Radiographic Assessment of Guided Growth: The Correlation Between Screw Divergence and Change in Anatomic Alignment

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Background: Assessment of changes in anatomic alignment following guided growth traditionally utilizes full-length standing radiographs which subjects patients to larger radiation doses than does a single anteroposterior radiograph of the knee. In an effort to minimize radiation exposure, the present study sought to determine whether changes in screw divergence (SD) of the 2-hole tension band plate used for hemiepiphysiodesis reliably predicts change in alignment.

Methods: A retrospective review was conducted involving all patients with genu varum or genu valgum treated with hemiepiphysiodesis at a single institution. Preoperative anatomic alignment of the femur, using anatomic lateral distal femoral angle (aLDFA) and anatomic femoral-tibial angle (aTFA), and intraoperative divergence of hemiepiphysiodesis screws were compared with postoperative imaging. Linear regression analysis determined the relationship between changes in SD and changes in alignment, and multivariate regression analysis explored the relationship between the angular changes being measured and various demographic factors.

Results: Linear regression analysis revealed that for every 1 degree change in SD there was a resultant 1.80 degrees of change in aTFA and 2.11 degrees of change in aLDFA. Change in aTFA is predicted by the equation: $\triangle aTFA = 0.41 \times |\triangle SD| + 1.39$. The change in aLDFA was predicted by the equation $\triangle aLDFA = 0.27 \times \triangle SD + 1.84$ with a R2 of 0.31. $\triangle$aTFA and $\triangle$SD had a correlation coefficient of 0.68 (95% confidence interval, 0.54-0.78.) $\triangle$aLDFA and $\triangle$SD had a correlation coefficient of 0.56 (95% confidence interval, 0.42-0.68). $\triangle$SD and sex were the only 2 independent predictors for $\triangle$aLDFA and $\triangle$aTFA as determined by multivariate regression analysis.

Conclusion: Change in coronal plane anatomic alignment in patients being treated for genu valgum or genu varum with hemiepiphysiodesis can be reasonably estimated by measuring the change in SD. Therefore, when following patients postoperatively, focal radiographic imaging of the knee can be utilized in lieu of standing full-length limb radiographs to limit radiation to the pelvis in this sensitive patient population.

Level of Evidence: Level III—retrospective comparative study.

Key Words: guided growth, genu valgum, genu varum, hemiepiphysiodesis

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In children, the anatomic alignment of the knee changes in predictable patterns as part of normal development, with ~15 degrees of varus angulation at birth, gradually progress to genu valgum, and eventually returning to what is considered normal physiologic alignment (slight valgus) around age 5 or 6.[1] Although most children's alignment corrects without intervention, some children may progress to pathologic genu valgum or genu varum. These deformities can cause significant problems, including pain, disruption of normal gait, and subsequent arthritis and joint instability if the abnormal alignment is left unaddressed.[2] When these deformities do not resolve spontaneously and physiological alignment is not achieved by early adolescence, surgical intervention is often indicated.[3]

Monitoring the changes in anatomic alignment which occur during guided growth, full-length standing radiographic films have been traditionally used. This view can allow for examination of multiple angles around the knee and examination of the mechanical axis of the lower extremity.[4] Specifically, the anatomic tibiofemoral angle (aTFA) has been shown to be a reliable measurement of alignment at the knee, and the anatomic lateral distal femoral angle (aLDFA) and anatomic medial proximal tibial angle (aMPTA) can be used as adjunct measurements to better quantify change.[5] As asymmetric growth occurs during hemiepiphysiodesis, the screws used in the construct diverge.[6] In modern systems, the 2 screws have

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the ability to diverge up to 30 degrees.[7] This study seeks to determine the relationship between a change in screw divergence (SD) and a change in knee alignment, and ultimately to provide a reliable measure for determining surgical correction.

