



Correction of coronal plane deformities around knee in children with two-hole tension band plates

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A coronal plane deformity around knee is a common problem encountered in pediatric population. These angular deformities can be idiopathic in origin, or they can emerge secondary to congenital and acquired abnormalities.^[1] Persistent coronal plane deformities around knee (genu varum/valgum) could lead to meniscal tears, collateral ligament laxity, cartilage degeneration, and early osteoarthritis due to gradual mechanical axis disruption.^[2-4]

There are several treatment modalities defined in the literature for the coronal deformities around knee in pediatric population. In the previous literature, corrective osteotomies are the commonly used technique to treat these deformities. However, in the recent literature, hemiepiphysiodesis (guided growth) has become one of the most common surgical procedures alternative to the corrective osteotomies in coronal plane deformities around the knee encountered in pediatric population.^[5]

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ABSTRACT

Objectives: This study aims to present the 10-year results and complications of two-hole tension band plate hemiepiphysiodesis for coronal deformities around knee in a large population from a single center.

Patients and methods: Seventy-seven patients (46 boys, 31 girls; mean age 93±36 months; range, 22 to 181 months) who underwent temporary hemiepiphysiodesis around knee between January 2009 and January 2019 with two-hole tension band plates were retrospectively evaluated. Improvement of joint orientation angles and mechanical axis deviations, deformity correction rates, etiology groups, and complications were noted.

Results: A total of 166 bone segments (93 femurs, 73 tibias) were included in the study. Mean follow-up duration after the implantation was 36±17 (range, 12 to 88) months. Plates were removed at mean 18±8 (range, 7 to 47) months of implantation. Of the bone segments, 95.2% (n=158) responded successfully to the plates. Mean correction rate of mechanical lateral distal femoral angle in femoral valgum deformity was 0.94±0.43° (range, 0.17 to 2.22)/month and mean correction rate of mechanical medial proximal tibial angle in tibial valgum deformity was 0.62±0.36° (range, 0.11 to 1.55)/month. Mean correction rate of mechanical lateral distal femoral angle in femoral varum deformity was 1.3±0.8° (range, 0.48 to 2.92)/month and mean correction rate of mechanical medial proximal tibial angle in tibial varum deformity was 0.94±0.49° (range, 0.26 to 1.67)/month. The most common complication observed was rebound deformity seen in 41.2% (n=70) of the bone segments. Nine bone segments had persistent hemiepiphysiodesis despite plate removal. Four screw breakages (three metaphyseal and one epiphyseal) were observed.

Conclusion: Two-hole tension band plate hemiepiphysiodesis appears to be an effective and safe method for the correction of coronal deformities around knee.

Keywords: Complication, coronal plane deformity, guided growth, hemiepiphysiodesis, tension band plate.

The technique which is used for hemiepiphysiodesis/guided growth relies on the restrictive effect of the surgical procedure on the cellular activity of the growth plate as described by Hueter-Volkman principle. Different types of guided growth techniques have gained popularity

due to low complication rates. Guided growth can be accomplished by permanent way as described by Phemister.^[6] However, precise timing is mandatory in permanent technique thus it can result in over/under corrections. The second option in the light of the current literature is temporary guided growth. It utilizes different types of implants, is technically easier, and the growth plate activity resumes once the implant is removed.^[7] Temporary guided growth can be accomplished with a staple, transphyseal screw or a two-hole tension band plate. The literature comprises good outcomes for staples in terms of deformity correction.^[8] On the other hand, complications including pull-out of the staple, migration, breakage, and premature physeal closure were also reported.^[9] Correction with percutaneous epiphysiodesis with transphyseal screws (PETS), which was introduced by Métaizeau et al.,^[10] is also effective although the risk of permanent physeal closure was reported in studies.^[11]

Two-hole plate mediated guided growth working as a tension band was described by Stevens^[12] and this guided growth technique with two-hole tension band plates for correction of coronal plane deformities of knee has been widely accepted by pediatric orthopedic surgeons.^[13] However, studies with large populations with longer follow-up are still missing in the literature. In this study, we aimed to present the ten-year results and complications of two-hole tension band plate hemiepiphysiodesis for coronal deformities around knee in a large population from a single center.

