Reliability of Lower-limb Alignment Measurements in Patients With Multiple Epiphyseal Dysplasia

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Abstract

Background Although radiographic measurements are used in multiple epiphyseal dysplasia (MED) during correction of lower-limb alignment, the reliabilities of the measurements are unclear.

Questions/Purposes We determined interobserver and intraobserver reliabilities of the measurement methods used in evaluation of lower-limb alignment in MED.

Methods After consensus building, we included 10 radiographic measurement methods widely used to evaluate lower-limb alignment: mechanical tibiofemoral angle, anatomic tibiofemoral angle, mechanical axis deviation, joint line convergence angle, mechanical lateral distal femoral angle, anatomic lateral distal femoral angle, mechanical medial proximal tibial angle, anatomic medial proximal tibial angle, epimetaphyseal angle, and tibial metadiaphyseal angle. A study group consisting of 30 patients with MED was

compared with a control group consisting of 30 sex- and age-matched patients with genu varum and genu valgum. Mean age in both groups was 11 years (study group: SD, 2 years; range, 6–16 years; control group: SD, 2 years; range, 6–15 years). Interobserver and intraobserver reliabilities of all radiographic measurement methods were obtained and expressed by intraclass correlation coefficients (ICCs).

Results Mechanical tibiofemoral angle, anatomic tibiofemoral angle, and mechanical axis deviation were associated with high interobserver reliability (ICCs, 0.987, 0.985 and 0.982, respectively). Epimetaphyseal angle had the lowest reliability (ICC, 0.280). Intraobserver reliability exhibited similar trends, with mechanical axis deviation and mechanical tibiofemoral angle having the highest ICCs and epimetaphyseal angle the lowest.

Conclusions Mechanical tibiofemoral angle, anatomic tibiofemoral angle, and mechanical axis deviation are reasonably reliable measures of alignment in MED. The lateral distal femoral angle and medial proximal tibial angle (mechanical and anatomic) can be used as complementary measurement methods.

Level of Evidence Level II, diagnostic study. See Instructions for Authors for a complete description of levels of evidence.

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Each author certifies that his or her institution has approved the human protocol for this investigation, that all investigations were conducted in conformity with ethical principles of research. Informed consent was waived by the institution review board due to retrospective nature of the study.

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Introduction

Multiple epiphyseal dysplasia (MED) is a common form of skeletal dysplasia and is characterized by variable degrees of epiphyseal abnormality primarily involving the hips and knees [11, 25]. The prevalence of MED is approximately one in 20,000 [1, 27].

Occasionally, MED requires orthopaedic intervention. The goal of surgery is to correct limb alignments or joint

Table 1. Reliabilities of radiographic indexes of lower-limb alignment reported in previous studies

Study	Year	Etiology	Number of limbs	Mean age of patients (years)	Radiographic indexes	Interobserver reliability	Intraobserver reliability
Marx et al. [15]	2011	Osteoarthritis	42	NR	MAD	0.93	0.94
Sled et al. [23]	2011	Osteoarthritis	200	63 (50–79)	mTFA	0.99	0.99
					aTFA	0.99	0.99
					JLCA	0.88	0.91
					mLDFA	0.96	0.97
					mMPTA	0.94	0.96
Gordon et al. [8]	2009	Various, without skeletal dysplasia	35	11 (7–15)	MAD	0.99	0.99
					LDFA	0.92	0.96
					MPTA	0.98	0.99
Lavelle et al. [12]	2008	Blount's disease	42	NR	TMDA	0.80	0.88
Sabharwal et al. [21]	2008	Various, without skeletal dysplasia	30	< 18	TFA		0.92
					MAD	NR	0.99
					JLCA		0.84
					mLDFA		0.92
					MPTA		0.83
Feldman et al. [5]	2007	NR	60	NR	aLDFA	0.89	0.94
					mMPTA	0.77	0.78
Inan et al. [9]	2006	Achondroplasia	150	(6–10)	aTFA	0.93	0.98
					aLDFA	0.56	0.73
					MPTA	0.58	0.88
Specogna et al. [24]	2004	Osteoarthritis	42	44 (21–65)	MAD	0.99	0.99

m = mechanical; a = anatomic; TFA = tibiofemoral angle; JLCA = joint line convergence angle; LDFA = lateral distal femoral angle; MPTA = medial proximal tibial angle; MAD = mechanical axis deviation; TMDA = tibial metadiaphyseal angle; NR = not reported.

