Published in final edited form as:

Rheumatol Int. 2011 January ; 31(1): 71–77. doi:10.1007/s00296-009-1236-5.

Reliability of lower limb alignment measures using an established landmark-based method with a customized computer software program

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Abstract

The objective of the study was to evaluate the reliability of frontal plane lower limb alignment measures using a landmark-based method by (1) comparing inter- and intra-reader reliability between measurements of alignment obtained manually with those using a computer program, and (2) determining inter- and intra-reader reliability of computer-assisted alignment measures from full-limb radiographs. An established method for measuring alignment was used, involving selection of 10 femoral and tibial bone landmarks. 1) To compare manual and computer methods, we used digital images and matching paper copies of five alignment patterns simulating healthy and malaligned limbs drawn using AutoCAD. Seven readers were trained in each system. Paper copies were measured manually and repeat measurements were performed daily for 3 days, followed by a similar routine with the digital images using the computer. 2) To examine the reliability of computer-assisted measures from full-limb radiographs, 100 images (200 limbs) were selected as a random sample from 1,500 full-limb digital radiographs which were part of the Multicenter Osteoarthritis (MOST) Study. Three trained readers used the software program to measure alignment twice from the batch of 100 images, with two or more weeks between batch handling. Manual and computer measures of alignment showed excellent agreement (intraclass correlations [ICCs] 0.977 – 0.999 for computer analysis; 0.820 – 0.995 for manual measures). The

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CONFLICT OF INTEREST

Conflict of interest statement: T. Derek V. Cooke, President and Principle Share Holder of OAISYS Inc.

computer program applied to full-limb radiographs produced alignment measurements with high inter- and intra-reader reliability (ICCs 0.839 – 0.998). In conclusion, alignment measures using a bone landmark-based approach and a computer program were highly reliable between multiple readers.

Keywords

Alignment; Diagnostic imaging; Radiology; Osteoarthritis, knee; Software

INTRODUCTION

Frontal plane lower limb malalignment is closely linked with the progression of knee osteoarthritis (OA) [1,2]. Therefore, measures of alignment are important for understanding the course of OA progression and for guiding the conservative and surgical management of knee OA [3–5].

Frontal plane lower limb alignment is generally measured from full-length radiographs of the whole limb in stance. Alignment may be defined as the angle between the mechanical axes of the femur and tibia. This angle has been termed the hip-knee-ankle (HKA) angle [3,6–8] or the mechanical axis angle [4–6,9]. Traditionally, measures have been made by hand, which require the clinician to draw lines on the radiographs representing the femoral and tibial mechanical or anatomic axes and to manually define the resulting angles. With the advent of digital imaging, radiographic film is being rapidly replaced by digital images. As the digital images cannot be evaluated manually, software programs with electronic tools have been developed to aid in the measurements of alignment from digital radiographs [10–16].

Comparisons between manual measures and computer-assisted analysis of alignment have indicated good reliability for both methods, with a tendency towards higher reliability using computer-assisted analysis [11–18]. Several of these studies investigated primarily the reliability of mechanical axis or anatomic axis angle measures [11,15–17]. Other studies have evaluated specific approaches to measure alignment and assessed the reliability of additional angular measures as well as leg lengths by hand and by computer [13,14,18]. However, to our knowledge, a systematic reliability evaluation of manual versus computer measures applying an overall alignment measurement system, including femoral and tibial bone geometry and leg length measures, has not been performed. In addition, analyses of these measures have not been employed using multiple readers.

In this two-part study, we evaluated a well-established method for measuring frontal plane limb alignment that uses bone landmarks to define a diverse set of alignment and linear parameters [3,7,8,10,18]. A custom software program (Horizon Surveyor, version 1.5, OAISYS Inc.) was developed for the computer-assisted analysis. The first study evaluated the method using schematics of limb deformities drawn with the aid of AutoCAD® 2006 software (Autodesk Inc., San Rafael, CA, USA). The purpose of this first part was to compare the reliability of manual and computer measures of alignment obtained using multiple readers. We postulated that semiautomated computer analysis of lower limb alignment would generate measurements with similar or greater reliability compared to those made only by hand.

