Effect of limb rotation on radiographic alignment measurement in mal-aligned knees

Xiaoshu Sun
Beihang University Department of Biological Engineering: BeiHang University School of Biological Science and Medical Engineering
Bin Yang
Peking University International Hospital
Shengzhao Xiao
BeiHang University School of Biological Science and Medical Engineering
Yichen Yan
Beihang University Department of Biological Engineering: BeiHang University School of Biological Science and Medical Engineering
Zifan Liu
BeiHang University School of Biological Science and Medical Engineering
Liang Yuan
Peking University International Hospital
Xiaohua Wang
Peking University International Hospital
Bin Sun
Peking University International Hospital
Jie Yao (astromilk@163.com)
Beihang University https://orcid.org/0000-0003-0044-7307
Yubo Fan
BeiHang University School of Biological Science and Medical Engineering, Shool of Medical Science and Engineering

Research Article

Keywords: Alignment measurement, Long-leg-radiography, Knee exion, Knee coronal deformity

Posted Date: September 3rd, 2021

DOI: https://doi.org/10.21203/rs.3.rs-850458/v1

Version of Record: A version of this preprint was published at BioMedical Engineering OnLine on November 27th, 2021. See the published version at https://doi.org/10.1186/s12938-021-00956-7.

Noname manuscript No.
(will be inserted by the editor)

Effect of limb rotation on radiographic alignment measurement in mal-aligned knees

the date of receipt and acceptance should be inserted later

Abstract Purpose. Long-leg-radiography (LLR) is commonly used for measurement of lower limb alignment. However, limb rotations during radiography may interfere with the alignment measurement. This study examines the effect of limb rotation on the accuracy of measurements based on the mechanical and anatomical axes of the femur and tibia, with variations in knee flexion and coronal deformity.
Methods. Forty-five lower limbs of thirty patients were scanned with CT. Virtual LLRs simulating 5 rotational positions (neutral, ±10°, and ±20° internal rotation) were generated from the CT images. Changes in the hip-knee-ankle angle (HKA) and the femorotibial angle (FTA) were measured on each image with respect to neutral values. These changes were related to knee flexion and coronal deformity under both weight- and non-weight-bearing conditions.
Results. The measurement errors of the HKA and FTA derived from limb rotation were up to 4.84±0.66° and 7.35±0.88° respectively, and were correlated with knee flexion ($p<0.001$) and severe coronal deformity ($p\leq0.001$). Compared with non-weight-bearing position, coronal deformity measured in weight-bearing condition was 2.62° greater, the correlation coefficients between the coronal deformity and the deviation ranges of HKA and FTA were also greater.
Conclusion. Flexion and severe coronal deformity have significant influence on the measurement error of lower limb alignment. Errors can be amplified in the weight-bearing condition compared with the non-weight-bearing condition. The error of measurement of the anatomic axis is greater than the mechanical axis. Considering LLR is the gold standard image modality, attention should be paid to the measurement of knee alignment. Especially for the possible errors derives from weight-bearing long leg radiographs of patients with severe knee deformities.

Address(es) of author(s) should be given

Keywords Alignment measurement · Long-leg-radiography · Knee flexion · Knee coronal deformity

1 Introduction

The lower limb alignment is an important reference for clinical diagnosis and treatment of conditions affecting the knee. Malalignment of the lower extremity is recognized as a critical component of the etiology of knee osteoarthritis[4][17][19]. Correct alignment is critical for the outcome of total knee arthroplasty (TKA)[12], especially for personalized surgical design[16][21]. Lower limb alignment is commonly assessed using measurements of anatomical or mechanical (weight-bearing) axes of the femur and the tibia, as depicted on plain radiographs. Quantification of these axes usually requires identification of anatomical landmarks from hip to ankle. For evaluation of the knee alignment, long leg radiographs (LLR) are considered as the gold standard image modality, with high inter- and intra-observer reliability.

Correct and standardized patient positioning during imaging is the prerequisite for the accuracy of the lower limb alignment measurement while using LLR. However, considering patients with knee osteoarthritis or other joint disease are not able to fully extend the knee, it is reasonable to study the possible alignment measurement errors of patients with severe deformity. Studies have reported that limb rotation or foot rotation could significantly affect the outcome [6][9][11][15]. The measurement error of hip-knee-ankle (HKA) angle could reach 4-10 degrees or even greater[14][15]. While the recommended HKA after TKA ranges from -3° to 3°, which represents a proper knee alignment and prosthesis position. Therefore, the preoperative measurement error directly affects knee osteotomy. Previous studies have suggested that improved methods of measuring lower limb alignment are of greater importance to the advancement of knee osteotomy than the technical details of the surgical procedure itself [11][13][15].

