Change of limb alignment in Korean children and adolescents with idiopathic genu valgum

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Abstract

There has been no study evaluating the change of limb alignment for patients with genu valgum. The purpose of this study was to investigate the change of limb alignments in children and adolescents with idiopathic genu valgum through evaluating distal femur, proximal tibia, and knee joint line.

Consecutive children and adolescents, under the age of 18, with genu valgum were included. Mechanical tibiofemoral angle, mechanical lateral distal femoral angle, mechanical medial proximal tibia angle, and joint line convergence angle were measured. The rate of changes for each radiographic measurement were analyzed using a linear mixed model.

A total of 1539 teleradiographs from 273 individuals were included in this study. Linear mixed model showed that the change of limb alignment was significantly associated with age, but not associated with gender and laterality. The mechanical tibiofemoral angle was most valgus initially, decreasing until reaching its lowest value of 2.8° at 10 years old. The mechanical lateral distal femoral angle decreases from initial neutral alignment and increases in valgus continuously. The mechanical medial proximal tibia angle decreases from initial valgus and progresses to be neutral at around the age of 10. The joint line convergence angle decreases sharply from initial valgus alignment to 0° at the age of 5.

Valgus alignment in children with idiopathic genu valgum decreases until approximately the age of 10. In younger children, the tibia and joint line contribute most to overall valgus alignment; in older children, the femur contributes the most. Based on our results, we recommend monitoring patient limb alignment until it stabilizes around the age of 10, and then carefully planning and performing corrective surgery with complete consideration of the changing bony alignment.

Abbreviations: AIC = Akaike Information Criterion, BIC = Bayesian Information Criterion, JLCA = joint line convergence angle, LMM = linear mixed model, mLDFA = mechanical lateral distal femoral angle, mMPTA = mechanical medial proximal tibia angle, mTFA = mechanical tibiofemoral angle.

Keywords: age, children, genu valgum, linear mixed model

1. Introduction

Genu valgum, or “knocked knees”, can be aesthetically concerning and may cause orthopedic complications. Valgus alignment of the lower limbs generates an abnormal load on the lateral compartment of the knee, leading to progressive degeneration and osteoarthritis.\textsuperscript{[1–4]} Although some cases of genu valgum are associated with multiple epiphyseal dysplasia, neurofibromatosis, and osteochondromatosis, many are idiopathic which is a concern for parents and orthopedist surgeons alike.\textsuperscript{[5–7]} A previous study found a higher prevalence of genu valgum among female than male participants and among overweight and obese individuals than among those with normal body mass index.\textsuperscript{[2,8]}

It has been well documented that the normal alignment of the lower limb changes during early development; specifically, the alignment is varus at birth, neutral at the age of 1.5 years, and of greatest valgus by 3 years of age, which then self-corrects to a normal range by 6 to 7 years.\textsuperscript{[9–11]} However, valgus alignment does not always spontaneously correct and it can be considered idiopathic genu valgum.\textsuperscript{[12]} For patients with unacceptable cosmesis, knee discomport, patella malalignment, altered gait, and decreased physical activity due to deformity, operative treatment is required.\textsuperscript{[12]} While the patient is still growing, genu valgum is commonly treated with minimally invasive surgery such as hemiepiphyseodesis.\textsuperscript{[13–15]} However, once the lower limbs have stopped growing, a more invasive method of osteotomy must be selected, which involves extensive postoperative care and a greater chance of major complications.\textsuperscript{[16,17]} Therefore, accurate assessment and estimation of the progression of limb alignment is crucial to provide optimal treatment guidance for the idiopathic genu valgum patient.
Previous studies have aimed to provide reference values for alignment of the lower limbs in typically developing children. These studies, however, only measure the tibiofemoral angle and do not evaluate the specific angles of the femur, tibia, and knee joint. A previous study estimated the natural recovery of limb alignment for cohort with physiologic genu varum in terms and knee joint. A previous study estimated the natural recovery of change of limb alignment in genu valgum.

In addition, we developed the statistical models to estimate the mLDFA, mMPTA, and JCLA per year. The models were determined using intraclass correlation coefficients and 95% confidence intervals. Intraclass correlation coefficients were calculated on 36 randomly selected subjects of the study group (18 right and 18 left lower limbs selected randomly). Single limbs per subject were selected to ensure statistical independence. The remaining measurements were performed by a single rater, who took part in the consensus building session and interobserver reliability assessment.

