The Fate of Overcorrection After Hemiepiphysiodesis in Valgus Deformities Around the Knee

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Background: Tension band plating is widely used in the surgical treatment of coronal plane deformities around the knee. The rebound phenomenon after implant removal is a common complication of this technique. Overcorrection of joint orientation angles is a method to minimize the effect of the rebound phenomenon. This study aims to investigate the natural course of overcorrected joint orientation angles after plate removal in patients with genu valgum deformity.

Methods: Patients who underwent hemiepiphysiodesis with tension band plating due to genu valgum deformity between 2010 and 2019 were retrospectively analyzed. Mechanical lateral distal femoral angles (mLDFA) and mechanical medial proximal tibial angles were calculated before plate application, before implant removal, and at the last follow-up. At the implant removal, mLDFA > 90 degrees and mechanical medial proximal tibial angles <85 degrees were accepted as overcorrected.

Results: Seventy-two segments from 45 patients were included. For femoral valgus deformities (n = 59), the mean mLDFAs at index surgery, implant removal, and the last follow-up were 79.8 ± 3.9 degrees, 95.5 ± 3.7 degrees, and 87.3 ± 5.1 degrees, respectively. In the more and less than 10 degrees rebound groups, the median age of patients at index surgery were 66 and 101 months ($P = 0.04$), the mLDFA during implant removal were 97.8 degrees and 94.4 degrees ($P = 0.005$), and the mean amount of correction in mLDFA was 17 degrees and 13 degrees ($P = 0.001$), respectively. At the last follow-up, joint orientation angles were found to be still overcorrected in 16 (22%), within normal limits in 36 (50%), and undercorrected in 20 (28%) segments. Ten (13%) segments required additional surgery due to residual deformity.

Conclusions: Overcorrection with tension band plating is an effective modality in the treatment of genu valgum deformity. Rebound after plate removal increases as the age at index surgery decreases and the amount of conscious overcorrection increases. Most segments return to normal joint orientation angle limits after overcorrection. We recommend a mean of 5 degrees routine overcorrection in patients with genu valgum deformity to overcome the rebound phenomenon and to make future interventions easier if ever needed.

Level of Evidence: Level III.

Key Words: tension band plate, hemiepiphysiodesis, overcorrection, genu valgum

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Coronal plane angular deformities of the knee are a common problem in children. Physiological variations of the angles according to patient age should always be considered when evaluating growing children. Deformities can be idiopathic or caused by pathologic conditions that affect physeal growth and must be managed accordingly to prevent long-term morbidity.

Coronal plane deformities around the knee can be successfully treated with permanent or temporary hemiepiphysiodesis. Temporary hemiepiphysiodesis can be achieved utilizing different techniques, including staples, transphyseal screws, and, more recently, tension band plating. Guided growth with tension band plating is a commonly used technique for hemiepiphysiodesis because it is temporary, simple to apply and remove, and maintains the physeal central axis of correction.[1] Growth modulation utilizing tension band plating can be used in both idiopathic deformities and also in patients with pathologic physes.[2] However, recurrence of the deformity following implant removal is a commonly reported complication of this procedure.[1,3–5] The recurrence, also known as the rebound phenomenon, was related to increased activity and catch-up growth at the cellular level in the physis demonstrated in an animal model.[6]

The rebound phenomenon was defined as an increase of 5 degrees or more in joint orientation angles in the direction of the initial deformity.[7] Overcorrection, the correction of joint orientation angles in the opposite

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Ethical approval for this study was obtained from the Hacettepe University Faculty of Medicine local ethics committee (GO 21/280, March 2, 2021).

Patients gave written informed consent for participation in the study and also for its publication.

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direction of initial deformity beyond the physiological values, has been recommended as a technique to reduce the impact of the rebound phenomenon.[1,3,8–11] Although there are numerous suggestions about overcorrection regarding specific etiologies, no explicit algorithm exists to guide surgeons toward better outcomes. Moreover, there is no comprehensive literature regarding the outcomes of overcorrected deformities around the knee joint.

The purpose of the present study is to investigate the natural progression of overcorrected knee joint orientation angles after plate removal in patients with initial genu valgum deformity.

METHODS

After approval was obtained from the local ethics committee (GO 21/280), a retrospective analysis of patients who underwent guided growth treatment utilizing a two-hole plate due to coronal plane valgus deformity of the knee between April 2010 and August 2019 was performed.