Although studies involving synthetic prosthesis[11][14], specimen of human lower limbs[3][20] and in-vivo images[7] all exsited, the magnitude of these errors varies dramatically. Some researchers believed the long leg radiograph is a reliable method[1][10] and reported that the error caused by limb rotation was less than 1 °within the acceptable range [18], whereas others found significant errors in the measurements of severe varus knees [8][14][15] [18]. Coronal deformity, knee flexion contracture or some other anatomical features in patients maight be important factors that potentially affect the magnitude of measurement errors. Considering the in-vivo images drived from patients can better reflect real clinical application scenarios, the measurement error of knee alignment in patients with complex deformities should be invistigated more in-depth. It is meaningful to quantify the magnitude of alignment measurment

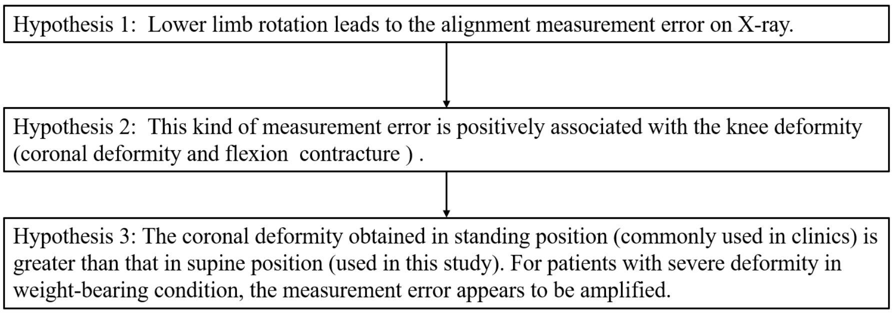

Fig. 1 This study attempts to prove these hypotheses.

errors in patients with different degrees of deformity.

The purposes of this study are: (1) to determine the influence of limb rotation on measurements of knee alignment derived from long-leg radiographs (2) to measure the additional influence of coronal deformity and knee flexion contracture; and (3) to determine whether weight-bearing affects the accuracy of the radiographic measurements. The significance of this study is to assist in reducing measurement errors of mechanical and anatomical leg axis. This study attempts to prove the following hypotheses(Fig.1).

2 Result

The median value of knee flexion was 5.32° (2.27°; 8.38°). The median knee coronal deformity was 7.37° (4.25°; 9.50°). Descriptive statistics of HKA and FTA deviation range were summarized in Table 3. The average deviation ranges of HKA and FTA were 4.84±0.66° (range: 0.56-25.03) and 7.35±0.88° (range: 1.30- 30.42), respectively. As shown in Fig.4, the mean difference between HKA and FTA deviation range was 2.50 ($p<0.01$). The intraclass correlation coefficients for HKA and FTA deviation range were perfect, 0.976 ($p<0.05$) and 0.935 ($p<0.05$), respectively.

According to the two-way ANVOA: there were statistical differences in both HKA deviation range and FTA deviation range significantly for patient with varying flexion and coronal deformity ($p<0.05$); the interaction between flexion and coronal deformity also had a significant effect on HKA and FTA deviation range ($p<0.05$). Fig.5 illustrated the average HKA and FTA deviation range in patient with different flexion and coronal deformity.

For flexion index, there were significant differences among the slight, moderate and severe groups in both HKA and FTA deviation range ($p<0.001$) (Table 4). For coronal deformity index, there was no significant difference between the slight and moderate groups in both HKA and FTA deviation

Table 1 HKA and FTA deviation range derived from varying degree of Flexion and Coronal deformity. Descriptive statistics

	HKA Deviation Range (M ± S.E.M.)	FTA Deviation Range (M ± S.E.M.)
Slight Flexion group	2.15±0.26°	3.95±0.45°
Moderate Flexion group	5.32±0.39°	7.47±0.43°
Severe Flexion group	12.81±2.20°	18.19±2.72°
Slight Coronal deformity group	4.57±1.67°	6.28±1.95°
Moderate Coronal deformity group	4.43±0.64°	6.85±0.87°
Severe Coronal deformity group	7.24±1.29°	11.92±2.34°
Total	4.84±0.66°	7.35±0.88°

Note: M = Mean; S.E.M = Standard Error of Mean;