PATIENTS AND METHODS

We retrospectively reviewed patients who were treated with guided growth utilizing two-hole tension band plating (Orthofix Medical Inc., Lewisville, TX, USA and TST Medical Devices, Istanbul, Turkey) between January 2009 and January 2019 in Department of Orthopedics and Traumatology of Hacettepe University Faculty of Medicine. A total of 209 bone segments (113 femurs, 96 tibias) of 98 children (61 boys, 37 girls) were analyzed. Patients treated for lower extremity coronal plane deformities (genu varum/valgum) who had regular full-length lower extremity weight-bearing radiographs, treated with two-hole tension band plate, and completed the treatment were included in the study. 166 bone segments (93 femurs, 73 tibias) of 77 patients (46 boys, 31 girls; mean age 93 ± 36 months; range, 22 to 181 months) met the inclusion criteria. The study protocol was approved by the Hacettepe University Faculty of Medicine Ethics Committee (GO 20/687). A written informed consent

was obtained from the legal guardian of each patient. The study was conducted in accordance with the principles of the Declaration of Helsinki.

Deformity analysis of the patients was performed pre- and postoperatively based on the full-length lower extremity weight-bearing radiographs with mechanical lateral distal femoral angle (mLDFA), mechanical medial proximal tibial angle (mMPTA), and mechanical axis deviation (MAD). Anatomic locations where the two-hole tension band plates were applied were decided based on joint orientation angles including mMPTA, mLDFA, and MAD measured as the distance in mm between the center of the knee and the mechanical axis line. Mechanical axis deviation values were given in genu varum bone segments as negative values and in genu valgum segments as positive values. Mechanical axis deviation evaluation was not used in patients who had a history of osteotomy. Surgical procedures were performed with previously described techniques by two pediatric orthopedic fellowship-trained surgeons as follows.^[12] The location where the plate would be applied was determined under fluoroscopic guidance. A 3 cm incision was performed on the sagittal plane centered on the physis and the bone was exposed without harming the periosteum. Then, the physis was marked with a needle to determine the optimal place for the plate. Following the fluoroscopic confirmation of the optimal plate placement on both anteroposterior and lateral planes, epiphysial and metaphysial screws were inserted. Patients were allowed to be weight bearing as tolerated immediately after surgery and they were followed-up regularly at four-month intervals until the desired correction was achieved. The plates were removed once the deformity was corrected (Figure 1 and 2). Deformity analysis was performed with full-length lower extremity weight-bearing radiographs in each control visit. Correction rate in mLDFA and mMPTA was calculated in degrees per month and MAD in millimeters per month based on preoperative and final measurements.

The deformity correction rates in joint orientation angles of the patients were analyzed based on etiology groups (Table I). Mechanical axis deviation correction rate was compared in patients treated for only femur, only tibia, or both femur and tibia. A subgroup analysis was performed on patients who had a prolonged treatment period (>24 months) with two-hole tension band plate. Complications were noted during the follow-ups.

Statistical analysis

Statistical analysis was performed using the IBM SPSS version 23.0 software

(IBM Corp., Armonk, NY, USA). Descriptive statistics were expressed as mean \pm standard deviation for continuous numerical variables, while categorical variables were expressed as the number of patients and percentage. Distribution of variables was measured with the Kolmogorov-Smirnov test. Statistical analysis was performed with paired sample t-test, Student t-test, and analysis of variance with posthoc Tukey test to compare mean values. The results were considered statistically significant when the p value was <0.05 .

RESULTS

A total of 140 bone segments had genu valgum and 26 bone segments had genu varum deformity. Mean follow-up duration after the implantation was 36 ± 17

(range, 12 to 88) months. Plates were removed at mean 18 ± 8 (range, 7 to 47) months of implantation. Of the bone segments, 95.2% ($n=158$) responded successfully to the plates and were corrected to normal alignment or slightly overcorrected.