METHODS

All patients between the ages of 3 and 18 diagnosed with genu varum and genu valgum treated with hemiepiphysiodesis using a 2-hole tension band plate between January 1, 2009 and January 1, 2015 were identified through a search of the medical records. For each individual patient identified, preoperative aTFA, aLDFA, and aMPTA were recorded using full-length standing lower extremity films. Initial SD was measured using intraoperative fluoroscopic images. At each subsequent clinic follow-up, aTFA, aLDFA, aMPTA, and SD was measured using full-length standing lower extremity films and compared to preoperative and intraoperative measurements to quantify the change in anatomic alignment and SD. Figure 1 illustrates the techniques used to obtain each measurement. For every patient, each subsequent postoperative image was used as an independent data point. A subset of limbs underwent simultaneous hemiepiphysiodesis of the distal femur and proximal tibia. In this subgroup of patients, only the aLDFA was used.

A subset of 15 patient films were reexamined 2 weeks after the initial review by both the original observers as well as an attending pediatric orthopaedic surgeon to determine intraobserver and interobserver reliability.

Statistics

Statistical analysis was performed using JMP Pro Software 10 (Cary, NC). For demographic data descriptive statistics were calculated and reported using frequency, range, and mean. A linear regression analysis (least squares method) was performed for modeling change in SD and the studied limb alignment variables. A multivariate logistic regression analysis was also performed to identify independent predictors of change in aTFA and aLDFA. Agreement correlation coefficients were calculated for intraobserver and interobserver reliability.

RESULTS

Demographics

A total of 31 patients and 48 limbs were identified including 13 males and 18 females. Table 1 provides details on demographic data. A subset of 12 limbs underwent simultaneous distal femoral and proximal tibial hemiepiphysiodesis. Most patients had multiple postoperative visits at which time full-length limb films were obtained. Each of these images were utilized as individual events to be compared to the preoperative imaging which resulted in a total of 107 distinct data points. Given that aTFA was not calculated for limbs that underwent simultaneous distal femoral and proximal tibial hemiepiphysiodesis, the total number of aTFA and aMPTA measurements utilized was 80 and the total number of aLDFA utilized was 107.

Linear Regression Analysis

For every 1 degree change in SD there was a resultant 1.80 degrees of change in aTFA and 2.11 degrees of change in aLDFA. Linear regression analysis allowed the relationship between △SD and changes in anatomic measurements to be mathematically modeled as a linear equation. The change in aTFA is predicted by the equation $\triangle aTFA = 0.41 \times \triangle SD + 1.39$ with a coefficient of determination (R^2) value of 0.50. The change in aLDFA was predicted by the equation: $\triangle aLDFA = 0.27 \times \triangle SD + 1.84$ with a R^2 of 0.31. Correlation was estimated by the Restricted Maximum Likelihood Method. △aTFA and △SD had a correlation coefficient of 0.68 [95% confidence interval (CI), 0.54-0.78]. △aLDFA and △SD had a correlation coefficient of 0.56 (95% CI, 0.42-0.68).

△aMPTA as compared to △SD was also analyzed. Linear regression modeling found no significant correlation between the 2 data sets. Furthermore, there was no significant change in aMPTA in patients undergoing isolated distal femoral hemiepiphysiodesis. These findings were expected due to the SD being measured from distal femoral constructs; however, the data is important as it serves as a control. The lack of relationship between △aMPTA and △SD confirms that angular correction in this patient population was a result of changes in the distal femur and not confounded by changes in tibial anatomy.

Multivariate Regression Analysis

△SD and sex were the only two independent predictors for △aLDFA and △aTFA. Individually, age at procedure (95% CI, 0.34-1.40), sex (CI, 1.48-5.26), weight (CI, 0.04-0.18), height (−0.23 to −0.05), and △SD (0.43-0.62) were all significant predictors of △aTFA. However, only △SD (CI, 0.23-0.39) and sex (CI −2.78 to −0.56) were predictors of △aLDFA. The R^2 was 0.71 for the △aTFA model and 0.45 for the △aLDFA model. Importantly, there was no correlation between △SD and the potential confounders of height, weight, sex, or ethnicity.