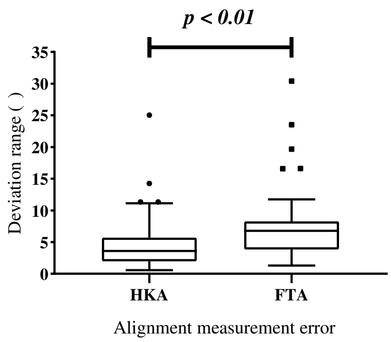

Fig. 2 Box-plot illustrating the average deviation ranges of HKA and FTA. P value<0.01, difference between HKA and FTA deviation range being significant.

range ($p>0.05$). Yet the coronal deformity index of the severe group was significantly different from that of the slight and moderate groups ($p \leq 0.001$) (Table 5). Among the different degrees of coronal deformity, only the severe group differed dramatically from the other two groups in HKA deviation range ($p \leq 0.001$) and in FTA deviation range ($p<0.001$). No significant difference was found between the slight coronal deformity group and the moderate coronal deformity group in HKA deviation range ($p>0.05$) and in FTA deviation range ($p>0.05$).

Table 2 Multiple Comparisons of Flexion group, the mean difference of HKA deviation range and the mean difference of FTA deviation range.

Flexion group	HKA deviation				FTA deviation			
	Mean Difference	S.E	Sig.	95% C.I.	Mean Difference	S.E	Sig.	95% C.I.
Slight- Moderate	-3.17*	0.49	<0.001	-4.16 ∼-2.17	-3.51*	0.80	<0.001	-5.14 ∼-1.89
Moderate-Severe	-8.04*	0.73	<0.001	-9.51 ∼-6.57	-11.98*	1.18	<0.001	-14.38∼-9.59
Slight - Severe	-11.20*	0.70	<0.001	-12.63 ∼-9.78	-15.50*	1.14	<0.001	-17.82 ∼-13.18

Note:S.E, stander error; Sig., significance probability; C.I., confidence interval.
∗: The mean difference is significant at the 0.05 level.

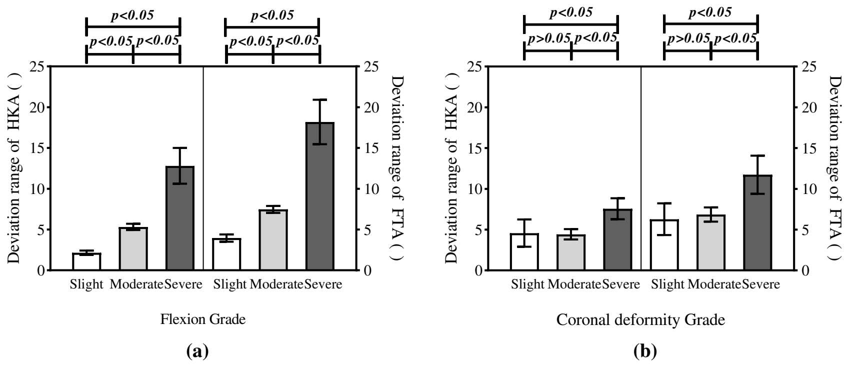

Fig. 3 The deviation range of HKA and FTA in patient with different flexion and coronal deformity. P value<0.05 means that difference between the two corresponding groups is significant in 95% confidence level. (a) Participates were divided into slight, moderate and severe flexion group by the degree of flexion contracture. Left part showed the HKA deviation range in the slight, moderate and severe flexion group, and the right part showed the FTA deviation range in the slight, moderate and severe flexion group. (b) Participates were divided into slight, moderate and severe coronal deformity group by the degree of coronal deformity. Left part showed the HKA deviation range in the slight, moderate and severe coronal deformity group, and the right part showed the FTA deviation range in the slight, moderate and severe coronal deformity group.

Table 3 Multiple Comparisons of Coronal deformity group, the mean difference of HKA deviation range and the mean difference of FTA deviation range.

Coronal deformity group	HKA deviation				FTA deviation			
	Mean Difference	S.E	Sig.	95% C.I.	Mean Difference	S.E	Sig.	95% C.I.
Slight- Moderate	0.14	0.51	0.783	-0.89∼1.17	-0.57	0.83	0.493	-2.26∼1.11
Moderate-Severe	-2.81*	0.69	<0.001	-4.22∼-1.40	-5.06*	1.13	<0.001	-7.35∼-2.78
Slight - Severe	-2.67*	0.75	0.001	-4.18∼-1.16	-5.64*	1.21	<0.001	-8.10∼-3.18

Note:S.E, stander error; Sig., significance probability; C.I., confidence interval.
∗: The mean difference is significant at the 0.05 level.