The deformity analysis performed was based on joint orientation angles,[12] mechanical lateral distal femoral angle (mLDFA), and mechanical medial proximal tibial angle (mMPTA), on full-length lower extremity weight-bearing radiographs. For the patients who had a preoperative valgus deformity of the knee, overcorrection was defined as mLDFA > 90 degrees and mMPTA < 85 degrees at the time of implant removal. Patients who had preoperative genu valgum deformity (mLDFA < 85 degrees, mMPTA > 90 degrees), had 2-hole plate removal surgery after the achievement of the deformity overcorrection at the time of implant removal, had a minimum follow-up of 12 months after implant removal, and had regular full-length lower extremity weight-bearing radiographs were included in the study.

Patients in this study were applied a routine intentional overcorrection in the studied segments as the practice of the senior authors to overcome the rebound phenomenon (C.A. and G.Y.). This overcorrection was planned only on patients with enough skeletal growth remaining and was aimed to be no-more-than 10 degrees over normal joint orientation angles in the direction of deformity correction.

After implant removal, changes in the direction of initial deformity were defined as recurrence, and changes in the direction of deformity correction were defined as continuity of hemiepiphysiodesis effect.

Patients' age (mo) at implant application and removal were recorded. The period from implant application to removal was assessed for each segment and defined as the correction period. The recurrence of the deformity (degrees), deformity correction rate (degrees/mo), and total correction in joint orientation angle after implant removal (degrees) were measured. The relation of the amount of deformity recurrence with age, laterality, sex, bone segment (femur and tibia), deformity correction rate, the total amount of deformity correction and overcorrection in joint orientation angles, the correction period and etiology (idiopathic and nonidiopathic) were analyzed. Patients were divided into 3 groups according to the course of the deformity after implant removal as follows: deformity recurrence ≥ 10 degrees; deformity recurrence <10 degrees; and continuity of deformity correction.

Femoral deformities during the latest follow-up were categorized as overcorrected, normal, and the recurrence of the deformity based on mLDFA values. Overcorrection was defined as > 90 degrees, normal was defined as ≤ 90 degrees and ≥ 85 degrees, and the recurrence of the deformity was defined as <85 degrees at final follow-up radiographs.

We also evaluated the annual recurrence of deformity by calculating the recurrence amount in mLDFA and mMPTA in patients who had been followed up for more than 2 years after implant removal.

The Kolmogorov–Smirnov test was used for the normality analysis of the variables. For related samples, Friedman's 2-Way Analysis of Variance by Ranks was used. Significance values had been adjusted by the Bonferroni correction for multiple tests. The independent samples *t* test, Mann–Whitney *U* test, and Kruskal-Wallis test were used for the comparison of quantitative data. The χ^2test was used for the comparison of qualitative data. Analysis of the data was performed using IBM SPSS Statistics 26.0 (IBM Corporation, Armonk, New York, USA). A *P* value lower than 0.05 was considered statistically significant for all tests performed.

RESULTS

A total of 222 bone segments of 98 patients, who underwent hemiepiphysiodesis with eight-plate, were evaluated. After the exclusion of segments that did not meet the inclusion criteria, 72 bone segments of 45 patients were included in the study. Demographics are given in Table 1.

For femoral segments with preoperative valgus deformities ($n = 59$), the mean mLDFAs at index surgery, implant removal, and the last follow-up were 79.8 ± 3.9 degrees, 95.5 ± 3.7 degrees, and 87.3 ± 5.1 degrees, respectively.

TABLE 1. Study Demographics

Parameter	N	%	
Sex	—	—	—
Female	14	31.1	—
Male	31	68.9	—
Bone segment	—	—	—
Femur	59	81.9	—
Tibia	13	18.1	—
Laterality	—	—	—
Left	32	44.4	—
Right	40	55.6	—
Parameter	**Value**	**Minimum**	**Maximum**
Mean age at index surgery (mo)	94.9	37	181
Mean age at implant removal (mo)	112.5	48	205
Mean correction period (mo)	17.4	8	45
Mean follow-up after implant removal (mo)	33.8	12	96

TABLE 2. Distribution of Femoral and Tibial Segments According to Rebound Degrees

Deformity recurrence	Tibias ($n=13$)	Femurs ($n=59$)
≥10°	3	21
<10°	10	35
Continuity of hemiepiphysiodesis effect	−	3

For tibial segments with preoperative valgus deformities ($n=13$), the mean mMPTAs at index surgery, implant removal, and the last follow-up were 99.1±5.6 degrees, 82.2±2.3 degrees, and 90±5.4 degrees, respectively.

