


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

Seo Ho Moon<sup>a</sup>, Soon-Sun Kwon, PhD<sup>b</sup>, Moon Seok Park, MD, PhD<sup>c</sup>, Nak Tscheol Kim, MD<sup>c</sup>,  
Ki Hyuk Sung, MD, PhD<sup>c,\*</sup> 

## 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 teleroentgenograms from 518 limbs of 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, mL DFA = 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.<sup>[1–4]</sup> 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.<sup>[5–7]</sup> 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.<sup>[2,8]</sup>

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.<sup>[9–11]</sup> However, valgus alignment does not always spontaneously correct and it can be considered idiopathic genu valgum.<sup>[12]</sup> For patients with unacceptable cosmesis, knee discomfort, patella malalignment, altered gait, and decreased physical activity due to deformity, operative treatment is required.<sup>[12]</sup> While the patient is still growing, genu valgum is commonly treated with minimally invasive surgery such as hemiepiphyseodesis.<sup>[13–15]</sup> 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.<sup>[16,17]</sup> Therefore, accurate assessment and estimation of the progression of limb alignment is crucial to provide optimal treatment guidance for the idiopathic genu valgum patient.

Editor: Mohammad Reza Amiri.

This research was carried out in accordance with the rules of the Declaration of Helsinki.

The authors have no funding and conflicts of interest to disclose.

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

<sup>a</sup> Department of Biology, Duke University, Durham, NC, <sup>b</sup> Department of Mathematics, College of Natural Sciences, Ajou University, Gyeonggi, Korea,

<sup>c</sup> Department of Orthopaedic Surgery, Seoul National University College of Medicine, Seoul National University Bundang Hospital, Gyeonggi, Korea.

\* Correspondence: Ki Hyuk Sung, Department of Orthopaedic Surgery, Seoul National University Bundang Hospital, 82 Gumi-ro 173 Beon-gil, Bundang-Gu, Sungnam, Gyeonggi 13620, Korea (e-mail: skh1219@naver.com).

Copyright © 2021 the Author(s). Published by Wolters Kluwer Health, Inc. This is an open access article distributed under the terms of the Creative Commons Attribution-Non Commercial License 4.0 (CCBY-NC), where it is permissible to download, share, remix, transform, and buildup the work provided it is properly cited. The work cannot be used commercially without permission from the journal.

How to cite this article: Moon SH, Kwon SS, Park MS, Kim NT, Sung KH. Change of limb alignment in Korean children and adolescents with idiopathic genu valgum. *Medicine* 2021;100:45(e27637).

Received: 17 May 2021 / Received in final form: 7 October 2021 / Accepted: 8 October 2021

<http://dx.doi.org/10.1097/MD.0000000000027637>

Previous studies have aimed to provide reference values for alignment of the lower limbs in typically developing children.<sup>[9–11,18]</sup> 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 of mechanical tibiofemoral angle (mTFA), mechanical lateral distal femoral angle (mLDFA), and mechanical medial proximal tibial angle (mMPTA).<sup>[19]</sup> However, there has been no study evaluating the change of limb alignment for patients with genu valgum. Comprehensive clinical evaluation of the lower limbs is important as valgus alignment may be caused by different parts of the leg.

Based on the fact that valgus limb alignment spontaneously resolved by 6 to 7 years of age during normal development, we hypothesized that valgus limb alignment in patients with genu valgum would not change over 7 years of age. The purpose of this study was to investigate the change of limb alignment in children and adolescents with idiopathic genu valgum through evaluation of the distal femur, proximal tibia, and knee joint line. In addition, we developed the statistical models to estimate the change of limb alignment in genu valgum.