2.2. Statistical methods

The Kolmogorov–Smirnov test was used to verify the normality of the distribution of continuous variables. Descriptive statistics included mean, standard deviation, and frequency.

For each of the 4 measurement angles (mTFA, mLDF, mMPTA, and JCLA), the rate of change was adjusted by multiple factors using a linear mixed model (LMM). The LMM was built to estimate the rate by incorporating the linear age effect and the quadratic age effect, with gender as the fixed effect and laterality and each subject as the random effect. The covariance structure was assumed as the variance component. The restricted maximum likelihood estimation was used to estimate parameters for the LMM. By examining the individual pattern of the annual changes in mTFA, mLDF, mMPTA, and JCLA along with age, an LMM with a random slope and a random intercept was suggested. Linear age effect, quadratic age effect, and gender effect were estimated to evaluate the progression rate of mTFA, mLDF, mMPTA, and JCLA per year. The models were validated for an estimation of the responses using the Akaike.

2. Materials and methods

This retrospective study was approved by the Institutional Review Board and conducted at Seoul National University Bundang Hospital. This investigation was carried out in accordance with the rules of the Declaration of Helsinki. Informed consent was waived due to retrospective design of this study.

The inclusion criteria were as follows: consecutive patients with genu varum between 2003 and 2020, patients under the age of 18, and patients with at least 2 standing teleroentgenograms with a minimum 6-month interval. Patients who had any underlying conditions affecting lower limb alignment, such as osteochondromatosis, post-traumatic genu valgum, multiple epiphyseal dysplasia, rickets, and neurofibromatosis, were excluded. If the patient had a bony surgical operation on the lower extremities, such as an osteotomy and hemiepiphysiosodesis, only the radiographs before the operation were considered.

Radiographs that were at least 6 months apart were analyzed, and teleroentgenograms taken in the supine position were excluded. If the patient had asymmetric genu valgum, only the limb with genu valgum was included.

Upon review of the medical records, the following information was obtained: gender, age, medical diagnosis, and laterality. Anteroposterior standing teleroentgenograms of the lower extremity were taken using a UT 2000 X-ray machine (Philips Research, Eindhoven, The Netherlands) at a source-to-image distance of approximately 180 cm at 50 kVp and 5 mAs. The patella was faced forward and both legs were weight-bearing. The images were taken with a single radiograph exposure of both lower limbs, with the X-ray beam centered at the knee. The radiograph images were retrieved and were measured using a picture archiving and communication system (IMPAX, Agfa Healthcare, Mortsel, Belgium).

2.1. Consensus building and interobserver reliability

A consensus building session was held to define the radiographic measurements. After a review of the literature, we chose 4 radiographic indices. The mTFA was defined as the angle formed between a line connecting the center of the proximal femoral epiphysis and the center of the distal femoral epiphysis, and a line connecting the center of the proximal tibial epiphysis and the center of the talus. The mTFA was expressed as a deviation from 180° with a positive value for valgus and a negative value for varus alignment. The mLDF was defined as the angle formed by a line connecting the center of the proximal femoral epiphysis and the center of the distal femoral epiphysis, and the knee joint line of the femur. The mMPTA was defined as the angle formed by a line connecting the center of the proximal tibial epiphysis and the center of the talar dome, and the knee joint line of the tibia. A smaller mLDF indicated greater valgus of the distal femur and a larger mMPTA indicated greater valgus of the proximal tibia. Joint line convergence angle (JLCA) was defined as the angle formed by the knee joint line of the tibia and the knee joint line of the femur. The JLCA was expressed with a positive value for valgus and a negative value for varus (Fig. 1). Because the epiphyses of younger children have not yet fully developed, they are not usually radiographically prominent. If the epiphysis was not fully ossified and could not be accurately measured, the plane of the correlative growth plate was chosen as an alternative line.