deformities. The contemporary methods used to manage MED are correction by osteotomy at the proximal tibial or distal femoral metaphysis, gradual correction using an external fixator and distraction osteogenesis, and asymmetric suppression of physeal growth using a staple, transphyseal screw, or tension band plate [3]. In addition, joint arthroplasty may be required for adult patients with MED. For all management techniques, measures of lower-extremity alignment have considerable influence on decision making and judging outcomes of the various procedures. Several studies reported on management of MED and provided the measures of lower limb malalignment, including tibiofemoral angle and mechanical axis deviation [3, 7, 28]. However, the reliability values for these measures were not provided. As radiographic methods used for measurement of lower-limb alignment often include joint lines and MED mainly affects the joint surfaces of bones, it often is problematic to perform the measurements. Thus, it is questionable whether the radiographic methods that are normally used in patients without skeletal dysplasia are relevant and reliable for use in patients with MED.

We therefore determined the interobserver and intraobserver reliabilities of radiographic measures of lower-limb alignment in MED.

Patients and Methods

We retrospectively compared two groups with respect to numerous measures of lower-limb alignment: a study group consisting of 30 patients with a clinical diagnosis of MED and a control group consisted of 30 sex- and age-matched patients having genu varum or genu valgum and without skeletal dysplasia. Each group had 14 boys and 16 girls. The mean age of patients in the study group was 11 years (SD, 2 years; range, 6–16 years) and the mean age in the control group was 11 years (SD, 2 years; range, 6–15 years). The inclusion criteria for the study group were patients with a clinical diagnosis of MED made since January 2003, based on patient history and findings of physical examinations and radiographs, and availability of a preoperative full-leg AP weightbearing teleroentgenogram (a radiograph taken sufficiently far away from the

Fig. 1A–D (A) An illustration and (B) a radiograph show a collapsed epiphysis in a patient with MED. (C) An illustration and (D) a radiograph show immature joint lines in normally developing children

and adolescents. Alternative joint lines are defined as lines tangential to growth plates.

subject that the beams are essentially parallel, in our study taken approximately 180 cm away from the patient). The inclusion criteria for the control group were patients with a clinical diagnosis of either genu varum or genu valgum, based on patient history and findings of physical examinations and radiographs; age and sex match with corresponding patients in the study group; and availability of full-leg AP weightbearing teleroentgenograms. Fifteen patients in the control group had infantile tibia vara whereas the other 15 had genu valgum. However, none of the patients in the study and control groups had surgery on the lower limbs at the time the teleroentgenograms were taken. None of patients in the control group had skeletal dysplasia, which was confirmed by examination of the medical records and radiographs. The exclusion criteria for the study and control groups were any trauma or surgical procedure, such as an osteotomy on lower limbs, or any concomitant disorder that might distort radiographic assessment of the main condition. All of the subjects were positioned standing AP, weightbearing, with patella forward. In the event of the proximal fibula overlapping the proximal tibia more than 60%, suggesting lack of

patella-forward position [26], the radiograph was excluded from the study. This study was approved by the institutional review board at our hospital.

We conducted sample size analysis to determine the minimum number of patients required. Minimum sample size for reliability was calculated as 20 lower limbs per group by setting the intraclass correlation coefficient (ICC) target as 0.85, 95% CI as 0.2, and number of raters as four [2]. The results of a single lower extremity in each patient were selected by block randomization and included in the statistical analysis to achieve statistical independence [17]. ICCs and their 95% CIs were used to summarize interobserver and intraobserver reliabilities and were calculated using a two-way random-effects model assuming a single measurement and absolute agreement [6].

Lower-extremity teleroentgenograms 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 mA. Radiographic images were retrieved using a PACS (IMPAX; Agfa Healthcare, Mortsel, Belgium), and radiographic measurements were performed using PACS software.