## 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 valgum 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 hemiepiphysiodesis, 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.<sup>[20]</sup> 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 talar dome. The mTFA was expressed as a deviation from 180° with a positive value for valgus and a negative value for varus alignment. The mLDFA 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 mLDFA 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, mLDFA, mMPTA, and JLCA to be  $-1^\circ$  (range,  $-3$  to  $1$ ),  $88^\circ$  (range,  $85$ – $90$ ),  $87^\circ$  (range,  $85$ – $90$ ), and  $0$  to  $2^\circ$ , respectively based on the reports of Paley.<sup>[20]</sup>

Prior to the main measurement, interobserver reliability was assessed. Thirty-six radiographs were randomly selected after sample size estimation.<sup>[21]</sup> 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.<sup>[22]</sup> 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.<sup>[23]</sup> 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, mLDFA, mMPTA, JLCA), 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.<sup>[24]</sup> By examining the individual pattern of the annual changes in mTFA, mLDFA, mMPTA, and JLCA 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, mLDFA, mMPTA, and JLCA per year. The models were validated for an estimation of the responses using the Akaike



**Figure 1.** Representation of mechanical tibiofemoral angle (mTFA), mechanical lateral distal femoral angle (mL DFA), mechanical medial proximal tibia angle (mMPTA), and joint line convergence angle (JLCA).

Information Criterion (AIC) and the Bayesian Information Criterion (BIC).<sup>[25]</sup> 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,

**Table 1**

**Inter-observer reliabilities of radiographic measurements.**

Radiographic indices	ICC	95% CI
mTFA	0.987	0.976 to 0.993
mL DFA	0.864	0.779 to 0.923
mMPTA	0.818	0.711 to 0.895
JLCA	0.841	0.725 to 0.913

CI=confidence interval, ICC=intraclass correlation coefficient, JLCA=joint line convergence angle, mL DFA=mechanical lateral distal femoral angle, mMPTA=mechanical medial proximal tibia angle, mTFA=mechanical tibiofemoral angle.

a total of 1539 teleröntgenograms from 518 limbs in 273 individuals were included. The mean age at the initial visit was  $5.2 \pm 3.2$  years (1.3–13.7 years), and the age at the time of teleröntgenograms ranged from 1.3 to 18 years. From 518 limbs measured, 351 were from males and 167 from females. The number of teleröntgenograms 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  $2.8^\circ$  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  $0^\circ$  at the age of 5 (Fig. 2 and Table 3).