Deformity recurrences calculated in all segments are given in Table 2.

Femoral segments with preoperative valgus deformities ($n=59$) were divided into 3 groups based on the final mLDFA: Deformity recurrence ≥10 degrees ($n=21$), deformity recurrence <10 degrees ($n=35$), and continuity of hemiepiphysiodesis effect ($n=3$). Three groups had mean mLDFAs of 97.8±4.2 degrees, 94.4±2.7 degrees, and 94.6±4.5 degrees at implant removal; the amount of corrections was 18.7±6.1 degrees, 14.0±4.3 degrees, and 16.3±6.1 degrees at implant removal, respectively. Correction rates were 1.21±0.42 degrees/month, 0.98±0.37 degrees/month, and 1.00±0.06 degrees/month. Due to the low number of segments in the continuity of hemiepiphysiodesis effect group, only the remaining 2 deformity recurrence groups were statistically investigated, and results are given in Table 3.

When operated segments with a minimum of 2-year follow-up after implant removal were analyzed, there were 45 femurs and 5 tibias. The median follow-up after implant removal was 32.4 (27–48.7) months. Five tibial segments were excluded from the analysis due to the insufficient number of annual follow-ups each year. Among 45 femurs, 42 (93%) had first year, 19 (42%) had second year, 9 (20%) had third year, and the rest had a minimum of 1 later-than-3-year follow-up. Annual amounts of mLDFA change (deformity recurrence) were calculated. In the first year, 22/42 (52.4%) segments had experienced ≥5° deformity recurrence, while in the second year, only 4/18 (22.2%) and after 2 years 3/19 (15.8%) had ≥5° deformity recurrence at mLDFAs. The median mLDFAs in a timeline graph are given in Figure 1. Annual changes in mLDFA amounts are given in Figure 2. When bone, laterality, and sex were compared for the amount of deformity recurrence, the differences were statistically insignificant.

Seventy-two segments were applied a mean 5.0±3.6 degrees overcorrection from normal joint orientation angles (Fig. 3). At their final follow-ups, 16 (22%) segments remained overcorrected, 36 (50%) segments were between normal limits, and 20 (28%) segments were undercorrected. Among 16 still overcorrected segments, 3 were above 5 degrees overcorrected (9 degrees, 11 degrees, 14 degrees), and all 3 were segments belonged to patients with pathologic physes (epiphyseal dysplasia, multiple hereditary exostoses, and cystinosis). Six still overcorrected segments with idiopathic etiology had 1.8±0.7 degrees; 10 still overcorrected segments with pathologic physes had 5±4.6 degrees of overcorrection from normal joint orientation angle limits ($P=0.031$).

Among 72 segments, 25 (35%) had idiopathic, and 47 (65%) had pathologic etiologies. Pathologic etiologies are given in Table 4. Fifty-nine femoral segments with valgus deformity were analyzed according to etiologies (Table 5).

There were 3 segments with continued hemiepiphysiodesis effect at their final follow-up (Fig. 4). Detailed descriptions of each segment are given in Table 6.

Ten bone segments required additional surgeries and only one had idiopathic etiology. Five segments required the re-insertion of eight plates and 3 segments required corrective osteotomy due to deformity recurrence. One segment with epiphyseal dysplasia required MCL reconstruction due to instability, and the remaining segment with the etiology of fibular hemimelia required lengthening due to limb length discrepancy.

DISCUSSION

Deformity recurrence after implant removal, or the so-called rebound phenomenon, is a highly expected complication in the correction of the coronal plane deformities of the knee.[5] Although there is no uniform definition for this phenomenon, risk factors associated with deformity recurrence were studied in several publications[3–5,7,13–16] proper methods to overcome this

TABLE 3. Comparative Analysis of Femoral Segments with Valgus Deformities Excluding the Continuity of Hemiepiphysiodesis Effect

Rebound of the Deformity	≥10 deg ($n=21$)	<10 deg ($n=35$)	*P*
Age at index surgery	66 (55−100.5) mo	101 (62−127) mo	***0.04****
Implant retention duration	15 (11−20) mo	12 (11−22) mo	*0.792*
Age at implant removal	92 (67.5−116.5) mo	112 (75−141) mo	*0.064*
Preoperative mLDFA, deg	80 (78−81.5)	82 (78−83)	*0.128*
mLDFA at implant removal, deg	97 (95.5−100)	94 (92−96)	***0.001****
mLDFA correction, deg	17 (14−22)	13 (12−15)	***0.001****
mLDFA correction rate, deg	1.05/mo (0.85−1.46/mo)	0.93/mo (0.69−1.30/mo)	*0.05*

*Bold values indicates statistically significant findings, with $P<0.05$.
mLDFA indicates mechanical lateral distal femoral angle.