Interoberver and Intraobserver Control

Three different readers read the same films twice a week apart to obtain an interrater and intrarater agreement. The interrater agreement was 0.97 and the intrarater agreement was 0.94.

DISCUSSION

An approach commonly used today is guided growth through hemiepiphysiodesis. Surgical indications for guided growth are considered to be a mechanical axis lying outside of the 2 central quadrants of the knee in a child with at least 6 months of remaining skeletal growth.[8] Options for fixation include traditional staples as well as newer 2-hole plates (also called 8-plates) or 4-hole plates.[1,6,7,9,10] Wiemann et al[9] retrospectively reviewed 63 cases of angular correction about the knee

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FIGURE 1. Measurement of anatomic femoral-tibial angle (aTFA), screw divergence (SD), anatomic lateral distal femoral angle (aLDFA), and anatomic medial proximal tibial angle (aMPTA).

using staples and 8-plates and found no difference between the 2 fixations with regards to the amount of correction and overall complication rates (6.7% in "normal" physes and 27.8% in "abnormal physes").

Rates of correction have been reported as ~10 degrees per year,[9] but this is dependent on the site of hemiepiphysiodesis. Ballal et al[8] prospectively followed 25 children (37 legs) and found mean rates of correction to be 0.7 degrees per month for the distal femur, 0.5 degrees per month for the proximal tibia, and 1.2 degrees per month when combined. The total amount of achievable correction is dependent on multiple factors, most notably the amount of skeletal growth remaining. In patients who reach skeletal maturity prior to achieving full correction, osteotomy remains a viable option.

Clinically following patients undergoing guided growth requires radiographic assessment of coronal plane alignment. Standing full-length limb studies are generally used to assess the change in anatomic and mechanical axis of the knee.[6–11] Although this imaging technique is the gold standard for measuring angular deformity of the knee, it involves the administration of ~170.9 cGy*cm^2

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TABLE 1. Demographic Patient Data

Sex	Male: 13	Female: 18	
Race	White: 21	African American: 9	Mixed/other: 1
	Range		Mean
Age (y)	7-22		16
Height (cm)	101-179		145
Weight (kg)	16.1-85.4		42.6
No. follow-ups	1-4		2
Length of follow-up (mo)	0.4-22.9		8.8

The mean values listed are weighted averages based on total individual data points.

of radiation.[12] In comparison, the 66.0 cGy*cm^2 from a standard anteroposterior knee radiograph represents a 61% reduction in total radiation exposure and a near elimination of radiation to the pelvis and genitalia seen in full-length limb studies.[13] Although individual practices may vary in the number of x-rays performed during the course of follow-up, multiple studies are typically done, thus making the lower radiation exposure more significant than it would be with a single exposure. The present study provides an alternative strategy to reliably assess changes in anatomic alignment while minimizing radiation exposure to sensitive structures in a pediatric population. We found that for every 1.0 degree change in SD, there was 1.8 degrees in FTA and 2.11 degrees in aLDFA. The correlation between change in SD and change in anatomic alignment was not affected by height, weight, sex, or age.

One limitation of the study is the possibility of changes in relationship between the rate of SD and angular correction over time. In other words, we are unable to assess whether the magnitude of change in SD is dependent on the existing magnitude of SD. It could also be argued that a limitation of the study is the use of intraoperative fluoroscopy as opposed to standard radiography to establish our initial measurements of SD. However, if care is used to obtain consistent true anteroposterior imaging intraoperatively, differences in the imaging modality should not present a problem.

CONCLUSIONS

Change in coronal plane anatomic alignment in patients being treated for genu valgum or genu varum with hemiepiphysiodesis can be reasonably estimated by measuring the change in SD. Therefore, when following patients postoperatively, focal radiographic imaging of the knee can be utilized in lieu of standing full-length limb radiographs to limit radiation to the pelvis and genitalia in this sensitive patient population.

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