### 4. Discussion

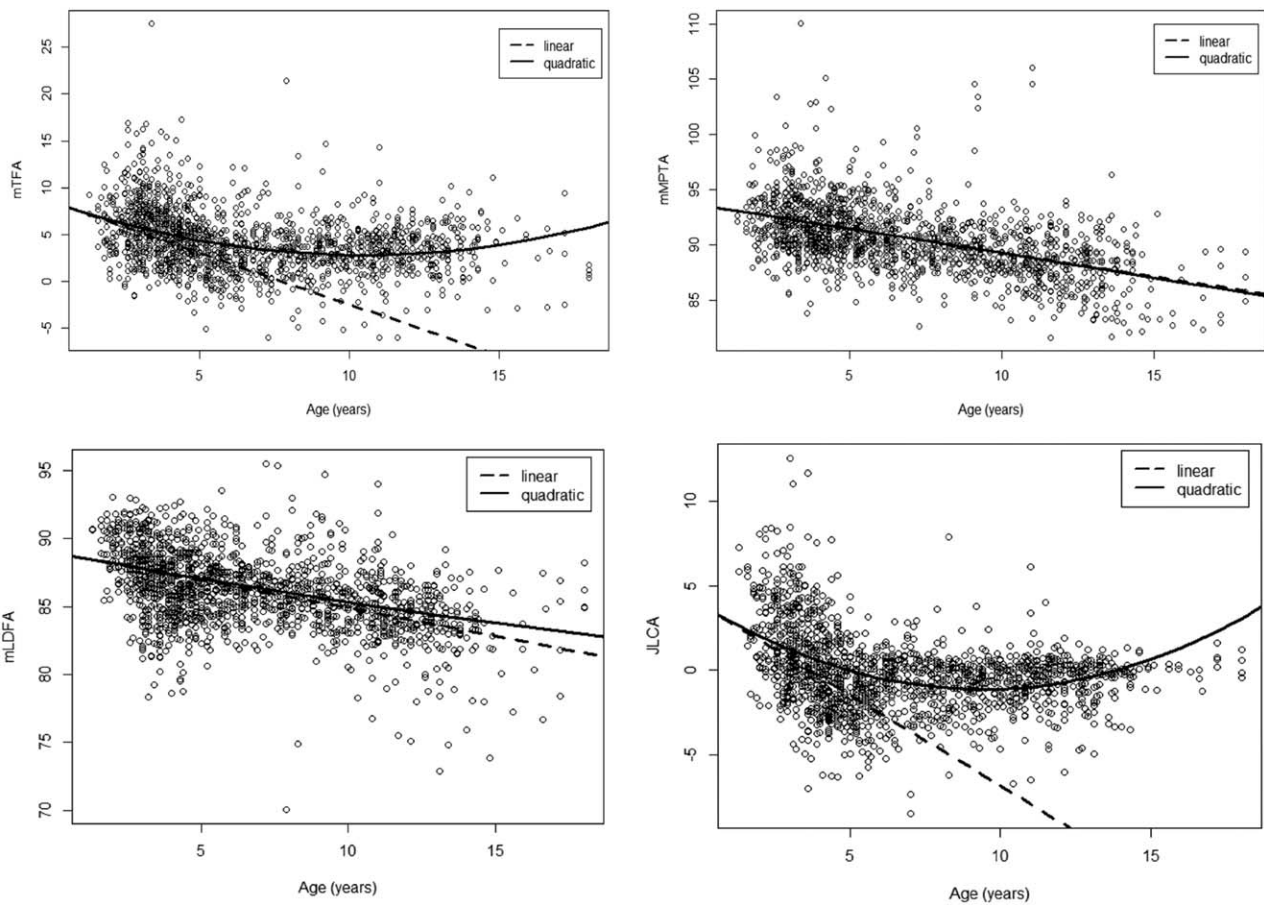
The aim of this study was to evaluate the change of limb alignment in children and adolescents with idiopathic genu valgum using an LMM. Our model shows that the overall valgus alignment, mTFA, decreases until the age of 10 and then stabilizes. In younger children around 2 to 4 years of age, the valgus 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.<sup>[26–28]</sup>

Several authors have reported the development of the knee angle in children based upon clinical measurements and radiological analysis.<sup>[9–11,18,29]</sup> 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

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

	Intercept	Age	Age <sup>2</sup>	Gender	Laterality
<b>mTFA</b>					
Coefficient	8.55	-1.1	0.05	-0.03	0.21
SE	0.38	0.10	0.01	0.17	0.16
<i>t</i>	22.31	-11.01	8.62	-0.19	1.37
<i>P</i>	<.001	<.001	<.001	.846	-
<b>mLDFA</b>					
Coefficient	88.80	-0.34	-	0.11	-0.75
SE	0.66	0.02	-	0.14	0.90
<i>t</i>	135.27	-19.51	-	0.83	-0.83
<i>P</i>	<.001	<.001	-	.405	-
<b>mMPTA</b>					
Coefficient	93.67	-0.44	-	-0.01	-0.20
SE	0.70	0.02	-	0.15	0.96
<i>t</i>	134.23	-23.52	-	-0.08	-0.21
<i>P</i>	<.001	<.001	-	.934	-
<b>JLCA</b>					
Coefficient	3.93	-1.08	0.06	0.08	-0.33
SE	0.27	0.07	0.00	0.12	0.11
<i>t</i>	14.74	-15.54	13.51	0.68	-3.08
<i>P</i>	<.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.