In the second part of the study, our purpose was to determine the reliability of the same set of alignment and leg length measures using the landmark-based approach when computer-

assisted analysis was applied to a large sample of full-limb radiographs. We hypothesized that these measures would demonstrate high inter- and intra-reader reliability.

MATERIALS AND METHODS

Methods common to both studies

Landmark-based Approach to Measuring Alignment—The approach selected for measuring frontal plane limb alignment uses ten bone landmarks of the femur and tibia to derive the frontal plane limb geometry [3,7,8,10,18]. The HKA angle was measured as the angle formed by the intersection of the femoral mechanical (FM) and tibial mechanical (TM) axes (Fig. 1). The FM axis was formed by a line from the centre of the femoral head to the mid-condylar point of the distal femur [19], while the TM axis was produced by a line from the centre of the tibial plateau (interspinous, intercruciate midpoint) to the centre of the tibial plafond distally [20]. The HKA angle was expressed as degrees of deviation from 180°, such that the HKA angle = 0° in neutral alignment. Varus angles were denoted as negative values and valgus angles as positive [3,8].

Also measured were the angular contributions of the femur and tibia to overall alignment and the angle formed by the femoral and tibial joint surface tangents. These angles included: condylar hip (CH), the angle of the femoral condylar tangent with respect to the FM axis; plateau ankle (PA), the angle between the tibial margin tangent and the TM axis; and condylar plateau (CP), the angle between the femoral and tibial joint surface tangents, which represents the joint's orientation (Fig. 1). These angles are related to the HKA angle, such that $HKA = CH + PA + CP$ [3,8]. The CH and PA angles were notated as degrees of deviation from 90° (negative for varus and positive for valgus). The CP angle was designated varus (−) if it narrowed medially and valgus (+) if it narrowed laterally [3,8].

In addition to the HKA angle, we defined the anatomic (shaft) axes of the femur (FS) and the tibia (TS) (Fig. 1). We derived the angular relationship between these anatomic axes (FS-TS) and the angular relationships with their mechanical counterparts (FM-FS, FM-TS, FS-TM). Finally, femoral length, tibial length and apparent leg length were measured.

Semiautomated computer program—The Horizon Surveyor (version 1.5, OAISYS Inc.) custom software program provided a selection of electronic tools, including straight line, ruler, circle and midline tools, which were used to define the ten femoral and tibial bone landmarks on digital images. Images for evaluation were imported as *.tiff, *.bmp or *.jpeg files. The program included the means by which to magnify and enhance the brightness and contrast of the image. The reader was prompted to identify each landmark in a defined sequence and the data for the landmark's X–Y coordinates were collected. Angular and linear dimensions were automatically derived by the software program.

Reader training—Readers with backgrounds in health sciences were recruited and trained in the method employed for the study. Training sessions involved identification of the specific bone landmarks, the derived angular geometry, use of the computer program for processing the images and application of the software tools used to define the landmarks.

Part 1: Comparison of manual and computer-assisted measures

Five patterns of frontal plane lower limb alignment, simulating full-length radiographs of healthy and malaligned limbs, were drawn using AutoCAD® software. The schematics of limb malalignment included variations in varus and valgus alignment, joint space slope, femoral and tibial deformity and apparent leg lengths. The five patterns are shown in Figure 2a–e. Paper copies of these images (8.5 × 14 inch paper size) were used for manual

measurements. The patterns were exported from AutoCAD® as digital images for computer-assisted measurements of alignment.

Seven trained readers performed manual measurements on all of the five alignment patterns daily for 3 days. Patterns were measured in a random order each day. Readers used a pencil and ruler (with 1 mm increments) to identify and mark the ten bone landmarks on the paper copies of the patterns. No magnification was used. Lines were drawn between these landmarks to define the FM and TM and anatomic (shaft) axes and the joint surface tangents. A protractor was then used to measure the angles formed from these axes and tangents. Bone lengths and apparent leg lengths were also measured. Fresh paper copies were used for each day, without reference to the results from prior days. The collected data were entered by hand into a Microsoft Excel® (Microsoft Office 2003, Microsoft Corporation, USA) spreadsheet for analysis.