Patients were evaluated separately in genu valgum and genu varum deformity groups. Mean age at surgery was 99 ± 38 (range, 37 to 181) months in genu valgum group and 71 ± 34 (range, 22 to 118) months in genu varum group. Mean follow-up duration in genu valgum and varum groups was 36 ± 18 (range, 12 to 88) months and 36 ± 11 (range, 18 to 54) months, respectively. Significant improvement at joint orientation angles and MAD distances was observed in both genu varum and genu

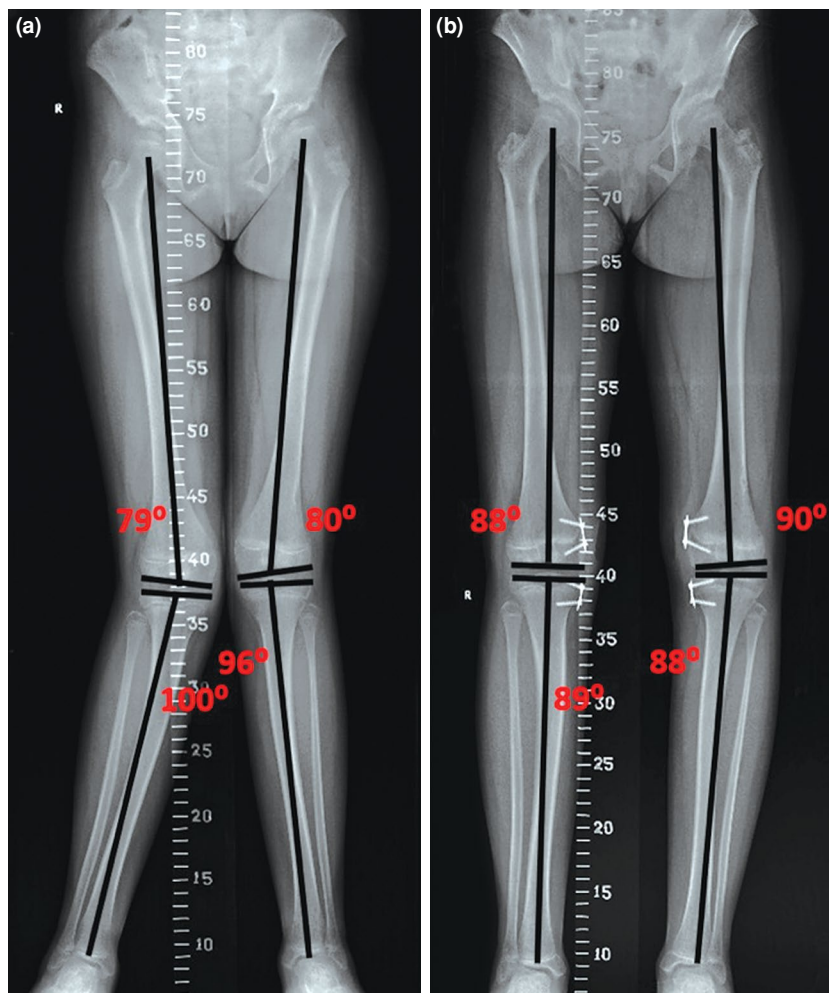


FIGURE 1. (a) Preoperative full-length lower extremity weight-bearing radiograph of a 10-year-old female patient with idiopathic bilateral genu valgum deformity. (b) Latest radiograph before implant removal following 12 months of treatment with two-hole tension band plates demonstrated correction of deformity.

valgum patients (Table II). Mean correction rate of mL DFA in femoral valgum and varum deformity was $0.94 \pm 0.43^\circ$ (range, 0.17 to 2.22)/month and $1.3 \pm 0.8^\circ$ (range, 0.48 to 2.92)/month, respectively. Mean correction rate of mMPTA in tibial valgum and varum deformity was $0.62 \pm 0.36^\circ$ (range, 0.11 to 1.55)/month and $0.94 \pm 0.49^\circ$ (range, 0.26 to 1.67)/month, respectively.