The deviation ranges of HKA and FTA were significantly correlated with the knee flexion and coronal deformity (Table 6). In non-weight-bearing condition, the correlation coefficient between coronal deformity and HKA deviation range was 0.307 ($p<0.05$); the correlation coefficient between coronal deformity and with FTA deviation range was 0.504 ($p<0.01$). In weight-bearing condition, the correlation coefficient between coronal deformity and HKA deviation range was 0.635 ($p<0.01$); the correlation coefficient between coronal deformity and with FTA deviation range was 0.639 ($p<0.01$). Remarkable correlations were found between the flexion angle and deviation ranges of both HKA (0.933, $p<0.01$) and FTA (0.861, $p<0.01$).

The box-plot in Fig.6 illustrates the coronal deformity measured from virtual LLR and real LLR. In neutral position, coronal deformity measured

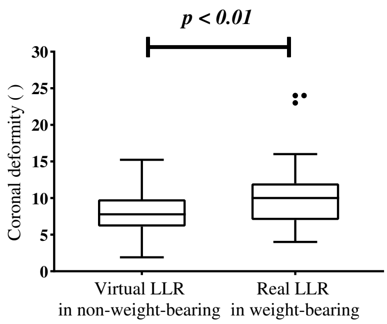

Fig. 4 Box-plot illustrating the coronal deformity measured in neutral position. Virtual LLR: virtual radiographs simulated from full-leg CT scan in non-weight-bearing condition. Real LLR: standing full-leg radiographs in weight-bearing condition.

on real LLR 10.52±0.94°was significantly greater than that on virtual LLR 7.90±0.54°. The mean difference of coronal deformity in non-weight-bearing condition and weight-bearing condition was 2.62±0.68° (p<0.01).

3 Discussion

The lower limb alignment measurement is a crucial factor in the preoperative plan and postoperative assessment of a knee replacement. Inconsistent positioning during the capture of X-ray and resulting projected image can bring the measurement errors of the lower limb alignment. However, the argument over whether these measurement errors are acceptive and related to the knee deformity has not settled. This study quantitatively revealed that the influence of limb rotation on measurements of knee alignment derived from long-leg radiographs, the measurement errors corresponding to different deformed knees, and the difference of radiographic measurements on weight-bearing and non-weight-bearing conditions.

In this study, limb rotation caused the deviation ranges of HKA and FTA measurement were greater than 3°. The degree of the anatomical axis variation was greater than that of the mechanical axis. Although tilted projections can lead to the measurement errors of the lower limb alignment, the magnitude of these errors measured in different studies vary dramatically. Wright JG[20] reported that the deviation range of FTA measurement was less than 1 ° under the limb rotation from 20° external rotation to 20° internal rotation, whereas Swanson KE [18] found significant errors in severe deformity knees up to 7.8°. This could be explained by the fact that the degree of deformity of the lower limb would influence the measurement error of the alignment axis.

Our results demonstrated that the coronal deformity affected the alignment measurement errors greatly. Multiple comparisons of slight, moderate and severe degrees of coronal deformity indicated that the severe group (coronal deformity>10°) differed significantly from the other two groups in alignment measurement errors. Compared with the non-weight-bearing condition, the coronal deformity of weight-bearing condition had greater influence on the measurement errors. However, the effects of coronal deformity on the assessment of alignment on LLR in the previous studies were controversial. Swanson et al.[18] discussed in a saw-bones research of alignment measurements in deformed limbs, that the FTA measurement in limbs with severe valgus or varus deformity was more sensitive to the effect of rotation than in normally aligned limbs. This is in line with our results that both mechanical and anatomical axis measurement errors in the severe coronal deformity group were greater than that in the slight or the moderate group. Jud et al.[7] conclude that deviations in mechanical leg axis measurements did not vary relevantly through the coronal deformity. This is an interesting conclusion that is consistent with the findings of the present study, because they only analyzed coronal deformity below 9 degrees. The coronal deformities of our research subjects ranged from 0.62 to 19.55 degrees. No significant difference was found between the slight and the moderate coronal deformity group in alignment measurement errors. While the severe group (coronal deformity>10°) had significant differences with the other two groups in alignment measurement errors. Additionally, this study measured both HKA and FTA deviation range of each subject. On the contrary, the study conducted by Kawakami et al.[8] reported no significant correlation between coronal deformity and measurement error. Kawakami et al. set different limb rotation ranges for different individuals to calculate the measurement error. In the present study, the limb rotation from internal 20° to external 20° was performed uniformly for each subject. And the present study further collected coronal deformity in the weight-bearing condition to compare with the result obtained from the non-weight-bearing condition. The opposite conclusion was probably reached from these two aspects. Therefore, the hypothesis that coronal deformity and the measurement errors were significantly related is credible. The effect of coronal deformity on the assessment of alignment on real LLR may be more pronounced. The method of alignment measurement should vary from slight to severe patients of varus and valgus.

