Faster Rate of Correction with Distal Femoral Transphyseal Screws Versus Plates in Hemiepiphysiodesis for Coronal-Plane Knee Deformity

Age- and Sex-Matched Cohorts of Skeletally Immature Patients

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Background: Hemiepiphysiodesis (guided-growth) procedures have become the primary method of treatment for coronal-plane knee deformities in skeletally immature patients. Two leading techniques involve the use of a transphyseal screw or a growth modulation plate. However, clinical references for the estimation of correction are lacking, and no consensus has been reached regarding the superiority of one technique over the other. Therefore, the purpose of this study was to compare the rates of correction for distal femoral transphyseal screws and growth modulation plates in age- and sex-matched cohorts with coronal deformities.

Methods: Thirty-one knees were included in each cohort on the basis of propensity scoring by chronological age and sex, and radiographic images were retrospectively reviewed preoperatively and postoperatively. Each case was measured for limb length, mechanical axis deviation (MAD), mechanical lateral distal femoral angle (LDFA), and bone age.

Results: Both the MAD and LDFA rate of correction significantly differed between the screw and plate cohorts. The MAD rate of correction was observed to be 0.42 ± 0.37 mm/week (1.69 mm/month) in the plate cohort and 0.66 ± 0.51 mm/week (2.64 mm/month) in the screw cohort. The LDFA rate of correction was observed to be 0.12° ± 0.13°/week (0.50°/month) in the plate cohort and 0.19° ± 0.19°/week (0.77°/month) in the screw cohort.

Conclusions: The current study provides simple clinical references for the rate of correction of MAD and the LDFA for 2 methods of hemiepiphysiodesis. The results suggest that transphyseal screws may correct coronal knee deformities during the initial treatment stage more quickly than growth modulation plates in distal femoral guided growth.

Level of Evidence: Therapeutic Level III. See Instructions for Authors for a complete description of levels of evidence.

Guided growth, or hemiepiphysiodesis, has become the new mainstay of correcting coronal-plane, lower-extremity deformities in skeletally immature patients[1]. Two leading methods of guided growth are the use of a physeal-bridging growth modulation plate (GMP) (Fig. 1) or a transphyseal screw (TS) (Fig. 2). A GMP consists of ≥1 screws in the metaphysis and in the epiphysis linked by a metal plate, which acts to restrict growth on one side of the physis while allowing natural growth on the other side to correct angular deformity[2]. The TS consists of 1 long screw that enters through the metaphysis to the epiphysis, or vice versa if in the antegrade position. This method also allows natural growth to correct angular deformity[3]. Because of the associated lower morbidity and greater safety, guided growth has replaced the use of osteotomies and has been shown to be effective for angular deformities in skeletally immature patients[4] while also allowing for a more flexible growth modulation than bone removal[1]. Low complication rates in children with lower-extremity deformities have been observed for both the use of TS[5-8] and GMP[6,8-12]. Neither technique has demonstrated notable rates of physeal arrest as a complication[3,13], and correction usually occurs very quickly, with both TS and GMP showing nearly full correction at 1 year[2,3].

The rate of correction is primarily measured by the mechanical lateral distal femoral angle (LDFA), a measurement of the

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alignment of the femoral condyles with the weight-bearing axis of the femur, which may be influenced by several factors. Age is likely a determining factor in the rate of correction, and children <10 years of age may show a quicker rate of correction because of their upcoming growth spurt. Bone age and limb length may also be correlated to the rate of correction, with some emphasizing the importance of bone age versus chronological age in peri- and post-pubertal children with respect to remaining growth[14-18]. The location of the physis may also be important, with femoral, tibial, and concurrent guided growth displaying different mean rates of correction[15,17,18]. The type of malalignment (varus or valgus) is also a likely factor in the rate of correction[15,17-19]; however, some say that the initial severity of malalignment is consequential[17], while others disagree[18].