The process was then repeated using the Horizon Surveyor computer software program. All five alignment patterns were measured daily for 3 days and patterns were measured in a random order each day. Each reader identified the same bone landmarks on the digital images of the patterns. Magnification of the image within the software program was possible and used as required. The program automatically derived the same angular parameters and leg lengths. Digital length measures were converted to the paper equivalent using a linear calibration factor and the computer measurements were exported to a Microsoft Excel® spreadsheet.

Part 2: Reliability analyses of alignment measures from full-limb radiographs

A batch of 100 images (representing 200 limbs) was selected as a random sample from 30 similar batches from over 1500 full-limb digital radiographs (3000 limbs) obtained as part of the Multicenter Osteoarthritis (MOST) Study. This prospective epidemiological study of community-dwelling adults aged 50 – 79 years was initiated to identify risk factors for incident, symptomatic knee OA and progressive knee OA. The study was conducted in accordance with U.S. Dept. of Health and Human Services Protection of Human Subjects regulations (45 CFR part 46) and privacy rules of the Health Insurance Portability and Accountability Act (HIPAA) of 1996. Study participants were recruited and enrolled at clinical centers at the University of Alabama at Birmingham and University of Iowa under local Institutional Review Board approval and with informed consent given prior to inclusion in the study.

The MOST study targeted persons with, or at risk for developing, knee OA. High risk individuals included those who were overweight, experienced knee symptoms and/or had a history of knee injury or surgery. Average age of the 100 participants (64 women, 36 men) whose radiographs were analyzed as part of the random sample of images for the current study was 63.3 ± 7.7 years (range: 50 – 79 years). Mean body mass was 88.7 ± 18.2 kg.

Weight-bearing, anteroposterior full-limb radiographs were obtained according to the method of Sharma et al. [2]. A 130×36 -cm graduated grid cassette was used and the X-ray beam was centred at the level of the knee joint at a distance of 2.4 m. Depending on limb size and tissue characteristics, settings of 100 – 300 mA/s and 80 – 90 kV were employed. Participants stood without footwear and were positioned with the tibial tubercles facing forwards. All radiographs showed both limbs, including the entire hip, knee and ankle joints.

Three trained readers each measured the same batch of 100 images (200 limbs) twice, with a two or more week interval between batch handling. The software program was used to obtain angular and linear dimensions which were exported for analysis.

Data Analysis

Part 1: Manual and computer-assisted measures from AutoCAD® patterns—

The data from all readers and all trials were reported using descriptive statistics (means and standard deviations for each measure). Different repeated measures analysis of variance (ANOVA) models treating patterns and readers as random effects were performed to (1) compare all patterns assessed manually (3 sets of 5 patterns from each of the 7 readers) to all patterns evaluated using the computer program; (2) determine the reliability of manual and computer methods by calculating the intraclass correlations (ICCs [type 3,1]; in this case, treating the condition [manual or computer-assisted measures] as a fixed effect); and (3) assess the agreement (using ICCs [type 2,1]) for each reader on all variables under the 2 measuring methods (manual and computer).

Part 2: Full-limb radiographs—Random effects two-way ANOVA models were applied to calculate the ICCs (type 2, 1) which evaluated inter- and intra-reader reliability for each of the angles and bone lengths. Statistical analysis was performed using the SAS statistical package (Version 9, SAS Institute Inc., Cary, NC, USA) and the alpha level was set at 0.05.

RESULTS

Part 1: Comparison of manual and computer-assisted measures

Analysis of the data derived from the AutoCAD® patterns revealed no significant differences between manual and computer-assisted methods for all angular measures and bone lengths ($P > 0.05$). Reliability statistics for manual and computer measures of angles and bone lengths are displayed in Table 1. Excellent agreement was found for all variables with both methods (ICCs from 0.977 to 0.999 for computer analysis; 0.820 to 0.995 for manual measures). For each measurement, the computer-assisted measure showed reliability that was slightly higher than the manual measurement. When each reader was evaluated individually, all measures demonstrated good to excellent intra-reader reliability using both applications (ICCs from 0.730 to 0.998).