The knee flexion angle plays an important role in the potential error of the alignment measurement. Multiple comparison of the slight, moderate and severe flexion group showed significant differences for all combinations in alignment measurement error. According to a study with synthetic model by Lonner et al.[11], the FTA deviation range of samples with flexion varied more than the control group. This statement was consistent with our study and a similar conclusion was reached in a radiographic cadaver study conducted by Brouwer et al. [3]. Differently, the present study recruited clinical patients instead of using synthetic models or specimen of human lower limbs. Both knee osteoarthritis and normal individuals under clinical condition were observed. Since the bony anatomy varies widely, the lower limbs alignment in vivo state can reflect the real morphology information. On the other hand, the knee flexion of each subject was not preset by the researchers, but appeared naturally. Knee flexion angles were calculated by the self-developed program for quantitative analysis.The difference of the measured coronal deformity was significant between the weight-bearing condition and the non-weight-bearing condition. Brouwer et al.[2] performed a standing and a supine LLR in 20 patients with varus deformity and found an average of 2 ° more varus deviation in the standing position than in the supine position. In our study, the virtual LLR reconstructed from CT scanning in the supine position was used to compare with the real LLR in the standing position. The average HKA measured on the virtual LLR is 2.83° less than that on the real LLR. This could be explained by the reduction of loading forces across the knee joint in the supine position. Although the clinical examination of standing LLR is different from the supine position LLR we used, it is not expected to alter the trends of above results observed from the virtual LLR in the present study.

There are some limitations to this study. Firstly, the virtual LLR were simulated from supine CT scanning, which results in a slight difference from the clinical examinations. It will be more ideal to obtain the CT images in the weight-bearing condition. Consequently, this study compared the lower limb alignment measured on virtual LLR with the real LLR, as the complement of our results obtained in non-weight-bearing position. Secondly, when exploring the relation between knee coronal deformity and measurement errors in the weight-bearing condition, it is not rigorous enough to use HKA reflected on the real LLR to represent knee coronal deformity. However, this provides some clues to the relation between coronal deformity and the measurement errors in clinics. Thirdly, the gender-specific differences of coronal alignment in osteoarthritic knees were not clear according to a review by Hess et al [5]. The participants of this study were mostly females (73%) and thus, we could not show a gender difference. Some studies proposed that assessing the lower limb alignment in subjects with an uneven gender ratio might be biased. The last limitation is associated with the low proportion of severe lower limb malformation subjects. However, current results demonstrated a trend that the more severe the deformity, the greater the lower limb alignment measurement error might be.

4 Conclusions

The alignment measurement of lower limb on LLR can be affected by the limb rotation. However, the measurement errors caused by this effect vary individually. Both knee flexion and coronal deformity have significant effect on such measurement error. When comparing the varying coronal deformity group, the severe group (coronal deformity>10°) differed significantly from the other two groups in HKA deviation range and in FTA deviation range. Moreover, compared with the non-weight-bearing condition, the influence of coronal deformity on measurement errors will be amplified in weight-bearing

Table 4 Patient baseline demographics and image information collection in clinics

	Participants (n = 30)
Median age, years (median 25th; 75th quartiles)	67.0 (62.0;67.5)
Female, n (%)	22 (73.3%)
Bilateral knee, n (%)	15 (50%)
Non-weight-bearing CT scan, n (%)	30 (100%)
Weight-bearing LLR image, n (%)	21 (70%)

condition. In addition, the error of measuring the anatomic axis on LLR is greater than that of mechanical axis. Therefore, attention should be paid to the errors of measuring lower limb alignment on LLR, especially for patients with severe knee deformity in weight-bearing condition.

5 Materials and Methods

5.1 Subjects and Imaging Procedure

From May 2018 to November 2019, 30 patients (45 knees) with the median age of 67 (range from 48 to 94) were enrolled in this study (Table. 1). Twenty-two patients (33 knees) were female and eight patients (12 knees) were males. Patients with a history of bone loss, infection, tumor, congenital disease, and lower extremity surgery were excluded from participation. CT scans of all subjects (45 knees) and weight-bearing LLR for some patients (31 Knees) with knee arthritis were detected preoperatively. Radiographs were performed with 7-22 mAs and 70-90 kVp, depending on the body mass. CT scans (Siemens SOMATOM Definition Flash, Germany) of the lower extremities in the supine position were obtained using a 1.0 mm section thickness with 120KVp. The method of measuring the knee flexion and coronal deformity is shown in Supplementary Materials. The knee flexion in supine position and coronal deformity of each patient appeared naturally were calculated by a custom program. According to the degree of knee flexion and coronal deformity in non-weight-bearing condition, 45 knees were graded as shown in Table 2. The degree of knee flexion and coronal deformity is divided by three levels: 0-5 degrees; 5-10 degrees; more than 10 degrees.