While some literature suggests that TS may correct slightly more quickly[18,20,21], the results are heavily dependent on the population tested. There continues to be wide variation in the rate of correction for both TS and GMP, and no consensus has been reached on the preference of one method over the other. Additionally, to our knowledge, there are no matched cohort studies comparing TS and GMP. Therefore, the purpose of the current study was to compare the initial rate of correction for distal femoral transphyseal screws and growth modulation plates in sex- and age-matched cohorts with coronal deformities.

Materials and Methods

This retrospective study was approved by the local institutional review board.

Fig. 1
A patient with genu valgum is treated with a growth modulation plate.

Fig. 2
A patient with genu valgum is treated with a transphyseal screw.

Patient Selection

The data of 62 knees treated at a tertiary pediatric orthopaedic hospital between September 2016 and July 2021 were retrospectively reviewed (Fig. 3). Thirty-one knees were included in each matched cohort. In the plate group, 8 patients had bilateral involvement and 15 patients, unilateral. In the screw group, 12 patients had bilateral involvement, and 7 patients, unilateral. Measurements were taken from full-length standing radiographic images. Patients were included if they were treated with TS or GMP for guided growth in the coronal plane of the distal femur and had at least 1 full-standing image both pre- and post-intervention. As the focus of this study was idiopathic abnormal coronal-plane mechanical axis alignment (genu varum or genu valgum), patients with osteochondromatous proliferation or other abnormal growth-modulating syndromes and/or conditions severely affecting bone density were excluded from the study. Patients treated with multiple screws or plates were also excluded.

Age- and Sex-Matching of Cohorts

To create the age- and sex-matched cohorts, patients within the TS group were systematically matched with a patient of similar chronological age and the same sex from the larger GMP data set using propensity score-based analysis. A propensity score was generated for all possible patients on the basis of these 2 factors, and a subset of the GMP data set was chosen to maximize the overlapping propensity-score distribution between the GMP group and the smaller TS group according to a 1:

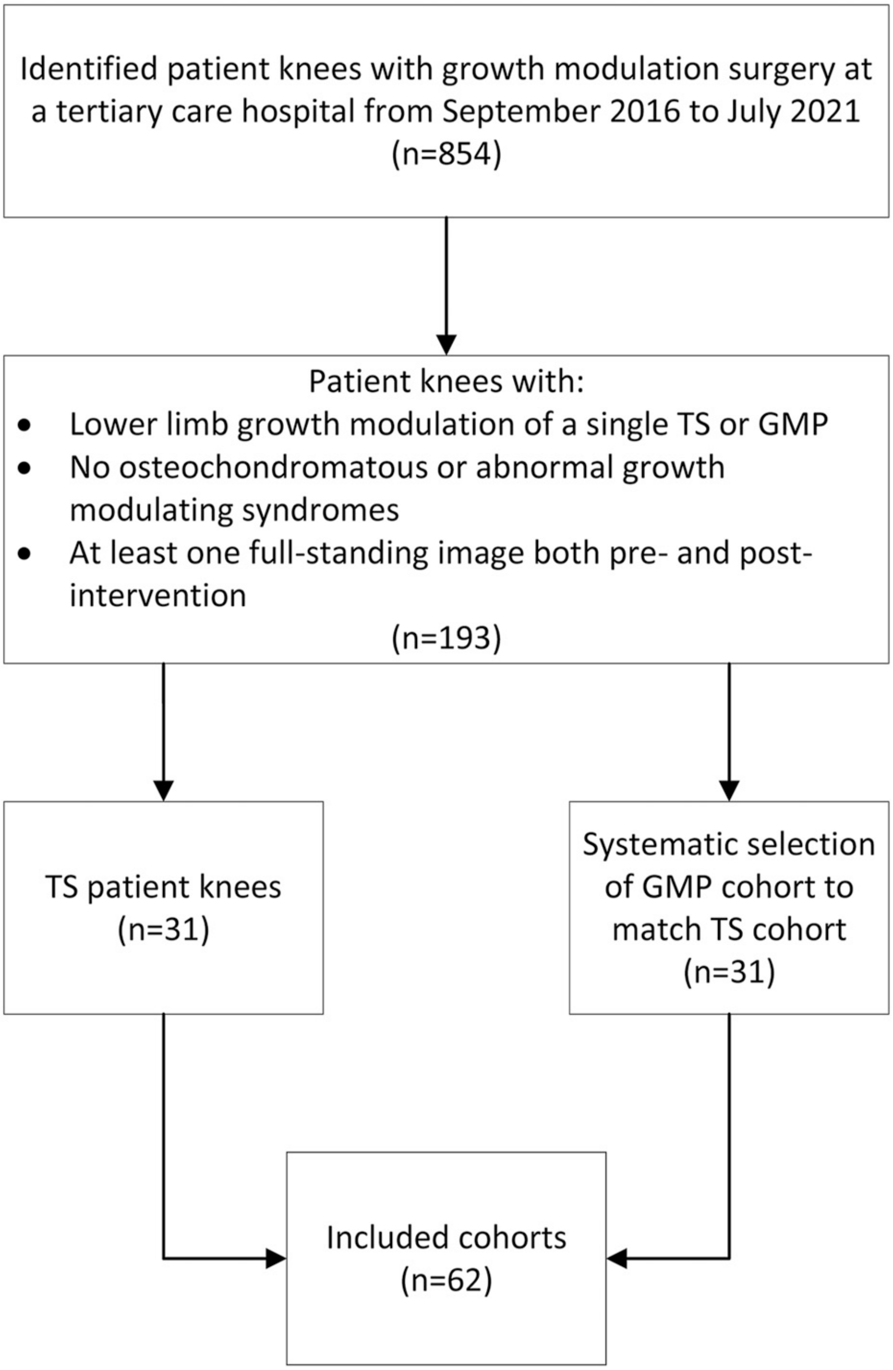

Fig. 3
Flowchart of patient selection.

1 nearest-neighbor method with a specified caliper distance of 0.3. Thirty-one knees in each group were identified and analyzed.

Bone age was calculated according to the method of O'Connor et al., a system of anteroposterior epiphyseal knee evaluation based on the findings and atlas by McKern and Stewart[22,23]. A score of 0 was given if a visible dark gap in the middle of the physis was observed. If ≥50% of the physis was radiolucent but the tibia showed largely incomplete union, a score of 1 was given. A score of 2 was given if <50% of the physis was radiolucent and the tibia showed nearly complete union. A score of 3 was given if complete union was observed but some amount of the physis remained radiolucent. If the physis was indistinguishable from normal bone, a score of 4 was given. Knee radiographs have shown validity for bone-age assessment in pediatric patients undergoing anterior cruciate ligament reconstruction[24], and the O'Connor system exhibited