The difference in time required to complete the measures manually compared to the computer method was considerable. Computer-assisted measures were acquired in approximately half the time taken to perform the manual measurements and additional time was also needed for data entry and verification of the manual measures.

Part 2: Reliability analyses of alignment measures from full-limb radiographs

Mean HKA angle measurements from the 100 radiographs (200 limbs) in the sample were $-2.1^\circ \pm 4.0^\circ$ (range from -17.6° varus angulation to 12.8° valgus angulation).

The computer software program applied to full-limb radiographs produced measures that were highly reliable. As shown in Table 2, ICCs for inter-reader reliability were 0.947 or greater for all measures, except the angles CP (ICC of 0.884) and FM-FS (ICC of 0.839). All measures demonstrated high intra-reader reliability, with ICCs ranging from 0.908 to 0.998 (Table 2). Figure 3 shows the inter-reader agreement between two readers measuring the HKA angle on right knees. Figure 4 illustrates the intra-reader agreement for HKA angle measurements for one reader.

DISCUSSION

The widespread use of digital imaging systems has necessitated the development of electronic methods, including software tools, for measurement of lower limb alignment [10–16]. In this report we wished to evaluate the reliability of an established landmark-based

approach for a full range of alignment measures and limb lengths obtained using a customized computer software program [3,7,8,10,18].

As a first step in our reliability evaluations we compared the use of computer-assisted analysis against traditional manual measurements on images simulating different limb alignments that were drawn in AutoCAD®. We chose to use line drawings created using AutoCAD® software as a means to derive a wide spectrum of limb deformities that could test the bone landmark method. We recognize that a direct comparison between simulated limb alignment patterns and radiographs was not made, but that this approach provided the opportunity to compare the measurement methods applied.

Results of the current study revealed that there were no significant differences between manual and computer-assisted methods for all alignment and leg length measures using the bone landmarks approach. Both methods were reliable, although for each of the specific measurements computer-assisted analysis showed slightly higher reliability in comparison to the manual method. All seven readers produced angular and linear measures that showed good to excellent intra-reader reliability. These findings indicate that a variety of readers can be trained in use of the landmark-based method and the custom computer program to derive reliable measurements.

Of relevance, all measurements were obtained much more quickly by use of the computer program. The specific electronic tools provided by the computer software, including image magnification and enhancement, aided in the selection of bone landmarks and the speed of data acquisition. The custom software also optimized data collation and transfer of data for statistical analysis.

Our results using AutoCAD® patterns are similar to findings from previous studies which evaluated alignment measures obtained by computer analysis and manual methods. Anatomic axis angle measurements from radiographs of the knee [11,16] and mechanical axis angle measures from full-limb radiographs [13–15,17] demonstrated good reliability when manual and computer methods were compared, with less variability using the computer. Other studies measuring various joint orientation angles at the femur and tibia [13,14], following the system of Paley et al. [21], reported that computer-assisted analysis significantly reduced the variability of these lower limb geometry measures. Also supporting our findings, manual and computer-assisted measures of femoral and tibial length [14] and apparent leg length [13] from full-limb radiographs showed good agreement. Finally, measurement times were reported to be significantly shorter using computer analysis compared to manual measurements (44% and 78% reduction in measuring time, respectively) in other papers [13,17] and in the current study.

In the second part of our study we evaluated reader reliability when applying the landmark-based method using the computer program to a large sample of full-limb digital radiographs. The images evaluated were from an ongoing multicenter OA project (MOST). Measurements of the HKA angle, other angular parameters and bone lengths all demonstrated high inter- and intra-reader reliability using the computer-assisted method. In particular, we obtained an ICC of 0.995 for inter-reader reliability of HKA angle measurements. These results are similar to other reported values of 0.91 [17] and 0.98 [15] for inter-reader reliability of the mechanical axis angle using computer-assisted analysis.

