months was mandatory. Mean follow-up after implant removal was 461 ± 296 days. When looking at the FKJLA, we found a loss of correction in 40% of the included cases indicating a rebound deformity. Of these cases, only n = 1 had a severe loss of correction. The remaining n = 17 were mild. The remaining 60% of the cases maintained a corrected mechanical axis during follow-up.

At time of correction of the mechanical axis, the collective was divided into 2 subgroups: cases with a FKJLA within the

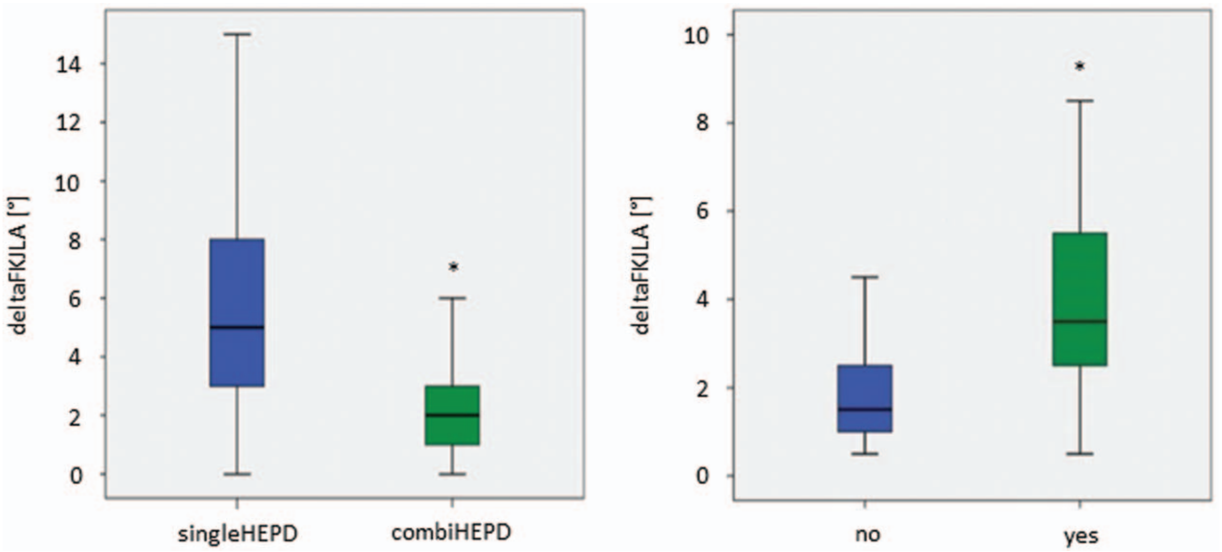

Figure 4. (Left) Mean shift of FKJLA (deltaFKJLA) was significantly higher (*$P < .001$) in the singleHEPD treatment group compared to combiHEPD. (Right) Deviation of FKJLA compared to an *ideal* value of 1.5° in patients with and without rebound deformity (loss of correction yes or no). Patients that ended up with an unphysiological FKJLA (>/<0°–3°) after correction of mechanical axis had a significantly higher (*$P = .008$) risk of developing a rebound deformity. HEPD = hemiepiphysiodesis, FKJLA = frontal knee joint line angle.

Table 5

Binary logistic regression analysis of covariates with potential impact on recurrence of deformity at time of implant removal. Statistical analysis revealed a 60.5% higher risk of a rebound of deformity for each degree of FKJLA deviation from an *ideal* value of 1.5°, which was significant ($P=.017$). None of the other factors had a significant impact on loss of correction.

	P	Odds ratio	95% CI
Age	.362	2.439	0.359, 16.575
BMI	.544	1.114	0.785, 1.582
Gender	.938	0.933	0.837, 1.179
DeltaFKJLA	.017	1.605	1.088, 2.367

BMI = body mass index, CI = confidence interval, FKJLA = frontal knee joint line angle.

previously defined physiological range of 0° to 3° (n=21), and cases with a FKJLA >/<0° to 3° (n=24) despite mechanical axis correction. In group 1, rebound deformity was clinically observed in 4/21 cases (19.1%) after implant removal in contrast to 14/24 cases in group 2 (58.3%). This difference was statistically significant ($P=.01$). In those cases with recurrent deformity (n=18/45), deltaFKJLA compared to *ideal* (1.5°) was significantly ($P=.008$) higher than in cases without rebound deformity (n=27/45; Fig. 4).

Binary logistic regression analysis revealed an odds ratio of 1.605 (confidence interval: 1.088, 2.367) corresponding to a 60.5% higher risk of a rebound of deformity for each degree of FKJLA deviation from an *ideal* value of 1.5°, which was significant ($P=.017$). None of the covariates patient age at time of surgery, gender, or body mass index had a significant impact on loss of correction (Table 5).