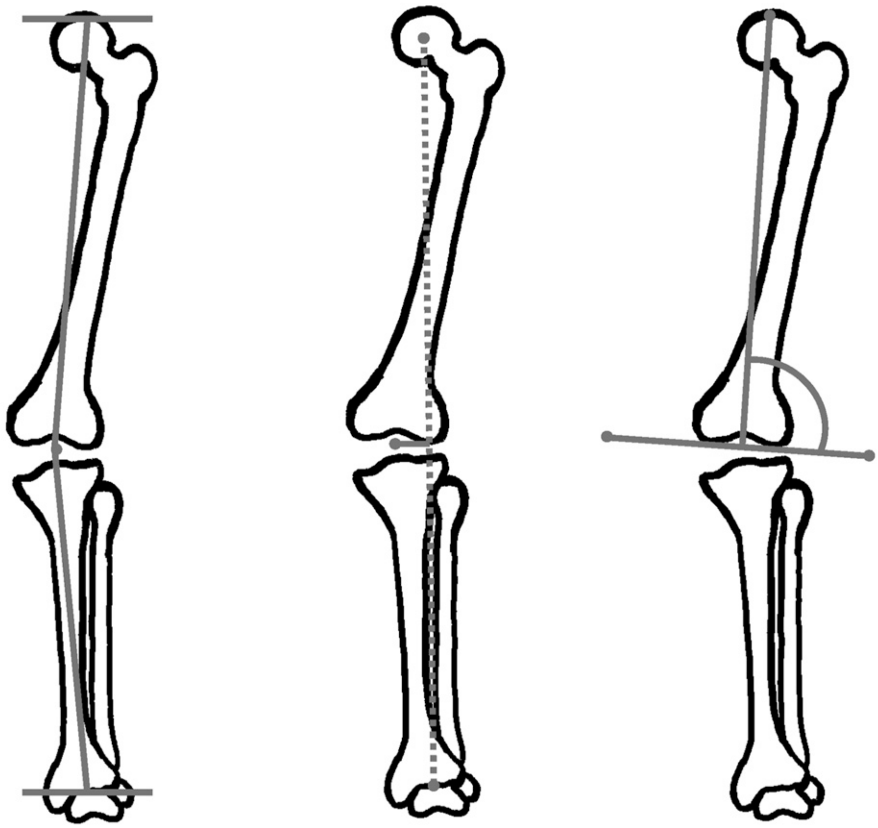

Fig. 4
Measurements of limb length, mechanical axis deviation (MAD), and lateral distal femoral angle (LDFA) are illustrated. MAD is measured as the length of the solid line.

good intraobserver reliability (0.841 to 0.956) according to a review of alternatives for EOS radiography[25].

Procedures

Guided-growth procedures were performed by 1 of 14 surgeons at the primary institution. Indications for guided growth were at the discretion of the individual surgeons, with common indications including patellar instability; lateral compartment chondral, meniscal, and/or osteochondral pathology; cosmetic appearance; or pain. Surgical techniques and postoperative protocols for guided growth were variable and based on surgeon preference but were consistent with prior described techniques[3,14,18]. For a percutaneous TS technique, a single cannulated screw was placed from proximal lateral to distal medial through the medial aspect of the distal femoral physis. The tension-band plate technique included the use of a single 2-hole plate that spanned the medial aspect of the distal femoral physis. Generally, patients were weight-bearing as tolerated in the postoperative period, with a return to full activity within 4 to 6 weeks.

Data were collected from patients' digital files, and measurements were conducted with the Sectra Workstation IDS7 (Sectra) by a single researcher. Surgery date, imaging dates, sex, race, ethnicity, and type of malalignment were collected from patients' medical records. Race was categorized as American Indian or Alaska Native, Asian, Black or African American, Native Hawaiian or Other Pacific Islander, Other, or White. Ethnicity was categorized as either Hispanic or Latino or Non-Hispanic or Latino. Measurements were taken for limb length, mechanical axis deviation (MAD), the LDFA, and bone age at all preoperative and postoperative dates. Only the first follow-up radiograph was included in this study to better observe the initial correction rate and to avoid observing possible overcorrection.

Limb length was defined as a 2-segmented measurement: first, from the apex of the femoral head to a central point on a tangent between the femoral condyles, and then, from that point to the bottom of the tibia, centered at the middle of the talus. Limb-length data were only collected for patients with EOS (EOS Imaging) images, which permit a long-leg radiographic image without projection bias[26]. MAD was measured as the magnitude of the distance between the mechanical axis and a central point on a tangent between the femoral condyles. The LDFA was measured as the magnitude of the angle between a line drawn from a central point on a tangent between the femoral condyles to

TABLE I Categorical Patient Demographics*

Variable	GMP *(no.)*	TS *(no.)*	P Value
Sex			0.442
Male	19	16	
Female	12	15	
Ethnicity			0.749
Hispanic or Latino	5	7	
Not Hispanic or Latino	26	24	
Race†			>0.999
White (includes Hispanic or Latino)	26	27	
Non-White	5	4	
Malalignment type			>0.999
Varus	2	2	
Valgus	29	29	
O'Connor bone age‡			0.445
0	4	1	
1	19	22	
2	8	8	

*GMP = growth modulation plate, and TS = transphyseal screw. †Non-White includes American Indian or Alaska Native, Asian, Black or African American, Native Hawaiian or Other Pacific Islander, or Other. ‡O'Connor bone age was calculated as 0 for a dark physis, 1 for a physis if ≥50% radiolucent and largely incomplete tibial union, and 2 for a physis if <50% radiolucent and nearly complete tibial union.

the apex of the femoral head and a line drawn along the bottom of both femoral condyles according to Paley's Principles of Deformity Correction[27]. Figure 4 illustrates the measurements.