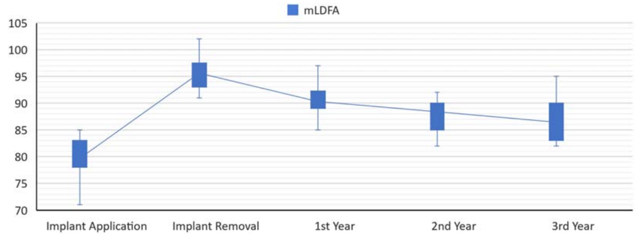

FIGURE 1. Illustration of the mean change of mLDFA in femurs with valgus deformity. mLDFA indicates mechanical lateral distal femoral angles.

phenomenon and their outcomes, however, were poorly investigated.

Overcorrection is both performed and criticized as a modality to prevent recurrence in growth modulation for coronal plane deformities of the knee. The current literature is lacking strong evidence for and against routine overcorrection. Leveille et al[3] showed that the amount of overcorrection in coronal deformity correction does not differ between rebounders and nonrebounders, and they recommended against routine overcorrection. Shabtai et al[8] concluded that overcorrection must be considered to prevent rebound but they were unable to provide a precise amount. Masquijo et al[2] recommended 3 degrees of modest overcorrection in high-risk patients with more than 1 year of anticipated growth remaining.

Stevens and Pease[17] suggested overcorrection to mechanical axis deviation (MAD) medial zone 1 in posttraumatic tibial valgus deformities, based on their finding of a mean 17 mm mechanical axis deviation compared with the contralateral normal sides 6 mm deviation in 16 patients. Yilmaz et al[18] stated that skeletal dysplasia patients who were prone to develop genu valgum deformity may benefit from slight overcorrection, yet, the amount and the outcomes were not clearly defined. Cho et al[19] recommended that overcorrection with epiphyseal stapling over zone 1 in mechanical axis deviation should be avoided, as physis behaves rather unpredictably after implant removal in multiple epiphyseal dysplasia patients. Westberry et al reported that their 2 overcorrected patients with fibular deficiency did not need additional procedures; thus, overcorrection should be done to a clinically acceptable alignment. They stated that younger patients tend to experience more rebound deformity, and it is imperative

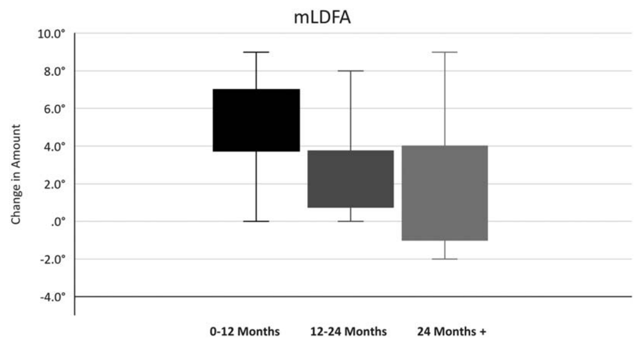

FIGURE 2. Demonstration of mean rebound degrees in each given time frame. mLDFA indicates mechanical lateral distal femoral angles.

FIGURE 3. A, Preoperative weight-bearing x-ray of a 5-year-old boy with genu valgum deformity of the left knee; B, 1 year postoperatively, distal femoral 8-plate was removed after achieving overcorrection; C, Final follow-up at 9 years of age, joint orientation angles were within normal limits.