Deformity correction rates of joint orientation angles were measured based on etiology groups. Mean mL DFA correction rate was $1.01 \pm 0.37^\circ$ (range, 0.50 to 1.89)/month in idiopathic group (n=23), $1.14 \pm 0.64^\circ$ (range, 0.22 to 2.33)/month in dysplastic group (n=18), $0.95 \pm 0.43^\circ$ (range, 0.22 to 1.81)/month in endocrine-metabolic disease group (n=20), $1.12 \pm 0.60^\circ$

(range, 0.17 to 2.92)/month in congenital group (n=19), and $0.83 \pm 0.57^\circ$ (range, 0.21 to 2.22)/month (n=13) in acquired group (p=0.530). Mean mMPTA correction rate was $0.75 \pm 0.32^\circ$ (range, 0.12 to 1.27)/month in idiopathic group (n=14), $0.84 \pm 0.58^\circ$ (range, 0.11 to 1.67)/month in dysplastic group (n=13), $0.58 \pm 0.27^\circ$ (range, 0.20 to 1.08)/month in endocrine-metabolic disease group (n=14), $0.64 \pm 0.47^\circ$ (range, 0.12 to 1.38)/month in congenital group (n=13), $0.63 \pm 0.22^\circ$ (range, 0.48 to 0.89)/month in Blount's disease group (n=8), and $0.62 \pm 0.35^\circ$ (range, 0.15 to 1.55)/month in acquired group (n=11) (p=0.582).

Mean correction rate of MAD was 2.1 ± 1.7 (range, 0.10 to 7.63) mm/month in bone segments only treated for femoral deformity (n=46) and 1.8 ± 1.1

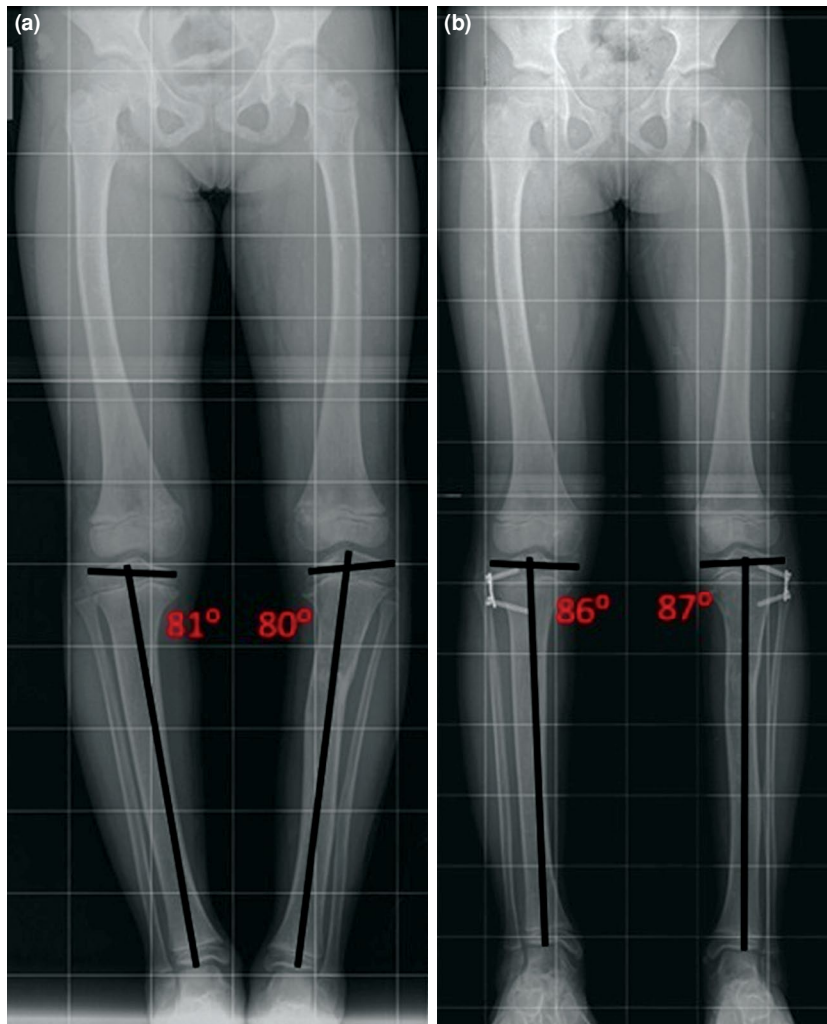


FIGURE 2. (a) Preoperative full-length lower extremity weight-bearing radiograph of a seven-year-old female patient with bilateral genu varum deformity due to Blount's disease. (b) Deformity was corrected in 23 months with two-hole tension band plate treatment.