5.2 Alignment measurement

The determination of anatomical planes depends on three landmarks from 3D models (Fig. 2 (a)): center of the femoral head (FH), center of ankle joint (AC), and tip of the greater trochanter (GT). To be specific, FH was defined as the well-fitting sphere center point of the femoral head; AC was defined as the diagonal intersection of the ankle joint surface; and GT was defined as the tip of the greater trochanter from the frontal forward direction. Then

Table 5 According the degree of knee flexion and coronal deformity, 45 knees were classified into the following levels.

Grade	Flexion or Coronal deformity angle	Knee (N= 45)
Slight Flexion	0-5°	22 (48.9%)
Moderate Flexion	5-10°	17 (37.8%)
Severe Flexion	>10°	6 (13.3%)
Slight Coronal deformity	0-5°	14 (31.1%)
Moderate Coronal deformity	5-10°	25 (55.6%)
Severe Coronal deformity	>10°	6 (13.3%)

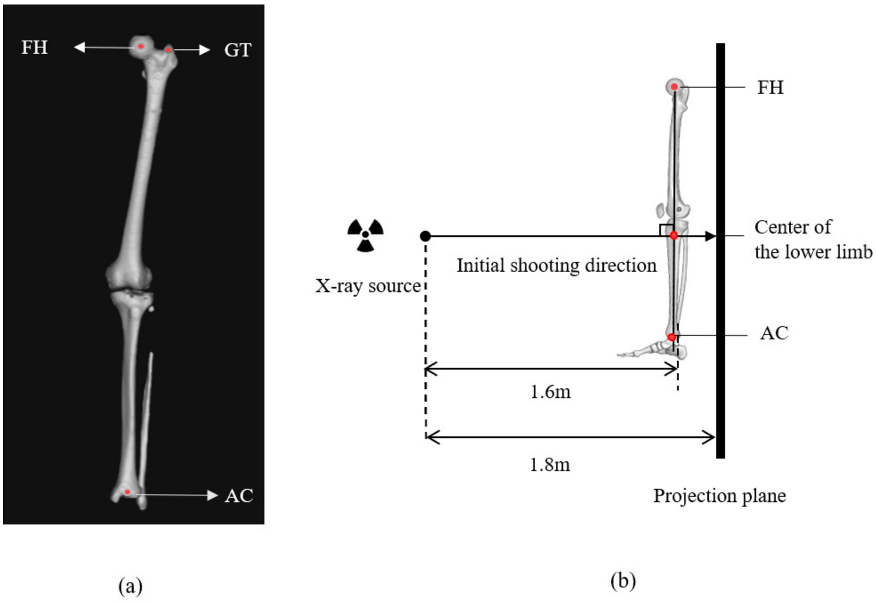

Fig. 5 Applying the 3D model of the lower limb reconstructed from CT scanning to set parameters and geometric relations for virtual X - ray capturing. (a) Three landmarks to determine anatomical planes on 3D model: center of the femoral head (FH), center of ankle joint (AC), and tip of the greater trochanter (GT). (b) The schematic diagram of capturing virtual X - ray by using the lower limb 3D model. The center of the lower limb was defined as the midpoint of line FH-AC. The X-ray source was 1.6 and 1.8 meters away from the center of the lower limb and the projection plane, respectively. The initial shooting direction was perpendicular to line FH-AC, passing through the center of the lower limb.

coronal plane was defined as the plane passing through Points FH, AC, and GT. Sagittal plane was defined as the plane perpendicular to coronal plane and passing through line FH-AC.

To measure the axial alignment of non-weight-bearing conditions and compare with weight-bearing LLRs, the virtual LLRs were reconstructed by a Python program. To simulate the real LLR imaging, the X-ray source was po-