Change in limb length was defined as the change in measurements between preoperative imaging and postoperative follow-up; however, the rate of change in MAD and the LDFA was calculated using the number of weeks between surgery and postoperative follow-up. The deviation in the LDFA was calculated as the magnitude of difference from 87.5°. The rate of change in MAD and the LDFA was also calculated with respect to the change in limb length. Changes in MAD and the LFDA were defined as positive if moving toward normal (0 mm and 87.5°, respectively) and negative if deviating further from normal. Additionally, the change in limb length was normalized by dividing the total change in limb length by the number of weeks between radiographic images to find the growth rate of the limb.

Statistical Analysis

Comparisons between the TS group and GMP group were accomplished by independent t tests or Mann-Whitney U tests with a 95% confidence interval, as appropriate, per Shapiro-Wilk normality testing. Categorical variables, such as sex, ethnicity, race, malalignment type, and O'Connor bone age, were compared using chi-square or Fisher exact tests, as appropriate. Statistical analysis was completed with R (R Foundation for Statistical Computing).

Source of Funding

No external funding was received for this study.

Results

A total of 62 age- and sex-matched patient knees were included in the analysis. Patient demographics are given in Table I. Twenty-one knees in the GMP group and 23 knees in the TS group had EOS imaging and were included in the limb-length analysis.

The average age (and standard deviation) at the time of the procedure was 12.9 ± 1.1 years. No significant differences in the time between imaging and procedure, preoperative limb length, postoperative limb length, or limb-length change were observed (Table II). Propensity score-based analysis yielded a standard difference of 0.196 for sex and 0.073 for age at procedure between the GMP and TS groups.

The mean MAD on both preoperative and postoperative imaging differed significantly ($p = 0.004$ and $p < 0.001$, respectively) between the GMP group and TS group (Table III). The mean change in MAD per week also differed significantly between the groups: the GMP group experienced 0.42 ± 0.37 mm/week (1.69 mm/month) of positive correction in MAD, whereas the TS group experienced 0.66 ± 0.51 mm/week (2.64 mm/month) of

TABLE II Continuous Patient Demographics*

Variable	GMP Mean (SD)	TS Mean (SD)	P Value
Age at procedure *(yr)*	12.9 (1.0)	12.8 (1.2)	0.927
No. of wks between preoperative image and procedure	9.1 (5.5)	7.3 (4.9)	0.185
No. of wks between procedure and postoperative image	24.8 (13.4)	18.7 (6.2)	0.052
Preoperative limb length *(mm)*	798.0 (72.0)	775.5 (67.0)	0.424
Postoperative limb length *(mm)*	817.1 (73.5)	789.8 (65.6)	0.250
Limb-length change per week *(mm/wk)*	0.7 (0.3)	0.9 (0.8)	0.466

*GMP = growth modulation plate, TS = transphyseal screw, and SD = standard deviation. Limb length was collected only for patients with EOS imaging (GMP, n = 21; and TS, n = 23). Limb-length change reflects the change from preoperative to postoperative imaging.

TABLE III Comparisons of Rates of Correction*

Variable	GMP Mean (SD)	TS Mean (SD)	P Value
Preoperative			
MAD *(mm)*	26.1 (8.7)	19.9 (8.0)	**0.004**
LDFA deviation *(deg)*	6.4 (3.7)	4.1 (1.7)	**0.003**
Postoperative			
MAD *(mm)*	16.1 (11.7)	6.8 (13.1)	**<0.001**
LDFA deviation *(deg)*	3.9 (3.7)	2.7 (2.3)	0.176
Correction			
MAD *(mm/wk)*	0.42 (0.37)	0.66 (0.51)	**0.003**
LDFA *(deg/wk)*	0.12 (0.13)	0.19 (0.19)	**0.019**
Correction relative to growth			
MAD *(mm/mm)*	0.62 (0.61)	1.38 (0.96)	**0.002**
LDFA *(deg/mm)*	0.19 (0.11)	0.39 (0.67)	**0.003**