TABLE I
Etiologies and numbers of patients in each group

Idiopathic (n=17)	Dysplastic (n=10)	n	Endocrine and metabolic diseases (n=13)	n	Congenital (n=19)	n	Blount's disease (n=5)	Acquired (n=13)	n
Epiphyseal dysplasia	6	6	Rickets	5	Fibular hemimelia	12	Post-traumatic	7	7
Mucopolysaccharidosis	3	3	Cystinosis	2	Proximal femoral insufficiency	2	Multiple hereditary exostosis	5	5
Pseudorheumatoid dysplasia	1	1	Renal failure	2	Fibrotic band	2	Epiphyseal tumor	1	1
			Fanconi anemia	1	Tibia pseudoarthrosis	2			
			Gaucher disease	1	Femoral condyle hypoplasia	1			
			Juvenile idiopathic arthritis	1					
			Thalassemia	1					

TABLE II

Pre- and postoperative mechanical lateral distal femoral angle, medial proximal tibial angle, and mechanical axis deviation distance measurements in genu varum (n=26 bone segments) and valgum (n=140 bone segments) patients

	Preoperative		Postoperative		p
	Mean±SD	Mean±SD	Mean±SD	Mean±SD	
mLDFA					
Genu varum	106±9.5°	87.5±5.0°			<0.001*
Genu valgum	79.5±4.2°	93.3±5.1°			<0.001*
mMPPTA					
Genu varum	79.6±5.3°	93.4±4.0°			<0.001*
Genu valgum	98.3±6.8°	88.6±8.5°			<0.001*
MAD					
Genu varum	-33±12.3 mm	10.7±6.2 mm			<0.001*
Genu valgum	32±15 mm	-7±14 mm			<0.001*

SD: Standard deviation; mLDFA: Mechanical lateral distal femoral angle; mMPPTA: Medial proximal tibial angle; MAD: Mechanical axis deviation.

(range, 0.14 to 4.58) mm/month in bone segments only treated for tibial deformity (n=25). Bone segments treated for both tibial and femoral deformities (n=82) on the ipsilateral extremity had mean 3.2±1.2 (range, 0.20 to 6.00) mm/month correction in the MAD which was higher compared to the isolated femur and tibial deformities (p<0.001, p<0.001).

Bone segments with prolonged treatment period (15 femurs, 12 tibias) were analyzed as a subgroup. At the annual follow-up, mean mLDFA correction rate of prolonged treatment group (0.52±0.27° [range, 0.17 to 0.92]/month versus 1.1±0.52° [range, 0.21 to 2.92]/month, p<0.001) and mean mMPPTA correction rate (0.44±0.40° [range, 0.11 to 1.21]/month versus 0.73±0.41° [range, 0.15 to 1.67]/month, p=0.033) were slower than the non-prolonged group. One valgus femur and one valgus tibia in the prolonged treatment group had persistent hemiepiphysiodesis effect after implant removal.

The most common complication observed was the rebound of the deformity seen in 70 bone segments (41.2%). We assumed a change in joint orientation angles 5° and above after implant removal as rebound deformity. In genu valgum deformity group, 40 (50.6%) femurs and 23 (37.7%) tibias had rebound deformity. In genu varum deformity group, two (7%) femurs and five (19%) tibias had rebound deformity. Two-hole tension band plates were re-implanted to rebounded four femurs and five tibias of the genu valgum groups.

Seven of the tibias including two fibular hemimelias, two rickets, one tibial pseudoarthrosis, one epiphyseal dysplasia, one post-traumatic, and one femur with femoral condyle hypoplasia who did not respond to the two-hole tension band plates in genu valgum group were treated with a corrective osteotomy (4.8%). The hemiepiphysiodesis effect persisted in five tibias (two valgus, three varus) and four femurs (two valgus, two varus) despite plate removal. The overall infection rate was 0.9% (two plates). Four screws (three metaphyseal and one epiphyseal) of three plates were broken. No plate breakage was observed.