We considered the normal values of mTFA, mLDF, mMPTA, and JLCA to be \(-1°\) (range, \(-3\) to \(1\)), \(88°\) (range, \(85\)–\(90\)), \(87°\) (range, \(85\)–\(90\)), and 0 to 2°, respectively based on the reports of Paley. Prior to the main measurement, interobserver reliability was assessed. Thirty-six radiographs were randomly selected after sample size estimation. Two orthopedic surgeons (1 with 8 and the other with 5 years of experience) and a research assistant independently measured the radiographic indices without knowledge of the patients’ clinical information. Interobserver reliability was determined using intraclass correlation coefficients and 95% confidence intervals. Intraclass correlation coefficients were calculated on 36 randomly selected subjects of the study group (18 right and 18 left lower limbs selected randomly). Single limbs per subject were selected to ensure statistical independence. The remaining measurements were performed by a single rater, who took part in the consensus building session and interobserver reliability assessment.
Information Criterion (AIC) and the Bayesian Information Criterion (BIC). A smaller AIC or BIC value was preferred in terms of model selection. The model had a low AIC/BIC score.

All statistical analyses were performed using the SAS Statistical package, version 9.4 (SAS Institute, Cary, NC) and R (version 3.5.1) (R Foundation for Statistical Computing, Vienna, Austria); all statistical tests were two-tailed, confidence intervals were considered significant when they did not include zero, and P-values < .05 were considered significant.

3. Results

Our database included 377 patients younger than 18 years of age with genu valgum. After implementation of the exclusion criteria, a total of 1539 teleorontgenograms from 518 limbs in 273 individuals were included. The mean age at the initial visit was 5.2 ± 3.2 years (1.3–13.7 years), and the age at the time of teleorontgenograms ranged from 1.3 to 18 years. From 518 limbs measured, 351 were from males and 167 from females. The number of teleorontgenograms per subject ranged from 2 to 15.

The interobserver reliability for radiographic analysis of the frontal plane alignment was found to be excellent for all parameters, including the mTFA, mL DFA, mMPTA, and JLCA (Table 1).

Between the linear model and the quadratic model, that with lower AIC/BIC value was determined to be a better fit. The quadratic model was a better fit for mTFA (AIC, 7829; BIC, 7827) and JLCA (AIC, 6712; BIC, 711). The linear model was a better fit for mL DFA (AIC, 7179; BIC, 7175) and mMPTA (AIC, 6712; BIC, 6711). Statistical analysis showed that the change of limb alignment was significantly associated with age, but not associated with gender and laterality (Table 2).

LMM models indicate that mTFA is in greater valgus initially, decreasing until reaching its lowest value of 2.8° at 10 years old. The mL DFA decreases from neutral alignment and increases in valgus continuously. The mMPTA decreases from initial valgus and progresses to be neutral at around the age of 10. The JLCA decreases sharply from initial valgus alignment to 0° at the age of 5 (Fig. 2 and Table 3).

4. Discussion

The aim of this study was to evaluate the change of limb alignment in children and adolescents with idiopathic genu valgum using an LMM. Our model shows that the overall valgus alignment, mTFA, decreases until the age of 10 and then stabilizes. In younger children around 2 to 4 years of age, the valgus alignment of the lower limb can be attributed to valgus orientation of the proximal tibia and the joint line. As age increases, the valgus alignment of the proximal tibia and joint line decrease, and even become slightly varus, but the distal femur increases in valgus orientation. These 2 contrasting tendencies indicate that the valgus alignment of the lower limb in older children can be attributed to the valgus alignment of the distal femur. This finding is consistent with the common practice of treating genu valgum through hemiepiphysiodesis or osteotomy of the distal femur.

Several authors have reported the development of the knee angle in children based upon clinical measurements and radiological analysis. The decrease in valgus alignment occurred until the age of 6 to 7 years. However, our model suggests that valgus alignment improved until the age of 10 years for patients with idiopathic genu valgum. The difference may be
Figure 2. Changes of limb alignment with age in terms of mechanical tibiofemoral angle (mTFA), mechanical lateral distal femoral angle (mLDFA), mechanical medial proximal tibia angle (mMPTA), and joint line convergence angle (JLCA). The dashed line represents the estimation of alignment by a linear age effect, whereas the solid line represents the estimation of alignment by a quadratic age effect. The quadratic model was a better fit for mTFA and JLCA. The linear model was a better fit for mLDFA and mMPTA.