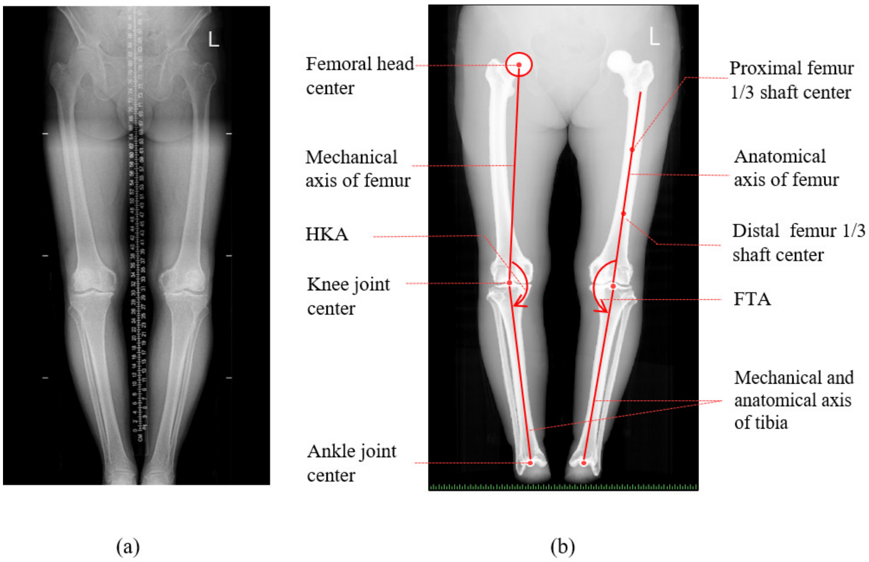

Fig. 6 A real long-leg radiograph in clinics and a virtual long-leg radiograph in this study. (a) Real long-leg radiograph was captured in weight-bearing condition. (b) Virtual long-leg radiograph was captured in non-weight-bearing condition. Both mechanical axis and anatomical axis were measured on virtual LLR. The HKA was defined as the mechanical axial of the femur and tibia. The FTA was defined as the anatomical axial of the femur and tibia.

sitioned at 1.6 meters forward from midpoint of line FH-AC and the projection plane was 1.8 meters from the X-ray source. The initial beam direction was oriented perpendicular to the coronal plane. Fig. 2(b) shows the schematic of capturing virtual LLR. The virtual LLR of each knee was reconstructed from the projection of the 3D model by using a self-developed python program. Real LLR in weight-bearing condition and virtual LLR in non-weight-bearing condition were shown in Fig. 3. From the radiograph, the mechanical axis of femur was defined as the line passing from the center of femoral head to the center of the knee joint; the anatomical axis of femur was defined as the line passing midpoint of the upper and lower 1/3 of the femoral medullary cavity; both the mechanical and anatomical axis of tibia were defined as the line passing the center of the knee and ankle joint. HKA was defined as the medial side angle of mechanical axis; and FTA was defined as the medial side angle of anatomical axis. Both HKA and FTA were measured on virtual LLR as shown in Fig. 3(a).

To simulate the clinical radiographic capture and quantify the variability of HKAs and FTAs measured on LLR, the 3D model was rotated from the neutral position. The rotation axis was defined as the line FH-AC. With the rotation of the lower limb in 10° increments, ranging from 20° internally to 20° externally, five series of virtual LLRs were obtained. The range (maximum minus minimum) of HKAs and FTAs in each group was defined as the HKA deviation and the FTA deviation, respectively.

5.3 Statistical Analysis

To assess the impact of knee coronal deformity and flexion angle on the deviation of HKA and FTA, two-way ANOVAs were calculated using SPSS 22.0 (SPSS Corp, Chicago, USA). The threshold for statistical significance was set at alpha = 0.05. The normality test and uniformity test of error variance are carried out for the raw data. Following that, multiple comparison least significant difference (LSD) was run to compare the mean changes between each event. In addition, Spearman's correlation coefficients were accessed to analysis the relationship between variables. The method of measuring the knee coronal and flexion angle were shown in Supplementary Materials. The percentages for categorical variables were summarized. Means, standard deviations and the standard error of mean or medians with interquartile ranges were performed for continuous variables. The differences of coronal deformity between virtual LLR (non-weight-bearing condition) and real LLR (weight-bearing condition) were analyzed by a paired t-test. Intra-observer reliability was calculated by the intraclass correlation coefficient (ICC). The interpretation scales of ICC are classified according to following: 0–0.20 is slight, 0.21–0.40 is fair, 0.41–0.60 is moderate, 0.61–0.80 is substantial, and 0.81–1.00 is perfect.