DISCUSSION

In the current study, we present 95.2% (n=158) correction of coronal deformities around the knee in a pediatric population with two-hole tension band plates operated in a single center through a ten-year period.^[14,15] Only 4.8% (n=8) of the patients required corrective osteotomies.

Before the clinical application of hemiepiphysiodesis techniques, corrective osteotomies were the preferred method of treatment of coronal plane deformities around knee in pediatric population. Mycoskie^[16] reported 63% complication rate after corrective osteotomy including loss of alignment, vascular complications, pathologic fractures, wound infection, anterior and posterior angulation at the osteotomy site, tibial tubercle prominence, and patellofemoral malalignment. In the current study, only eight patients (4.8%) underwent a corrective osteotomy for deformity correction despite treatment with two-hole tension band plates and 95.2% of the patients avoided corrective osteotomies. Use of two-hole tension band plates may reduce osteotomy requirement in coronal plane deformity correction in children and osteotomy related complications.

The definition of success in the treatment of coronal plane deformities around knee has been commonly made based on the requirement of the corrective osteotomy. Stevens^[12] reported that 63 of 65 (97%) deformities were treated with guided growth, preventing corrective osteotomies. Burghardt and Herzenberg^[17] demonstrated treatment success in 50 of 54 bone segments (90%) with use of tension band plates. We successfully treated 158 of 166 bone segments (95.2%) with two-hole tension band plate hemiepiphysiodesis. The results of the current study were consistent with the previous literature.^[12,17]

Many previous studies have reported the overall correction rates for mL DFA, mMP TA, and MAD without grouping according to etiologies utilizing two-hole tension band plating.^[17-19] Danino et al.^[19] reported the results of a multinational study including 967 bone segments of 537 patients with different etiologies who were treated with two-hole tension band plates. They had a mean 0.77° month correction rate for mL DFA and 0.79° month correction rate for mMP TA. Burghardt and Herzenberg^[17] demonstrated a mean 0.65° (range, 0.05 to 1.67) month correction rate for mL DFA and 0.58° (range, 0.13 to 1.67) month correction rate for mMP TA. The authors also stated that they had overall 1.73 (range, 0 to 6.4) mm/month correction of MAD. We had mean 0.94±0.43° (range, 0.17 to 2.22)/month correction rate for mL DFA and 0.62±0.36° (range, 0.11 to 1.55)/month correction rate for mMP TA in genu valgum group and had 1.3±0.8° (range, 0.48 to 2.92)/month correction rate for mL DFA and 0.94±0.49° (range, 0.26 to 1.67)/month correction rate for mMP TA in genu varum group. We evaluated the change in MAD based on operated bone segments. Our mean correction rate of MAD was 2.1±1.7 (range, 0.10 to 7.63) mm/month in bone segments only treated for femoral deformity (n=46), 1.8±1.1 (range, 0.14 to 4.58) mm/month in bone segments only treated for tibial deformity (n=25), and 3.2±1.2 (range, 0.20 to 6.00) mm/month for bone segments treated for both tibial and femoral deformities (n=82). The overall correction rates for mL DFA, mMP TA, and MAD were consistent with the literature.^[17-19] As expected, mean correction rate of MAD was higher when both segments were operated on the ipsilateral extremity. In contrast to the results of Danino et al.^[19] and Burghardt and Herzenberg^[17] regarding overall deformity correction rates with heterogeneous etiologies, Guzman et al.^[20] reported a mean 0.32°/month deformity correction rate in mL DFA in a homogenous patient population including only idiopathic genu valgum patients. Mielke and Stevens^[8] stated that idiopathic bone segments have faster correction rate compared to bone segments with pathological growth plates. We had similar correction rate on joint orientation angles according to different etiology groups (idiopathic, dysplastic, endocrine-metabolic, congenital, Blount's disease, acquired). Although our aim in grouping the etiologies was to evaluate the patients in a more homogenous way, different etiologies in the same groups in the current study may have led to inconsistent results with the literature. Further research with more homogenous groups would be beneficial.