4. Discussion

We found a mean time until correction of 9.0±5.6 months, whereby ROC of females was faster. Complete ROC of the mechanical axis was 91%. In 6.4% of all physes we documented an overcorrection that had to be addressed by contralateral HEPD. Femoral deformities corrected faster than tibial deformities. ROC of the TFA, mMPTA, and mLDFA was faster in valgus compared to varus deformities and after combiHEPD compared to singleHEPD. Correction of mMPTA and mLDFA were physiological both in varus and valgus knees (88°–89°, respectively). Our results are consistent with a recent, large (patients: n=206) multicenter study by Danino et al.[6] The latter authors described a ROC of 92% to 93% with mMPTA and mLDFA being 89° to 85°, respectively. The rate of overcorrection was 5% to 6% of all physes. And femoral and valgus ROC was significantly faster than tibial and varus ROC.

The initial study by Stevens using eight-plates encompassed a heterogeneous and small patient population (patients: n=34) including idiopathic *and* secondary angular deformities.[3,8] He described a ROC of 94%. For the first time the FKJLA was applied. In contrast to mechanical angles, the FKJLA is independent from the mechanical axis, does address the JLCA and is therefore considered to be useful.[14] However, all patients with corrected TFA had a FKJLA within a range of 0° to 3°. Overall rate of recurrence was 11.7% (all valgus deformities).

Burghardt and Herzenberg[9] published a study (patients: n=43) with a ROC of 90% and a rate of recurrence of 77% of all treated deformities with open physes at time of implant removal. To compensate subsequent recurrence the authors contemplated the possibility of intentional overcorrection of angular deformity. In the context of recurrence, the FKJLA was unconsidered.

In conclusion, HEPD seems to be safe and successful in treating coronal plane deformities around the knee.[15] Previously defined constants moreover enable prediction of correction.[6,16,17] Recurrence is an issue nevertheless. Therefore, the present study was set up to test the suitability of the FKJLA to predict recurrence of deformity eventually.

According to Shabtai and Herzenberg[5] and Boero et al,[18] idiopathic angular deformities are most predictable. Therefore, we excluded secondary deformities and cases with overcorrections and completed growth during follow-up in our recurrence calculation using the FKJLA. Within a 6 months follow-up after implant removal while physes were still open, we found a loss of correction indicating recurrence in 40%. Our results demonstrate that patients that ended up with a non-physiological FKJLA (>/<0°–3°) after correction of mechanical axis was achieved had a significantly higher risk of developing a rebound deformity. Binary logistic regression analysis revealed a 60.5% higher risk of a rebound of deformity for each degree of deltaFKJLA from an *ideal* value of 1.5°. Moreover, pathological shift of FKJLA was significantly higher in the singleHEPD group compared to combiHEPD. Interestingly, none of the covariates patient age at time of surgery, gender, or body mass index had a significant impact on loss of correction.

Our results are supported by Yilmaz et al[11] and Burghardt and Herzenberg.[9] The latter authors described an average rebound of the MAD of 15.7 mm (1.0 mm/month) after implant removal. At time of axial correction, knee joint orientation angles and thus the FKJL were out of normal range in 62% of these cases. Interestingly, when follow-up radiographs revealed recurrence, only 2 of these 13 cases had a pathological mLDFA or mMPTA. Apparently, the FKJL had aligned horizontally again, although this was associated with a loss of correction of the mechanical axis.

It therefore remains controversial, if a persisting pathological FKJL during growth is of clinical relevance. In addition to unfavorable knee strain and consecutive complaints eventually, we provide evidence of an increased risk for recurrent deterioration of the mechanical axis after implant removal with the growth plates being still open. It is yet questionable if intentional overcorrection is legitimate in order to retain imminent recurrence.[8,19–22]

Limitations of the present cohort study are the retrospective design and the heterogeneity of the deformities. Future studies ought to focus either on varus or valgus deformities to draw conclusions. Idiopathic lower limb angular deformities in the coronal plane, however, are frequently accompanied by different types of skeletal dysplasia or bone metabolism disorders, or multiplanar and rotatory deformities. Large cohorts are therefore difficult to achieve.

5. Conclusions

HEPD is a suitable and successful procedure for the correction of angular lower limb deformities in the coronal plane. Mechanical angles are inevitable to monitor the progress of correction. A non-physiological FKJL at time of correction of mechanical axis and a large deltaFKJLA upon HEPD increases significantly the risk for loss of correction yet. CombiHEPD procedures correct faster and seem to decrease the risk for recurrence in cases of physiological pre-operative FKJLA, whereas singleHEPD at the site of highest angle deviation seems to be indicated in cases with non-physiological pre-operative FKJLA.

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