Table 2
The values of linear mixed model incorporated with linear age, quadratic age, sex, and direction of lower limb terms.

|        | Intercept | Age | Age² | Gender | Laterality |
|--------|-----------|-----|------|--------|------------|
| mTFA   | Coefficient | 8.55 | −1.1 | 0.05   | −0.03      | 0.21        |
|        | SE        | 0.38 | 0.10 | 0.01   | 0.17       | 0.16        |
|        | t         | 22.31| −11.01| 8.62  | −0.19      | 1.37        |
|        | p         | <.001| <.001| <.001 | 0.846      | –           |
| mLDFA  | Coefficient | 88.80| −0.34| –      | 0.11       | −0.75       |
|        | SE        | 0.66 | 0.02 | –      | 0.14       | 0.90        |
|        | t         | 135.27| −19.51| –     | 0.83       | −0.83       |
|        | p         | <.001| <.001| –      | .405       | –           |
| mMPTA  | Coefficient | 93.67| −0.44| –      | −0.01      | −0.20       |
|        | SE        | 0.70 | 0.02 | –      | 0.15       | 0.96        |
|        | t         | 134.23| −23.52| –     | −0.08      | −0.21       |
|        | p         | <.001| <.001| –      | .934       | –           |
| JLCA   | Coefficient | 3.93 | −1.08| 0.06   | 0.08       | −0.33       |
|        | SE        | 0.27 | 0.07 | 0.00   | 0.12       | 0.11        |
|        | t         | 14.74| −15.54| 13.51 | 0.68       | −3.08       |
|        | p         | <.001| <.001| <.001 | .499       | –           |

JLCA = joint line convergence angle, mLDFA = mechanical lateral distal femoral angle, mMPTA = mechanical medial proximal tibia angle, mTFA = mechanical tibiofemoral angle.

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due to the fact that we uniquely analyzed genu valgum patients. Inclusion of children that exhibit genu varum, in other studies, may offset the continuous change in alignment of children with genu valgum. Therefore, physician should consider that limb alignment can improve until the age of 10 years in patients with genu valgum when considering surgical correction.

The statistical models used in our study may be used as a reference guide and a predictive tool to assess genu valgum. By using the LMM, the following formulas can be used to predict the changes in limb alignments.

Predicted mTFA = current mTFA – 1.1 (age – current age) + 0.05 (age\(^2\) – current age\(^2\))

Predicted mL DFA = current mL DFA – 0.34 (age – current age)

Predicted mMPTA = current mMPTA – 0.44 (age – current age)

Predicted JLCA = current JLCA – 1.08 (age – current age) + 0.06 (age\(^2\) – current age\(^2\))

For example, if a patient with idiopathic genu valgum had 9° of mTFA at the age of 5 years, the predicted mTFA at age 10 would be: 9 to 1.1 (10–5)+0.05 (102–52)=7.25°. These estimated values of mTFA, mL DFA, mMPTA, and JLCA will allow orthopedists to better plan for possible surgical interventions and better inform patients and their parents whether surgery will be needed.

There are some limitations in our study. First, in younger patients without a prominent epiphysis, the growth plate was a required alternative since anatomies can cause inconsistency in data. However, measurement based on the growth plate was a required alternative since our study aimed to provide reference points for both younger and older children. Second, there were more males than females in our study, which may have caused a bias in our data; however, because the overall lower limb alignment in our study showed no statistical difference between gender, this appears to have minimal overall effect. This difference in the number of male and female genu valgum patients could be investigated in future studies.

5. Conclusions

Our study is, to the best of our knowledge, the first to investigate the changes of alignment specific to idiopathic genu valgum. Our results suggest that valgus alignment in idiopathic genu valgum decreases until approximately the age of 10. In younger children, the tibia and joint line contribute most to overall valgus alignment; in older children, the femur contributes the most. Based on our results, we recommend monitoring patient limb alignment until it stabilizes around the age of 10, and then carefully planning and performing corrective surgery with complete consideration for the femur, tibia, and joint line alignment. Furthermore, the statistical models developed in this study may be used as a reference guide and predictive tool to assess the patients with idiopathic genu valgum.

Author contributions

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