*GMP = growth modulation plate, TS = transphyseal screw, SD = standard deviation, MAD = mechanical axis deviation, and LDFA = lateral distal femoral angle. Significant values are shown in bold. The LDFA was calculated as the mechanical LDFA, with a positive value indicating correction toward normal. LDFA deviation refers to the magnitude of difference from 87.5°. Correction relative to growth is included only for those with EOS imaging (GMP, n = 21; TS, n = 23).

positive correction in MAD (p = 0.003) (Fig. 5). A significant difference was found in the mean preoperative LDFA deviation from normal between the groups (p = 0.003) but not in the postoperative LDFA deviation. Furthermore, the GMP group experienced a mean of 0.12° ± 0.13°/week (0.50°/month) of positive correction in the LDFA, while the TS group experienced 0.19° ± 0.19°/week (0.77°/month) of positive correction in the LDFA (p = 0.019) (Fig. 6). When normalized to growth, the GMP group experienced a mean of 0.62 ± 0.61 mm of positive correction in MAD per mm of change in limb length, while the TS group experienced 1.38 ± 0.96 mm of MAD positive correction per mm of growth (p = 0.002). The LDFA was observed to have positive correction of 0.19° ± 0.11° per mm of growth in the GMP group compared with 0.39° ± 0.67° per mm of growth in the TS group (p = 0.003).

Discussion

Validity of the Matched Cohort

In the current study, we documented the rate of correction observed for transphyseal screws and growth modulation plates in an age- and sex-matched cohort and found that TS effected correction of MAD and the LDFA more rapidly. As suggested by past literature[14,15,17,18], age and/or growth stage may alter the rate of correction; however, change in limb length did not differ significantly between the TS and GMP groups. By using only EOS images for limb-length measurements, the potential confounder of image variability and projection error was minimized. Also the