Table 2. Measurements of lower-limb alignment

Measurement	Axis 1	Axis 2	Definition of values
Mechanical tibiofemoral angle	Line between center of proximal femoral epiphysis and center of distal femoral epiphysis	Line between center of proximal tibial epiphysis and center of talar dome	Valgus (+) Varus (−)
Anatomic tibiofemoral angle	Line between center of proximal diaphysis of femur and center of distal diaphysis of femur	Line between center of proximal diaphysis of tibia and center of distal diaphysis of tibia	Valgus (+) Varus (−)
Mechanical axis deviation	Distance between mechanical axis and midpoint of tibial plateau expressed as percentage to ½ of width of tibial plateau		Valgus (−) Varus (+)
Joint line convergence angle	Tangent to distal femoral epiphysis or line parallel to growth plate of distal femur	Tangent to proximal tibial epiphysis or line parallel to growth plate of proximal tibia	Valgus (+) Varus (−)
Mechanical lateral distal femoral angle	Line between center of proximal femoral epiphysis and center of distal femoral epiphysis	Tangent to distal femoral epiphysis or line parallel to growth plate of distal femur	Increases as degree of varus increase
Anatomic lateral distal femoral angle	Line between center of proximal diaphysis of femur and center of distal diaphysis of femur	Tangent to distal femoral epiphysis or line parallel to growth plate of distal femur	Increases as degree of varus increase
Mechanical medial proximal tibial angle	Line between center of proximal tibial epiphysis and center of talar dome	Tangent to proximal tibial epiphysis or line parallel to growth plate of proximal tibia	Increases as degree of valgus increase
Anatomic medial proximal tibial angle	Line between center of proximal diaphysis of tibia and center of distal diaphysis of tibia	Tangent to proximal tibial epiphysis or line parallel to growth plate of proximal tibia	Increases as degree of valgus increase
Epimetaphyseal angle	Tangent to proximal tibial epiphysis or line parallel to growth plate of proximal tibia	Line between midpoint of base of ossification center and most distal point on medial beak of proximal tibial metaphysis	Varus (+) Larger value indicates more severe varus deformity
Tibial metadiaphyseal angle	Line between most distal point on medial beak and most distal point on lateral beak of proximal tibial metaphysis	Line perpendicular to anatomic axis of tibia	Valgus (−) Varus (+) Larger value indicates more severe varus deformity

Selection of radiographic measurements was based on a review of the literature. Along with specialty literature book reviews, we conducted a PubMed search using the key words “multiple epiphyseal dysplasia,” “radiography AND multiple epiphyseal dysplasia,” “genu varum OR genu valgum AND reliability,” and “reliability AND tibiofemoral angle.” One of the orthopaedic surgeons (KHS) reviewed the abstracts and articles, and most commonly referred radiographic measurement methods were pooled for consensus building. In total, we identified 39 radiographic measurement methods and modifications used to measure alignment in the lower limbs.

Consensus building sessions were held by five orthopaedic surgeons with experience in orthopaedics for 12 (MSP), 9 (KML), 8 (KHS), 5 (TWK), and 2 (BA) years. It was decided to choose measurement methods representing lower-limb alignment around the knee in the frontal plane. Unanimous agreement was reached on all measurement methods during consensus sessions. The 10 radiographic

measurement methods finally selected were mechanical tibiofemoral angle [16], anatomic tibiofemoral angle [16], mechanical axis deviation [3], joint line convergence angle [16], mechanical lateral distal femoral angle [11], anatomic lateral distal femoral angle [16], mechanical medial proximal tibial angle [16], anatomic medial proximal tibial angle [15], epimetaphyseal angle [4], and tibial metadiaphyseal angle [4, 13]. All selected measurement methods had high reliabilities in conditions where bone epiphyses were not compromised (Table 1) [5, 8, 12, 15, 20–24]. During the consensus building, the landmarks of lines and the use of alternative lines for children with underdeveloped physes were clarified. Because in children younger than 10 years and in some patients with MED the epiphyses were not prominent radiographically, the planes of correlative growth plates were chosen as “joint lines” (Fig. 1). We used alternative joint lines in joint line convergence angle, mechanical lateral distal femoral angle, anatomic lateral distal femoral angle, mechanical medial