Patients treated with guided growth for coronal plane deformities around knee are commonly followed-up with full-length lower extremity weight-bearing radiographs in every three to six months.^[12,18] However, some patients have slower correction rates hence they may be exposed to higher radiation doses due to the full-length lower extremity weight-bearing radiographs obtained in every three to six months.^[21] We evaluated patients who had a prolonged treatment period (>24 months). Patients in the prolonged treatment group had slower deformity correction rate (mean mL DFA correction rate was $0.52 \pm 0.27^\circ$ [range, 0.17 to 0.92]/month, mean mMP TA correction rate was $0.44 \pm 0.40^\circ$ [range, 0.11 to 1.21]/month) in their annual follow-up compared to the non-prolonged treatment group (mean mL DFA was $1.1 \pm 0.52^\circ$ [range, 0.21 to 2.92]/month, mean mMP TA correction rate was $0.73 \pm 0.41^\circ$ [range, 0.15 to 1.67]/month). Considering the radiation exposure in the prolonged treatment group, patients who had a mean correction rate for mL DFA under 0.5° /month and for mMP TA under 0.4° /month in the annual follow-up may be followed-up with wider periods than four months or could be evaluated with regular anteroposterior knee radiographs.

Staple hemiepiphyseal arthrodesis has been one of the options for the correction of coronal deformities around knee since it was first described by Blount.^[22] Some serious complications such as implant breakage and physeal arrest have been reported in the previous literature.^[23] In addition, PETS has been an alternative technique for temporary epiphyseal arthrodesis. It provides minimally invasive surgery; however, has permanent arrest risk of the growth plates.^[11] Removal of staples and transphyseal screws within two years after implantation is recommended to avoid permanent physeal arrest.^[11,12] According to our results, two-hole tension band plate hemiepiphyseal arthrodesis can be continued for over two years until the achievement of target correction. However, we observed permanent hemiepiphyseal arthrodesis effect after implant removal of two bone segments (one valgus femur, one valgus tibia) in the prolonged treatment group (>24 months). In addition, a total of five tibias (two valgus, three varus) and four femurs (two valgus, two varus) had hemiepiphyseal arthrodesis effect despite plate removal. Adhesions, small bone bridges or physeal damage during plate insertion or removal may cause the hemiepiphyseal arthrodesis effect after implant removal. It can be concluded that two-hole tension band plate hemiepiphyseal arthrodesis

may also cause growth arrest as staple or PETS hemiepiphyseal arthrodesis.

Rebound growth of the deformity seems to be the main problem of the two-hole tension band plate hemiepiphyseal arthrodesis. Zajonz et al.^[18] reported a 3.8% rebound rate and Stevens^[12] reported a 12.8% rebound rate; however, the quantitative measurement of rebound growth in these studies has not been clearly defined. In the current study, we assumed the rebound phenomenon as a change in mL DFA and mMP TA 5° and above. We reported 41.2% rebound rate after implant removal. Since rebound growth was not the topic of the current study, we believe further studies defining the rebound growth after two-hole tension band plate hemiepiphyseal arthrodesis and investigating the underlying risk factors would be beneficial.

Since two-hole tension band plates offer dynamic construct in contrast to staples which provide a rigid construct over its length, implant breakage can still present in patients' follow-ups.^[23] Danino et al.^[19] reported 0.53% screw breakage rate in their large series and stated that all of the broken screws were metaphyseal. Burghardt et al.^[24] investigated the mechanical failures of two-hole tension band plates and reported that mechanical failures almost always occur at metaphyseal screws. None of the plates were broken in our patients but we observed 1.4% (n=4) screw breakage rate (three metaphyseal and one epiphyseal).

Its retrospective design and absence of a control group are the major limitations of our study. Body mass index values of the patients were not available in the current study which may have affected the results. Since these deformities may be caused by some rare disorders, we have presented the results of a diverse population. Further controlled studies with more homogenous groups would be enlightening.

In conclusion, two-hole tension band plate hemiepiphyseal arthrodesis appears to be an effective and safe method for the correction of coronal deformities around knee.

Declaration of conflicting interests

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