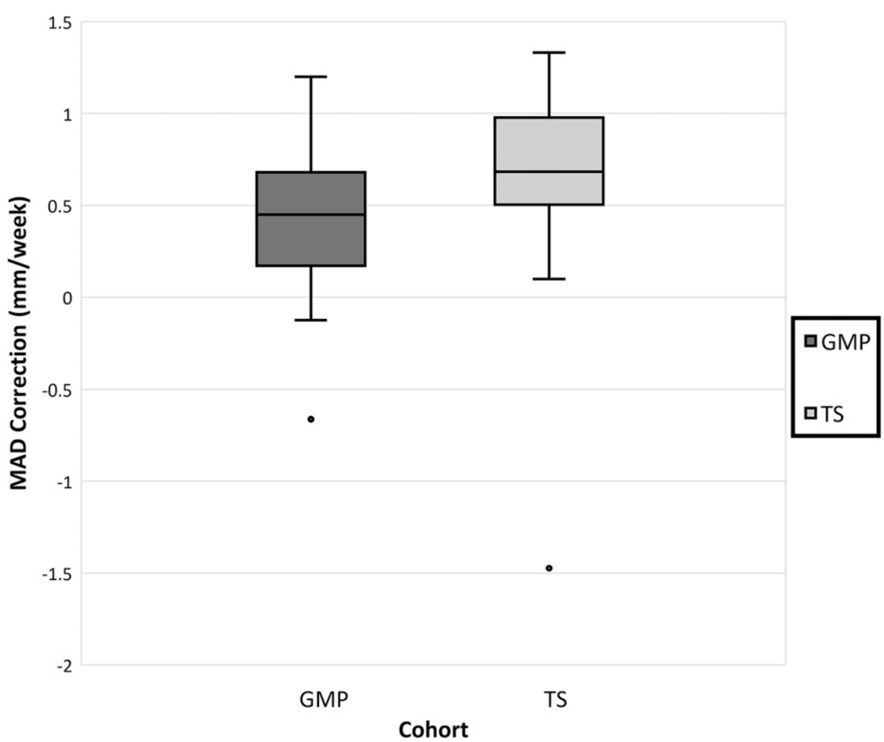

Fig. 5

Change in mechanical axis deviation (MAD) per week. GMP = growth modulation plate, and TS = transphyseal screw. The upper and lower bars correspond to the first and third quartile. The horizontal line represents the median. The whiskers represent a range of 1.5 times the interquartile range above the third quartile and below the first quartile, and the dots represent outliers.

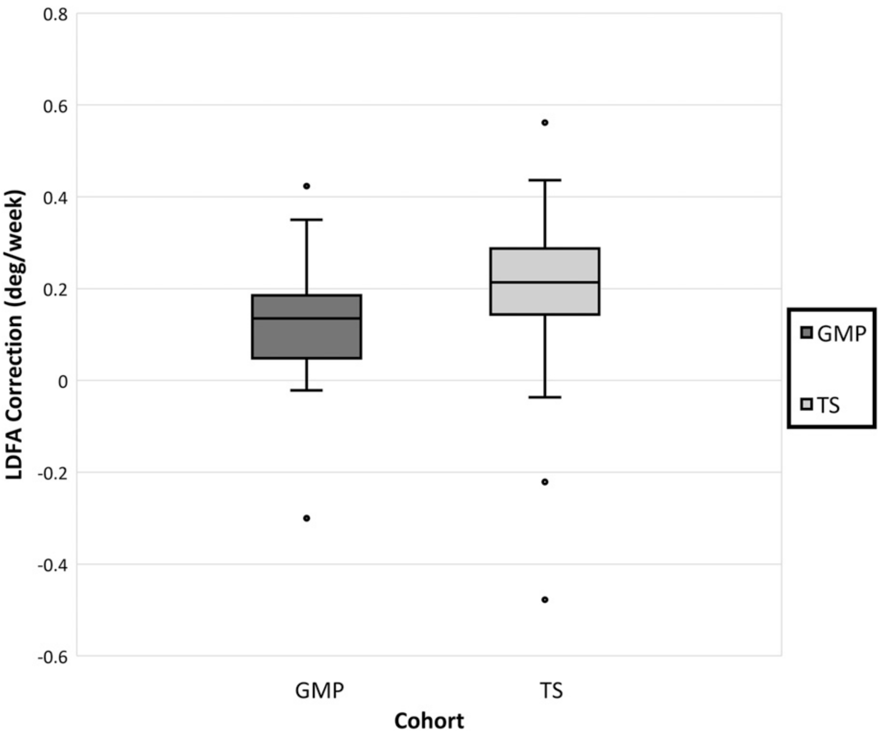

Fig. 6

Change in the lateral distal femoral angle (LDFA) per week. GMP = growth modulation plate, and TS = transphyseal screw. The upper and lower bars correspond to the first and third quartile. The horizontal line represents the median. The whiskers represent a range of 1.5 times the interquartile range above the third quartile and below the first quartile, and the dots represent outliers.

age and sex distribution in the TS cohort was similar to that of the larger GMP cohort. Other measurements at the knee remain valid, as EOS and standard radiographs have been shown to be similar near the center of the images[26,28,29]. Furthermore, the demographics and time between imaging and surgery also showed high similarity between the TS and GMP groups, further validating the cohort.

A significant difference between the TS and GMP groups was observed in MAD on both preoperative and follow-up imaging as well as in the preoperative LDFA deviation from normal. As the influence of the severity of malalignment on the achievable rate of correction is not agreed upon[17,18], we cannot be sure how the results may have been affected. Nonetheless, the GMP group demonstrated greater MAD at both time points, and yet it was observed that the GMP group had a slower rate of correction. If 2 patients were to have equal growth on 1 side of the physis, this may result in equal change in the LDFA; however, the patient who had the larger MAD would show disproportionately greater correction simply because of the longer distance needed to reach normal. Therefore, larger malalignment, if anything, would seem to lead to a faster rate of correction of MAD. As greater MAD was observed in the group with a smaller rate of MAD correction, it is unlikely that the severity of malalignment played a confounding role.