In the current study two angular measures demonstrated slightly lower reliability with computer-assisted analysis applied to full-limb radiographs. Intraclass correlation coefficients for inter-reader reliability (0.884) and intra-reader reliability (0.908) of the condylar plateau (CP) angle were lower in comparison to the corresponding inter- and intra-reader reliability measures for the other angles and leg lengths using computer analysis. The

CP angle represents the orientation of the knee joint's articulating surfaces. One possible reason for lower reliability is that the bone landmarks used to derive this angle are located close together at the knee, which would increase the potential for greater variance in the angular measurement compared to angles for which the bone landmarks are located far apart.

Femoral mechanical-femoral shaft axis (FM-FS) angle measurements demonstrated somewhat lower inter-reader reliability (ICC of 0.839), but higher intra-reader reliability (ICC of 0.934). A possible explanation for the inter-reader differences is that the femoral intertrochanteric bone landmark required to construct the femoral shaft axis is a less precisely defined point than the femoral head center and, therefore, open to more inter-reader variation in its acquisition.

Our study has compared the semiautomated landmark-based computer program to traditional manual methods and demonstrated that measures were highly reliable when applied to standardized but varied alignment images with a number of trained readers. It has confirmed the general findings of previous studies from the literature investigating computer-aided measures of mechanical axis alignment and leg lengths. We have demonstrated the reliability of this approach to define other angular contributions of the femur, the tibia and the knee joint surfaces to overall alignment. We have also confirmed that alignment measures obtained with the computer method demonstrated excellent inter- and intra-reader reliability when evaluated with a large number of long limb images.

In summary, the landmark-based approach employed for measurements of long limb alignment, geometry and limb lengths was readily learned by multiple readers and produced high reliability coefficients when applied using computer-assisted analysis. Although training is required for these measures, our data indicate that the skills needed are learned rapidly. The consistency evident between multiple readers using the electronic method, the speed of data acquisition and the growing use of digital images lend support for the application of digital measurement systems employing a landmark-based approach.

Acknowledgments

The second study, using full-limb radiographs, was supported by the National Institutes of Health grants AR47785 and AG18820 and MOST Ancillary Study grant AP07-04. The authors wish to acknowledge the contribution of Mr. Christopher Wale, BSc (I-M Innovations, Inc.), in the design of the computer software tools and analysis program. The support of OAISYS Inc. in provision of the Horizon Surveyor Software Program used in these studies is appreciated.

References

1. Cerejo R, Dunlop DD, Cahue S, Channin D, Song J, Sharma L. The influence of alignment on risk of knee osteoarthritis progression according to baseline stage of disease. *Arthritis Rheum* 2002;46:2632–2636. [PubMed: 12384921]
2. Sharma L, Song J, Felson DT, Cahue S, Shamiyeh E, Dunlop DD. The role of knee alignment in disease progression and functional decline in knee osteoarthritis. *JAMA* 2001;286:188–195. [PubMed: 11448282]
3. Cooke TD, Li J, Scudamore RA. Radiographic assessment of bony contributions to knee deformity. *Orthop Clin North Am* 1994;25:387–393. [PubMed: 8028882]
4. Hsu RW, Himeno S, Coventry MB, Chao EY. Normal axial alignment of the lower extremity and load-bearing distribution at the knee. *Clin Orthop Relat Res* 1990;255:215–227. [PubMed: 2347155]
5. Tetsworth K, Paley D. Malalignment and degenerative arthropathy. *Orthop Clin North Am* 1994;25:367–377. [PubMed: 8028880]