Fig. 2A–D (A) An illustration representing an epiphyseal lesion in MED, (B) a radiograph of the leg of a patient with MED, (C) an illustration of genu varum, and (D) a radiograph of the leg of a patient with genu varum show the radiographic measurement method of the mechanical tibiofemoral angle (mTFA), which is formed by two lines:

the first line connects the center of proximal femoral epiphysis (dotted circle) and the center of distal femoral epiphyses and the second line connects the center of the epiphysis of the proximal tibia and the center of talar dome.

proximal tibial angle, anatomic medial proximal tibial angle, and epimetaphyseal angle. All measures were defined (Table 2). Mechanical tibiofemoral angle was the angle formed between the line connecting the center of proximal femoral epiphysis and the center of distal femoral epiphysis and the line connecting the center of proximal tibial epiphysis and the center of talar dome (Fig. 2). Anatomic tibiofemoral angle was the angle formed between the line connecting the center of the proximal diaphysis of the femur and the center of the distal diaphysis of the femur and the line connecting the center of the proximal diaphysis of the tibia and the center of the distal diaphysis of the tibia (Fig. 3). Mechanical axis deviation was the distance between the mechanical axis of the lower

extremity and the midpoint of the tibial plateau expressed as a percentage to $\frac{1}{2}$ of the width of the tibial plateau (Fig. 4). Joint line convergence angle was the angle between the line parallel to the growth plate of the distal femur and the line parallel to the growth plate of the proximal tibia (alternative joint lines). The mechanical lateral distal femoral angle was the angle formed by the line connecting the center of the proximal femoral epiphysis and the center of the distal femoral epiphysis and the line parallel to the growth plate of the distal femur (Fig. 5). The anatomic lateral distal femoral angle was the angle formed by the line connecting the center of the proximal diaphysis of the femur and the center of the distal diaphysis of the femur and the line parallel to the growth plate of the

Fig. 3A–D (A) An illustration representing an epiphyseal lesion in MED, (B) a radiograph of the leg of a patient with MED, (C) an illustration of genu varum, and (D) a radiograph of the leg of a patient with genu varum show the radiographic measurement method of the anatomic tibiofemoral angle (aTFA), which is formed by two lines:

distal femur. The mechanical medial proximal tibial angle was the angle formed by the line connecting the center of the proximal tibial epiphysis and the center of the talar dome and the line parallel to the growth plate of the proximal tibia (Fig. 6). The anatomic medial proximal tibial angle was the angle formed by the line connecting the center of the proximal diaphysis of the tibia and the center of the distal diaphysis of the tibia and the line parallel to the growth plate of the proximal tibia. The epimetaphyseal angle was the angle formed by the line parallel to the growth plate of the proximal tibia and the line connecting the midpoint of the base of the ossification center and the most distal point on the medial beak of the proximal tibial metaphysis. The tibial metadiaphyseal angle was the angle

the first line connects the center of the proximal diaphysis of the femur and the center of the distal diaphysis of the femur and the second line connects the center of the proximal diaphysis of the tibia and the center of the distal diaphysis of the tibia.

formed between the line connecting the most distal point on the medial beak and the most distal point on the lateral beak of the proximal tibial metaphysis and the line perpendicular to the anatomic axis of the tibia. In MED, the distal femoral epiphyses and proximal tibial epiphyses often are seriously compromised, causing difficulties for definition of midpoints in the distal femur and proximal tibia and consequently use of conventional radiographic measures. For that reason, we decided to take the midpoint in the widest part of the epiphysis or physis (whichever had greater value) in the planes perpendicular to the mechanical axis of the long bones.

We assessed the interobserver reliabilities of the radiographic measurement methods for four examiners (MSP,

Fig. 4A–D (A) An illustration representing an epiphyseal lesion in MED, (B) a radiograph of the leg of a patient with MED, (C) an illustration of genu varum, and (D) a radiograph of the leg of a patient with genu varum show the radiographic measurement method of mechanical axis deviation (MAD), which is defined as the distance between the mechanical axis of the lower limb and the midpoint of

the tibial plateau or growth plate (D) expressed as a percentage to $\frac{1}{2}$ of the width of the tibial plateau or growth plate (l): $MAD = D/l$ (%). Positive values are assigned for varus alignment and negative values for valgus. The long dotted line represents the mechanical axis drawn between the centers of the proximal femoral epiphysis (dotted circle) and the talar dome.