TABLE 4. Nonidiopathic Cases of Genu Valgum Deformity

Pathologic etiologies for segments	n = 47
Fibular hemimelia	10
Cystinosis	6
Mucopolysaccharidosis type IV	6
Epiphyseal dysplasia	4
Multiple hereditary exostoses	4
Fanconi	3
Renal failure	3
Traumatic	2
Pseudo-rheumatoid dysplasia	2
Rickets	1
Blount's disease	1
Congenital femoral deficiency	1
Gaucher's disease	1
Juvenile rheumatoid arthritis	1
Thalassemia	1
Tibial hemimelia	1

TABLE 5. Variables of Femoral Segments with Valgus Deformities Were Given According to Etiologies

Etiology	Idiopathic ($n = 18$)	Pathologic ($n = 41$)	P
Preoperative mLDFA, deg	81.6 ± 2.4	79.1 ± 4.2	***0.003****
mLDFA correction, deg	13.2 ± 3.1	16.7 ± 5.8	***0.002****
Overcorrection amount, deg	4.9 ± 2.4	5.9 ± 4.1	*0.12*
Final mLDFA, deg	88.3 ± 2.8	86.8 ± 5.8	*0.09*
Rebound amount, deg	6.5 ± 3.4	9 ± 6.1	***0.025****
Final Outcome, n (%)			
Undercorrected	–	16 (39)	—
Normal	13 (72)	16 (39)	—
Overcorrected	5 (28)	9 (22)	—

mLDFA indicates Mechanical Lateral Distal Femoral Angle.
*Bold values indicates statistically significant findings, with $P < 0.05$.

to inform families about the pros and cons of both overcorrection and under-correction.[11] This also applies but is not limited to specific etiologies mentioned above.

In our study, we applied a mean of 5 degrees overcorrection from normal joint orientation angles. In the idiopathic group, this treatment method was mostly satisfactory. Only 1 (4%) patient required additional surgery due to under-correction at the final follow-up, and all patients were within 3 degrees of normal limits. In segments with pathologic physes, outcomes were not as successful as idiopathic cases; still, 35 (74%) of 47 segments were within 3 degrees of normal limits at the final follow-up. Nine patients in the pathologic group needed further surgical interventions. Recurrence is higher in pathologic limbs. Thus, overcorrection may be considered as a routine strategy in this patient group. Moreover, even if the deformity recurs at the final follow-up, it can be thought that this strategy makes future corrective osteotomies relatively easier.[20] We believe this statement is valid for all of the segments with pathologic physes. After analyzing the final data, we recommend to aim for a 5 degrees overcorrection for bone segments, with valgus deformity in both idiopathic and pathologic physes with enough skeletal growth remaining.

Some studies mentioned overcorrection as a complication of poor patient follow-up.[16,21,22] To prevent misconceptions, it is imperative to state that we applied intentional overcorrection in the studied segments, and all follow-up visits were routinely carried out.

MAD is a widely used measurement in the evaluation of coronal plane deformities of the knee.[5] It provides a general interpretation of lower extremity deformity. It should be taken into consideration that 2 segments