6. Issa SN, Dunlop D, Chang A, et al. Full-limb and knee radiography assessments of varus-valgus alignment and their relationship to osteoarthritis disease features by magnetic resonance imaging. *Arthritis Rheum* 2007;57:398–406. [PubMed: 17394225]
7. Cooke TD, Sled EA, Scudamore RA. Frontal plane knee alignment: a call for standardized measurement. *J Rheumatol* 2007;34:1796–1801. [PubMed: 17787049]
8. Cooke, TDV.; Scudamore, A. Healthy Knee Alignment and Mechanics. In: Callaghan, JJ.; Rosenberg, AG.; Rubash, HE.; Simonian, PT.; Wickiewicz, TL., editors. *The Adult Knee*. Philadelphia, PA: Lippincott Williams & Wilkins; 2003. p. 175-186.
9. Chao EY, Neluhani EV, Hsu RW, Paley D. Biomechanics of malalignment. *Orthop Clin North Am* 1994;25:379–386. [PubMed: 8028881]
10. Cooke TD, Scudamore RA, Bryant JT, Sorbie C, Siu D, Fisher B. A quantitative approach to radiography of the lower limb. Principles and applications. *J Bone Joint Surg Br* 1991;73:715–720. [PubMed: 1894656]
11. Prakash U, Wigderowitz CA, McGurty DW, Rowley DI. Computerised measurement of tibiofemoral alignment. *J Bone Joint Surg Br* 2001;83:819–824. [PubMed: 11521921]
12. Sled E, Costigan P, Cooke TDV, Sheehy L, Hundt H, Qiu M. Measuring malalignment in knee OA. *Osteoarthritis Cartilage* 2005;13:S120. [abstract].
13. Hankemeier S, Gosling T, Richter M, Hufner T, Hochhausen C, Krettek C. Computer-assisted analysis of lower limb geometry: higher intraobserver reliability compared to conventional method. *Comput Aided Surg* 2006;11:81–86. [PubMed: 16782643]
14. Rozzanigo U, Pizzoli A, Minari C, Caudana R. Alignment and articular orientation of lower limbs: manual vs computer-aided measurements on digital radiograms. *Radiol Med* 2005;109:234–238. [PubMed: 15775892]
15. Specogna AV, Birmingham TB, DaSilva JJ, et al. Reliability of lower limb frontal plane alignment measurements using plain radiographs and digitized images. *J Knee Surg* 2004;17:203–210. [PubMed: 15553587]
16. Takahashi T, Yamanaka N, Komatsu M, Ogawa Y, Yoshida S, Yamamoto H. A new computer-assisted method for measuring the tibio-femoral angle in patients with osteoarthritis of the knee. *Osteoarthritis Cartilage* 2004;12:256–259. [PubMed: 14972344]
17. Sailer J, Scharitzer M, Peloschek P, Giurea A, Imhof H, Grampp S. Quantification of axial alignment of the lower extremity on conventional and digital total leg radiographs. *Eur Radiol* 2005;15:170–173. [PubMed: 15300399]
18. Sanfridsson J, Ryd L, Eklund K, Kouvaras Y, Jonsson K. Angular configuration of the knee. Comparison of conventional measurements and the QUESTOR Precision Radiography system. *Acta Radiol* 1996;37:633–638. [PubMed: 8915266]
19. Yoshioka Y, Siu D, Cooke TD. The anatomy and functional axes of the femur. *J Bone Joint Surg Am* 1987;69:873–880. [PubMed: 3597501]
20. Yoshioka Y, Siu DW, Scudamore RA, Cooke TD. Tibial anatomy and functional axes. *J Orthop Res* 1989;7:132–137. [PubMed: 2908904]
21. Paley, D. Principles of Deformity Correction. New York: Springer-Verlag; 2003.

Fig. 1.

Diagram of frontal plane axes and angles in a limb with varus alignment, modified from Cooke et al.[7].

LBA = load-bearing axis

CH = condylar-hip angle: the angle of the femoral condylar tangent with respect to the femoral mechanical axis; varus negative, valgus positive

PA = plateau-ankle angle: the angle between the tibial margin tangent and the tibial mechanical axis; varus negative, valgus positive

CP = condylar-plateau angle: the angle between the femoral and tibial joint surface tangents; narrowing medially negative and laterally positive

HKA = hip-knee-ankle angle: the angle between the femoral and tibial mechanical axes; varus negative, valgus positive

FM = femoral mechanical axis

TM = tibial mechanical axis

FS = femoral shaft axis

TS = tibial shaft axis (*Note: TM and TS are typically co-incident when measurements are made from the full length of the tibia*)

FM-FS = angle between the femoral mechanical axis and the femoral shaft axis

Fig. 2.