Rate of Correction

Given a lack of clinical references for the estimation of MAD and LDFA rates of correction, a primary goal of the current study was to provide more data for each measure. We found that the GMP group experienced an LDFA rate of correction of 0.50°/month compared with 0.77°/month in the TS group, which is similar to the findings of others in the literature. In a review by Bouchard, the average rate of correction with screws was 0.73° to 0.75°/month[13]. Baghdadi et al. reported 0.52°/month with plates[30]. In studying valgus deformity, Ko et al. observed that screws achieved 0.65° ± 0.25°/month and plates, 0.71° ± 0.23°/month, but the plate group showed greater occurrence of rebound while the screw group showed progressive genu varum after implant removal[31]. Park et al. reported a rate of correction of 0.92°/month with screws and 0.64°/month with plates[18]. A subsequent study by Park et al. revealed that transphyseal screws again achieved a quicker rate of correction, at 1.0° ± 0.4°/month, while plates achieved 0.8° ± 0.3°/month[21]. Shapiro et al. suggested that screws took less time than plates for optimal correction, working over twice as fast in correcting MAD and significantly faster in correcting the LDFA for all ages[20]. Therefore, the results presented in this study corroborate most values obtained for the LDFA rate of correction with screws and plates.

Comparison Between Screws and Plates

Overall, our data in the current study suggest that transphyseal screws achieve a faster initial rate of correction than growth modulation plates for both MAD and the LDFA in adolescent patients. As this is the first study, to our knowledge, to compare plates and screws in an age- and sex-matched cohort, future studies involving differing populations may serve to further corroborate this evidence. Recent studies of unmatched cohorts have suggested that screws may effect change more rapidly[18,20,21]. The authors of another study disagreed[31]; however, that study did not observe MAD as an outcome. Since the first use of TS and GMP in studies published in 1998[3] and 2007[2], respectively, much of the literature suggests that postoperative complications appear similar between the 2 methods[5-12]. However, while not directly evaluated within the current series, limited data point to higher rebound rates using the GMP technique, which may result in the loss of correction after removal of the growth modulation device[21,31]. Therefore, the results of this study should provide physicians with increased confidence in transphyseal screws as a useful and perhaps more rapid intervention for guided-growth procedures in skeletally immature patients with coronal knee deformities during the initial months of treatment. Specifically, transphyseal screws may be more fitting for skeletally immature patients who will soon reach maturity because of the faster rate of correction and similar or fewer postoperative complications.

Limitations

Primarily, this study was limited by its small sample size. While necessary to ensure adequate matching by age and sex, the results are at higher risk of being skewed by any cases demonstrating extreme over- or undercorrection. Additionally, while diagnosis was not considered in our analysis, patients with abnormal bone-growth syndromes or previous growth modulations were excluded, and therefore, most patients presented with idiopathic genu valgum or genu varum. Moreover, although a propensity score-based technique was used for matching, there is a possibility that unmeasured confounders may exist outside of the included variables. One of those confounders could be surgical technique in applying the devices. Finally, categorical variables did not differ significantly between the screw and plate groups, but they were not always distributed equally. The potential underrepresentation of younger bone age, genu varum, or certain demographics may result in skewed data. Future studies should aim to observe the correction rate over the treatment duration, considering the long-term efficacy and possible overcorrection effects.

Conclusions

The current study is the first, to our knowledge, to retrospectively compare age- and sex-matched cohorts of coronal knee growth modulation utilizing transphyseal screws and growth modulation plates. This study generated proposed simple clinical references of the estimation of the rate of correction of the LDFA and MAD for both hemiepiphysiodesis methods. The results also suggest that transphyseal screws may effect optimal correction measured by MAD and the LDFA more quickly than growth modulation plates for distal femoral guided growth in coronal knee deformities during the initial months of treatment. ■

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