**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 3**  
**Estimation of limb alignment. Linear and quadratic model of LMM.**

Age	0	2	4	6	8	10	12	14	16	18
mTFA	8.6	6.6	5.0	3.8	3.1	2.8	2.9	3.5	4.4	5.8
95% CI	7.8 to 9.3	5.4 to 7.8	3.3 to 6.7	1.5 to 6.2	0.0 to 6.2	-1.1 to 6.7	-1.9 to 7.8	-2.4 to 9.3	-2.5 to 11.4	-2.4 to 13.9
mLDFA	88.8	88.1	87.4	86.7	86.0	85.4	84.7	84.0	83.3	82.6
95% CI	88.4 to 89.2	87.7 to 88.5	86.9 to 87.9	86.2 to 87.3	85.4 to 86.7	84.6 to 86.1	83.9 to 85.4	83.1 to 84.8	82.4 to 84.2	81.6 to 83.6
mMPTA	93.7	92.8	91.9	91.0	90.1	89.3	88.4	87.5	86.6	85.7
95% CI	93.3 to 94.0	92.3 to 93.2	91.4 to 92.4	90.4 to 91.6	89.5 to 90.8	88.5 to 90.0	87.5 to 89.2	86.6 to 88.4	85.6 to 87.6	84.7 to 86.8
JLCA	3.9	2.0	0.5	-0.5	-1.0	-1.1	-0.8	0.1	1.3	3.1
95% CI	3.4 to 4.4	1.2 to 2.8	-0.7 to 1.7	-2.1 to 1.2	-3.2 to 1.1	-3.9 to 1.6	-4.1 to 2.6	-4.0 to 4.11	-3.5 to 6.2	-2.6 to 8.7

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

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<sup>2</sup> - current age<sup>2</sup>)

Predicted mLDFA=current mLDFA - 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<sup>2</sup> - current age<sup>2</sup>)

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 (10<sup>2</sup>-5<sup>2</sup>) = 7.25°. These estimated values of mTFA, mLDFA, 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 used as an alternative line. Measurements based on 2 different 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

**Conceptualization:** Moon Seok Park, Ki Hyuk Sung.

**Data curation:** Seo Ho Moon, Soon-Sun Kwon, Nak Tscheol Kim.

**Formal analysis:** Soon-Sun Kwon.

**Investigation:** Nak Tscheol Kim.

**Methodology:** Soon-Sun Kwon.

**Project administration:** Ki Hyuk Sung.

**Resources:** Moon Seok Park, Ki Hyuk Sung.

**Supervision:** Moon Seok Park.

**Visualization:** Ki Hyuk Sung.

**Writing - original draft:** Seo Ho Moon.

**Writing - review & editing:** Seo Ho Moon, Nak Tscheol Kim, Ki Hyuk Sung.

## References

- [1] Elahi S, Cahue S, Felson DT, Engelman L, Sharma L. The association between varus-valgus alignment and patellofemoral osteoarthritis. *Arthritis Rheum* 2000;43:1874-80.
- [2] Shohat N, Machluf Y, Farkash R, Finestone AS, Chaïter Y. Clinical knee alignment among adolescents and association with body mass index: a large prevalence study. *Isr Med Assoc J* 2018;20:75-9.
- [3] McWalter EJ, Cibere J, MacIntyre NJ, Nicolaou S, Schulzer M, Wilson DR. Relationship between varus-valgus alignment and patellar kinematics in individuals with knee osteoarthritis. *J Bone Joint Surg Am* 2007;89:2723-31.
- [4] Felson DT, Niu J, Gross KD, et al. Valgus malalignment is a risk factor for lateral knee osteoarthritis incidence and progression: findings from the multicenter osteoarthritis study and the osteoarthritis initiative. *Arthritis Rheum* 2013;65:355-62.
- [5] Denduluri SK, Lu M, Bielski RJ. Development of genu valgum after removal of osteochondromas from the proximal tibia. *J Pediatr Orthop B* 2016;25:582-6.
- [6] Miura H, Noguchi Y, Mitsuyasu H, et al. Clinical features of multiple epiphyseal dysplasia expressed in the knee. *Clin Orthop Relat Res* 2000;184-90. doi: 10.1097/00003086-200011000-00025.
- [7] Crawford AH, Schorry EK. Neurofibromatosis in children: the role of the orthopaedist. *J Am Acad Orthop Surg* 1999;7:217-30.
- [8] Walker JL, Hosseinzadeh P, White H, et al. Idiopathic genu valgum and its association with obesity in children and adolescents. *J Pediatr Orthop* 2019;39:347-52.
- [9] Salenius P, Vankka E. The development of the tibiofemoral angle in children. *J Bone Joint Surg Am* 1975;57:259-61.