KHS, TWK, BA). Reliabilities were determined using ICCs and were performed on 15 right and 15 left randomly selected lower limbs in the study group (single limbs were selected to ensure statistical independence [17]) and on 15 with genu varum (nine right) and 15 with genu valgum (six right) in the control group. The interobserver reliabilities of the 10 radiographic measures were calculated using ICCs and the results of the four examiners. Intraobserver reliability sessions were performed using remeasurements made by one examiner 3 weeks after first measurements. All examiners were unaware of the measurements made by other examiners and patient information. Orders of

measurements were assigned randomly to each observer and all data were collected by a research assistant (HMK) who did not participate in the reliability sessions. All the calculations were obtained using SPSS® for Windows® (Version 15.0; SPSS Inc, Chicago, IL, USA).

Results

Mean mechanical tibiofemoral angle was 2° (SD, 9°) in the study group and 0° (SD, 5°) in the control group (Table 3). In the study group, mechanical tibiofemoral angle was

Fig. 5A–D (A) An illustration representing an epiphyseal lesion in MED, (B) a radiograph of the femur of a patient with MED, (C) an illustration of genu varum, and (D) a radiograph of the femur of a patient with genu varum show the radiographic measurement method of the mechanical lateral distal femoral angle (mLDFA), which is

formed by two lines: the first line connects the center of the proximal femoral epiphysis (dotted circle) and the center of the distal femoral epiphyses and the second line is parallel to the growth plate of the distal femur.

associated with the highest interobserver reliability with an ICC of 0.987 (95% CI, 0.977–0.993) followed by anatomic tibiofemoral angle (ICC, 0.985; 95% CI, 0.975–0.992) and mechanical axis deviation (ICC, 0.982; 95% CI, 0.965–0.991). In the control group, the highest ICC was for anatomic tibiofemoral angle (ICC, 0.990; 95% CI, 0.982–0.995) followed by mechanical tibiofemoral angle (ICC, 0.985; 95% CI, 0.965–0.993) and mechanical axis deviation (ICC, 0.978; 95% CI, 0.962–0.988). The ICC of the epimetaphyseal angle was 0.280 (95% CI, 0.09–0.509) in the study group and 0.265 (95% CI, 0.067–0.523) in the control group, which were the lowest ICCs encountered (Table 4).

The intraobserver reliability exhibited similar trends, with mechanical axis deviation (ICC, 0.996; 95% CI, 0.991–0.998) and mechanical tibiofemoral angle (ICC, 0.992; 95% CI, 0.984–0.996) having highest reliability in the study and control groups, respectively. Epimetaphyseal angle had the lowest reliability in the study (ICC, 0.609; 95% CI, 0.317–0.795) and control (ICC, 0.496; 95% CI, 0.162–0.729) groups (Table 5).

Discussion

MED is a genetic disorder that causes abnormalities in growth of bone epiphysis. Often the condition requires surgical intervention. The malalignment in lower extremities can be corrected by several orthopaedic surgical methods, however requiring thorough evaluation of the deformities. Evaluation of lower-limb alignment usually is performed by examining the patient's AP standing weightbearing teleroentgenograms and obtaining the measures of lower-limb alignment. Even though radiographic measurements are used in MED during correction of lower-limb alignment, the reliabilities of these measurements are unclear. We therefore determined interobserver and intraobserver reliabilities of methods used in evaluation of lower-limb alignment in MED.

Our study does have some limitations. First, we defined alternative joint lines, as we assumed the growth plate to be parallel to the plane of the epiphysis. However, because it often is not feasible to determine joint lines in children

Fig. 6A–D (A) An illustration representing an epiphyseal lesion in MED, (B) a radiograph of the tibia of a patient with MED, (C) an illustration of genu varum, and (D) a radiograph of the tibia of a patient with genu varum show the radiographic measurement method

of the mechanical medial proximal tibial angle (mMPTA), which is formed by two lines: the first line connects the center of proximal tibial epiphysis and the center of the talar dome and the second line is parallel to the growth plate of the proximal tibia.