Five patterns of frontal plane lower limb alignment, simulating full-length radiographs of healthy and malaligned limbs, drawn using AutoCAD® software.

- A. neutral limb with joint obliquity
- B. valgus limb
- C. knee varus, tibia valga
- D. knee valgus, tibia vara
- E. neutral limb

Fig. 3.
Hip-knee-ankle (*HKA*) angle measures from full-limb radiographs: inter-reader agreement for two readers measuring on right knees.

Fig. 4. Hip-knee-ankle (*HKA*) angle measures from full-limb radiographs: intra-reader agreement for one reader.

Table 1

Intraclass correlation coefficients (ICCs) and confidence intervals for manual versus computer-assisted measures of angles and bone lengths from patterns drawn using AutoCAD® software. A total of 105 manual measures (3 sets of 5 patterns from each of the 7 readers) and 105 computer-generated measures for each of the angles and bone lengths were evaluated in the reliability analysis.

Variable	Intraclass Correlation Coefficient (95% Confidence Interval)	
	Manual Measurement	Computer Measures
HKA	0.993 (0.987, 0.996)	0.999 (0.999, 1.000)
CH	0.990 (0.983, 0.995)	0.992 (0.986, 0.996)
PA	0.906 (0.843, 0.948)	0.980 (0.964, 0.989)
CP	0.991 (0.985, 0.995)	0.995 (0.990, 0.997)
FM-FS	0.820 (0.710, 0.897)	0.977 (0.959, 0.988)
FM-TS	0.995 (0.991, 0.997)	0.999 (0.997, 0.999)
FS-TM	0.984 (0.972, 0.991)	0.999 (0.999, 1.000)
FS-TS	0.982 (0.969, 0.990)	0.998 (0.996, 0.999)
Femoral length	0.952 (0.918, 0.974)	0.997 (0.995, 0.998)
Tibial length	0.865 (0.779, 0.924)	0.982 (0.968, 0.990)
Apparent leg length	0.969 (0.946, 0.983)	0.999 (0.998, 0.999)

HKA: hip-knee-ankle angle

CH: condylar-hip angle

PA: plateau-ankle angle

CP: condylar-plateau angle

FM-FS: femoral mechanical axis–femoral shaft axis angle

FM-TS: femoral mechanical axis–tibial shaft axis angle

FS-TM: femoral shaft axis–tibial mechanical axis angle

FS-TS: femoral shaft axis–tibial shaft axis angle

Table 2

Intraclass correlation coefficients (ICCs) and confidence intervals for computer-assisted measures of angles and bone lengths on 100 full-limb radiographs (200 limbs).

Variable	Intraclass Correlation Coefficient (95% Confidence Interval)	
	Inter-reader reliability	Intra-reader reliability
HKA	0.995 (0.994, 1)	0.998 (0.998, 1)
CH	0.960 (0.953, 1)	0.966 (0.961, 1)
PA	0.947 (0.937, 1)	0.964 (0.959, 1)
CP	0.884 (0.864, 1)	0.908 (0.896, 1)
FM-FS	0.839 (0.720, 1)	0.934 (0.925, 1)
FS-TM	0.993 (0.989, 1)	0.998 (0.997, 1)
FS-TS	0.990 (0.988, 1)	0.996 (0.995, 1)
Femoral length	0.993 (0.992, 1)	0.994 (0.993, 1)
Tibial length	0.993 (0.989, 1)	0.995 (0.994, 1)
Apparent leg length	0.995 (0.993, 1)	0.995 (0.994, 1)

HKA: hip-knee-ankle angle

CH: condylar-hip angle

PA: plateau-ankle angle

CP: condylar-plateau angle

FM-FS: femoral mechanical axis–femoral shaft axis angle

FM-TS: femoral mechanical axis–tibial shaft axis angle

FS-TM: femoral shaft axis–tibial mechanical axis angle

FS-TS: femoral shaft axis–tibial shaft axis angle