References

1. Babazadeh S, Dowsey MM, Bingham RJ, Ek ET, Stoney JD, Choong PFM (2013) The long leg radiograph is a reliable method of assessing alignment when compared to computer-assisted navigation and computer tomography. The Knee 20:242-249
2. Brouwer RW, Jakma TSC, Bierma-Zeinstra SMA, Ginai AZ, Verhaar JAN (2003) The whole leg radiograph - Standing versus supine for determining axial alignment. Acta Orthopaedica Scandinavica 74:565-568
3. Brouwer RW, Jakma TSC, Brouwer KH, Verhaar JA (2007) Pitfalls in determining knee alignment: a radiographic cadaver study. J Knee Surg 20:210-215
4. Felson DT, Niu J, Gross KD, Englund M, Nevitt MC (2013) Valgus Malalignment Is a Risk Factor for Lateral Knee Osteoarthritis Incidence and Progression Findings From the Multicenter Osteoarthritis Study and the Osteoarthritis Initiative. Arthritis & Rheumatology 65:355-362
5. Hess S, Moser LB, Amsler F, Behrend H, Hirschmann MT (2019) Highly variable coronal tibial and femoral alignment in osteoarthritic knees: a systematic review. Knee Surgery Sports Traumatology Arthroscopy 27:1368-1377
6. Jiang CC, Insall JN (1989) Effect of rotation on the axial alignment of the femur. Pitfalls in the use of femoral intramedullary guides in total knee arthroplasty. Clin Orthop Relat Res 248:50-56
7. Jud L, Trache T, Tondelli T, Furnstahl P, Fucentese SF, Vlachopoulos L (2019) Rotation or flexion alters mechanical leg axis measurements comparably in patients with different coronal alignment. Knee Surgery Sports Traumatology Arthroscopy:7. doi:10.1007/s00167-019-05779-7
8. Kawakami H, Sugano N, Yonenobu K, Yoshikawa H, Ochi T, Hattori A, Suzuki N (2004) Effects of rotation on measurement of lower limb alignment for knee osteotomy. J Orthop Res 22:1248-1253

9. Lee YS, Lee BK, Lee SH, Park HG, Jun DS, Moon DH (2013) Effect of foot rotation on the mechanical axis and correlation between knee and whole leg radiographs. Knee Surg Sports Traumatol Arthrosc 21:2542-2547
10. León−Muoz VJ, López−López M, Martínez−Martínez F, Santonja−Medina F (2020) Comparison of weight−bearing full−length radiographs and computed−tomography−scan−based three−dimensional models in the assessment of knee joint coronal alignment. The Knee 22:543-551
11. Lonner JH, Laird MT, Stuchin SA (1996) Effect of rotation and knee flexion on radiographic alignment in total knee arthroplasties. Clin Orthop Relat Res 331:102-106
12. Lotke PA, Ecker ML (1977) Influence of positioning of prosthesis in total knee replacement. Journal of Bone & Joint Surgery American Volume 59:77-79
13. Mcgrory JE, Trousdale RT, Pagnano MW, Nigbur M (2002) Preoperative Hip to Ankle Radiographs in Total Knee Arthroplasty. Clin Orthop Relat Res 404:196-202
14. Meijer MF, Velleman T, Boerboom AL, Bulstra SK, Otten E, Stevens M, Reininga IH (2016) The Validity of a New Low-Dose Stereoradiography System to Perform 2D and 3D Knee Prosthetic Alignment Measurements. PLoS One 11:e0146187
15. Radtke K, Becher C, Noll Y, Ostermeier S (2010) Effect of limb rotation on radiographic alignment in total knee arthroplasties. Arch Orthop Trauma Surg 130:451-457
16. Seung-Beom H, Jung KH, Dae-Hee L (2017) Effect of Computer Navigation on Accuracy and Reliability of Limb Alignment Correction following Open-Wedge High Tibial Osteotomy: A Meta-Analysis. BioMed research international. doi:10.1155/2017/3803457
17. Sharma L, Song J, Felson DT, Cahue S, Shamiyeh E, Dunlop DD (2001) The role of knee alignment in disease progression and functional decline in knee osteoarthritis. Jama-Journal of the American Medical Association 286:188-195
18. Swanson KE, Stocks GW, Warren PD, Hazel MR, Janssen HF (2000) Does Axial Limb Rotation Affect the Alignment Measurements in Deformed Limbs? Clin Orthop Relat Res 371:246-252
19. Tanamas S, Hanna FS, Cicuttini FM, Wluka AE, Berry P, Urquhart DM (2009) Does knee malalignment increase the risk of development and progression of knee osteoarthritis? A systematic review. Arthritis Care & Research 61:459-467
20. Wright JG, Treble N, Feinstein AR (1991) Measurement of lower limb alignment using long radiographs. J Bone Joint Surg Br 73:721-723
21. Yang CS, Chen CF, Luo CA, Chang MC, Lee OK, Huang Y, Lin SC (2018) Clinical Experience Using a 3D-Printed Patient-Specific Instrument for Medial Opening Wedge High Tibial Osteotomy. Biomed Research International 2018:1-9

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- SupplementaryMaterials.pdf