Table 3. Patient demographics and summary of radiographic measurements for study and control groups

Variable	Study group	Control group
Number of patients	30	30 (15 physiologic genu varum, 15 physiologic genu valgum)
Age (years)*	11.4 ± 2.2 (6.5–15.8)	11.4 ± 2.1 (6.4–15.3)
Male:female (number of patients)	14:16	14:16
Right:left (number of patients)	15:15	15:15
Mechanical tibiofemoral angle (°)*	2.5 ± 9.3 (–20.5 to 22.5)	–0.1 ± 5.3 (–14.3 to 8.2)
Anatomic tibiofemoral angle (°)*	8.2 ± 9.6 (–15.6 to 27.3)	5.3 ± 5.2 (–8.4 to 13.9)
Mechanical axis deviation (%)*	–16.7 ± 83.7 (–209.3 to 168.5)	11.4 ± 46.6 (–63.0 to 130.5)
Joint line convergence angle (°)*	1.1 ± 3.6 (–7.2 to 11.9)	–0.5 ± 1.8 (–6.1 to 2.2)
Mechanical lateral distal femoral angle (°)*	86.3 ± 5.7 (75.0–97.4)	87.5 ± 2.9 (81.1–95.6)
Anatomic lateral distal femoral angle (°)*	80.3 ± 5.8 (69.6–91.3)	81.7 ± 2.8 (76.1–88.6)
Mechanical medial proximal tibial angle (°)*	88.9 ± 4.1 (77.0–97.8)	88.4 ± 3.1 (82.1–93.8)
Anatomic medial proximal tibial angle (°)*	88.8 ± 4.2 (76.3–98.3)	88.1 ± 3.2 (81.8–92.9)
Epimetaphyseal angle (°)*	11.3 ± 3.8 (5.7–23.7)	9.7 ± 3.1 (4.7–15.9)
Tibial metadiaphyseal angle (°)*	0.3 ± 5.3 (–12.7 to 16.9)	–0.4 ± 3.2 (–5.3 to 9.3)

* Values are expressed as mean ± SD, with range in parentheses; for definition of values, see Table 2.

with compromised or immature epiphyses on radiographs, we conditionally accepted the plane of the physis to be parallel to the plane of the epiphysis in the distal femur. In fact, the distal femoral epiphysis is slightly valgus compared with its physis [14]. Second, diagnoses in the study group were not confirmed by genetic testing. However, we believe not all patients with MED require genetic analyses for proper diagnosis. Third, interobserver reliability was

performed for four raters whereas intraobserver reliability was performed for one rater. However, interobserver reliability is more clinically useful than intraobserver reliability, and if researchers document an acceptable level of interobserver reliability in the appropriate context, no further reliability testing is necessary [10]. Fourth, in some types of MED, the ligamentous laxity may be expressed. In this event, ligamentous laxity will affect the long-leg

Table 4. Interobserver reliabilities for study and control groups

Measurement	Study group		Control group	
	ICC	95% CI	ICC	95% CI
Mechanical tibiofemoral angle	0.987	0.977–0.993	0.985	0.965–0.993
Anatomic tibiofemoral angle	0.985	0.975–0.992	0.990	0.982–0.995
Mechanical axis deviation	0.982	0.965–0.991	0.978	0.962–0.988
Joint line convergence angle	0.579	0.399–0.746	0.497	0.317–0.678
Mechanical lateral distal femoral angle	0.719	0.556–0.843	0.624	0.347–0.803
Anatomic lateral distal femoral angle	0.773	0.628–0.877	0.588	0.291–0.783
Mechanical medial proximal tibial angle	0.568	0.394–0.732	0.735	0.572–0.853
Anatomic medial proximal tibial angle	0.533	0.355–0.706	0.775	0.810–0.881
Epimetaphyseal angle	0.280	0.090–0.509	0.265	0.067–0.523
Tibial metadiaphyseal angle	0.754	0.608–0.866	0.580	0.372–0.771

ICC = intraclass correlation coefficient.