- [10] Sabharwal S, Zhao C, Edgar M. Lower limb alignment in children: reference values based on a full-length standing radiograph. *J Pediatr Orthop* 2008;28:740–6.
- [11] Yoo JH, Choi IH, Cho TJ, Chung CY, Yoo WJ. Development of tibiofemoral angle in Korean children. *J Korean Med Sci* 2008;23:714–7.
- [12] White GR, Mencia GA. Genu valgum in children: diagnostic and therapeutic alternatives. *J Am Acad Orthop Surg* 1995;3:275–83.
- [13] Castañeda P, Urquhart B, Sullivan E, Haynes RJ. Hemiepiphysiodesis for the correction of angular deformity about the knee. *J Pediatr Orthop* 2008;28:188–91.
- [14] Ballal MS, Bruce CE, Nayagam S. Correcting genu varum and genu valgum in children by guided growth: temporary hemiepiphysiodesis using tension band plates. *J Bone Joint Surg Br* 2010;92:273–6.
- [15] Farr S, Alrabai HM, Meizer E, Ganger R, Radler C. Rebound of frontal plane malalignment after tension band plating. *J Pediatr Orthop* 2018;38:365–9.
- [16] Yokoyama M, Nakamura Y, Onishi T, Hirano K, Doi M. Healing period after open high tibial osteotomy and related factors: can we really say that it is long? *Springerplus* 2016;5:123.
- [17] Sherman SL, Thompson SF, Clohisey JCF. Distal femoral varus osteotomy for the management of valgus deformity of the knee. *J Am Acad Orthop Surg* 2018;26:313–24.
- [18] Saini UC, Bali K, Sheth B, Gahlot N, Gahlot A. Normal development of the knee angle in healthy Indian children: a clinical study of 215 children. *J Child Orthop* 2010;4:579–86.
- [19] Akhmedov B, Ahn S, Chung CY, et al. Estimation of the recovery of physiological genu varum with linear mixed model. *J Pediatr Orthop* 2013;33:439–45.
- [20] Paley D. *Principles of Deformity Correction*. Berlin, Germany: Springer-Verlag; 2002.
- [21] Bonett DG. Sample size requirements for estimating intraclass correlations with desired precision. *Stat Med* 2002;21:1331–5.
- [22] Lee KM, Lee J, Chung CY, et al. Pitfalls and important issues in testing reliability using intraclass correlation coefficients in orthopaedic research. *Clin Orthop Surg* 2012;4:149–55.
- [23] Park MS, Kim SJ, Chung CY, Choi IH, Lee SH, Lee KM. Statistical consideration for bilateral cases in orthopaedic research. *J Bone Joint Surg Am* 2010;92:1732–7.
- [24] Kwon SS, Lee KM, Chung CY, Lee SY, Park MS. An introduction to the linear mixed model for orthopaedic research. *JBJS Rev* 2014;2:e5.
- [25] West B, Welch KB, Galecki AT. *Linear Mixed Models: A Practical Guide Using Statistical Software*. Boca Raton: Chapman & Hall/CRC; 2007.
- [26] Haviv B, Bronak S, Thein R, Thein R. The results of corrective osteotomy for valgus arthritic knees. *Knee Surg Sports Traumatol Arthrosc* 2013;21:49–56.
- [27] Nha KW, Ha Y, Oh S, et al. Surgical treatment with closing-wedge distal femoral osteotomy for recurrent patellar dislocation with genu valgum. *Am J Sports Med* 2018;46:1632–40.
- [28] Martínez G, Gündel A, Ruiz P, Cañete I, Hodgson F. Distal femoral hemiepiphysiodesis with screws and suture versus 8-plate for the treatment of genu valgum in children. *Orthop Traumatol Surg Res* 2019;105:751–5.
- [29] Oginni LM, Badru OS, Sharp CA, Davie MW, Worsfold M. Knee angles and rickets in nigerian children. *J Pediatr Orthop* 2004;24:403–7.