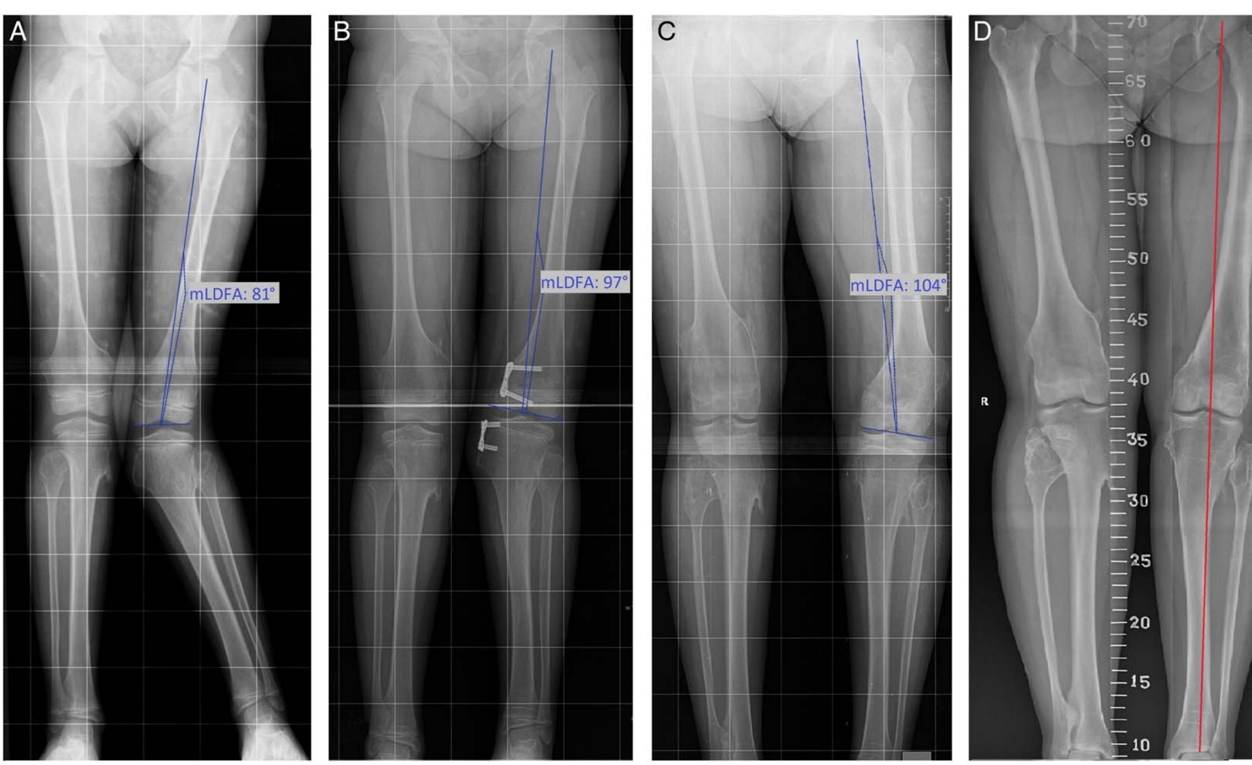

FIGURE 4. A, Preoperative weight-bearing x-ray of a 7-year-old girl with multiple hereditary exostoses; B, One year after initial surgery, at the implant removal; C, 3 years after implant removal, indicating 7 degrees of continuity of deformity correction in the varus direction; note that this deformity was caused by the exostosis in the lateral distal femur rather than tethering in medial physis; D, Final follow-up shows neutral axis in left lower extremity after multiplanar deformity correction with osteotomy and hexapodal external fixation (This image was given for last follow-up was not included in our data analysis due to the additional surgery performed). mLDFA indicates mechanical lateral distal femoral angles.

TABLE 6. Segments with Continued Hemiepiphysiodesis Effect

P #	Sex	S #	Bone	Age at initial procedure (y)	Duration plates retainer (mo)	Follow-up after implant removal (mo)	Continued effect after implant removal (deg)	Final joint orientation angles (mLDFA) (deg)	Etiology	Further intervention
1	F	1	Femur	7,33	14	34	7	104	MHE	Femoral osteotomy
2	M	2	Femur	13,67	13	73	1	93	Idiopathic	No
3	F	3	Femur	10,75	12	18	1	92	Idiopathic	No

F indicates Female; M, Male; MHE, multiple hereditary exostoses; *P*, Patient; S, Segment.

(femur and tibia) may contribute to the deformity independently, and metric measurement would be inappropriate in comparing deformities in children with different bone widths and lengths. In our patients, we also recorded MADs; however, due to the relatively high number of surgical interventions of different segments, we mainly analyzed joint orientation angles (mLDFA and mMPTA), as MAD was insufficient and far from the characterization of different segmental deformities precisely. In contrast, joint orientation angles were principally correlated with each segment involved and more precise about defining specific values about described segments.

The main strength of this study was being the largest reported cohort up-to-date about overcorrection of the genu valgum deformity. Also, we focused on the outcomes of overcorrection, which the current literature was lacking. Limitations of this study are, firstly, its retrospective design. Secondly, due to the low number of patients in subgroups, apart from femoral segments, the statistical analysis failed to provide valuable data for the aforementioned segments. Thirdly, patients were not followed up on their skeletal maturity. This may be a bias in the interpretation of the outcomes in this study. To mitigate the effect of this bias, we included the patients with a minimum of 1 year and a mean of 33 months follow-up and carried out analysis for rebound amounts for respective years, when feasible, to demonstrate the amount of recurrence in each year. This analysis was able to provide adequate data to reflect the outcomes.

In conclusion, overcorrection is an effective modality to employ in the correction of genu valgum deformity. We recommend overcorrection in both idiopathic cases and patients with pathologic physes. In our cohort, even if the rebound phenomenon occurred, most of the patients had remained within physiological joint orientation angles. Pathologic etiology, a faster rate of deformity correction, and younger age of patients at index surgery were associated with a higher risk of rebound phenomenon in the overcorrected segments. Patients' families should be well informed about all possible consequences of overcorrection beforehand.

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