Table 5. Intraobserver reliabilities for study and control groups

Measurement	Study group		Control group	
	ICC	95% CI	ICC	95% CI
Mechanical tibiofemoral angle	0.992	0.984–0.996	0.992	0.984–0.996
Anatomic tibiofemoral angle	0.993	0.986–0.997	0.944	0.885–0.973
Mechanical axis deviation	0.996	0.991–0.998	0.981	0.960–0.991
Joint line convergence angle	0.645	0.370–0.816	0.637	0.362–0.810
Mechanical lateral distal femoral angle	0.894	0.790–0.948	0.954	0.904–0.978
Anatomic lateral distal femoral angle	0.932	0.863–0.967	0.912	0.819–0.958
Mechanical medial proximal tibial angle	0.882	0.766–0.942	0.897	0.797–0.949
Anatomic medial proximal tibial angle	0.810	0.639–0.905	0.890	0.785–0.946
Epimetaphyseal angle	0.609	0.317–0.795	0.496	0.162–0.729
Tibial metadiaphyseal angle	0.880	0.764–0.941	0.897	0.793–0.951

ICC = intraclass correlation coefficient.

methods (mechanical tibiofemoral angle, anatomic tibiofemoral angle, mechanical axis deviation) and joint line convergence angle in contrast to mechanical medial proximal tibial angle, epimetaphyseal angle, and tibial metadiaphyseal angle. Consequently, the measurements

obtained at supine and weightbearing positions may cause discrepancies in the outcomes owing to ligamentous laxity. We believe the possibility of ligamentous laxity should be considered. Fifth, while we showed the reliability of measurements for MED, the value of these measures for predicting outcome are not established yet. Since we retrospectively collected data for this study, we do not possess longitudinal data to establish the concurrent and predictive validity for clinical outcome. This will require further investigation. Sixth, the epiphysis and physal plate may show different degrees of maturation as the child advances in age. The age group studied ranged from 6.5 to 15.8 years with an average of 11.4 years. If we further divided the group according to age, there might be different reliability results. However, we had insufficient subjects for subgroup analysis, and therefore cannot account for the variability in maturation.

Of the 10 measurements of lower-extremity alignment we made, mechanical tibiofemoral angle, anatomic tibiofemoral angle, and mechanical axis deviation had the highest interobserver and intraobserver reliabilities, and these reliabilities were comparable to measurements in genu varum and valgum. Mechanical tibiofemoral angle, anatomic tibiofemoral angle, mechanical axis deviation, and joint line convergence angle mainly reflect overall alignment of the lower limb. Among these measurement methods, the first three had almost perfect reliability, whereas joint line convergence angle showed one of the lowest values. We believe the reason for this is that mechanical tibiofemoral angle, anatomic tibiofemoral angle, and mechanical axis deviation do not require measurement around bone epiphyses, where most irregularity is observed in MED. However, these three measurements provide little information on the location of the deformity. Moreover, hip and ankle deformities may influence mechanical tibiofemoral angle and mechanical axis deviation. We believe measurements in the distal femur and proximal tibia should complement the long-leg measures. Even though tibial metadiaphyseal angle showed substantial ICCs in the study group, we believe it should be used as a complementary method, since the ICCs were not confirmed by the control group.

As one of the possible procedures performed in MED, hemiepiphyseal stapling is suggested at earlier ages to ensure physal bone growth after the correction [3, 7]. Moreover, physal behavior on staple removal may be unpredictable in patients with abnormal growth plates [3, 18, 19], resulting in recurrence or growth arrest as possible complications of the procedure. In such cases, measurement of deformity caused by the joint line incongruence is more relevant, rather than the one used for study of the overall limb alignment. Naturally, joint line convergence angle may be assumed for evaluation of knee frontal plane

deformities. However, our results suggest joint line convergence angle has rather low reliability scores, and its relevance for evaluation of knee alignment in MED should be questioned.

We believe mechanical lateral distal femoral angle (Fig. 5) and mechanical medial proximal tibial angle (Fig. 6) should be used as supplementary methods for evaluation of malalignment in the distal femur and proximal tibia, respectively, in MED.

We conclude reliable lower-limb alignment measurement methods applicable for deformity assessment in MED are mechanical tibiofemoral angle, anatomic tibiofemoral angle, and mechanical axis deviation. Lateral distal femoral angle and medial proximal tibial angle (mechanical and anatomic) may be used as complementary measurement methods. Use of joint line convergence angle and epimetaphyseal angle is less reliable.

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