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Comparing inter- and intraobserver reliability between two-dimensional and three-dimensional measurements in the tibial component position of unicompartmental knee arthroplasty

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In unicompartmental knee arthroplasty (UKA), the tibial component has a small coronal plane width, the tibia and tibial component rotations are mismatched, and the large tibial component posterior tilt may make accurate measurements of component positions difficult in radiography. The study aimed to assess the intra- and interobserver reliabilities of radiographic (2D) and 3D computed tomography (3D-CT) measurements and to determine the minimum detectable change (95% confidence level, MDC_{95}) in the tibial component position measurements in UKA. The study included 23 females and 7 males. Two surgeons measured the tibial component position. Intraclass and interclass correlation coefficients (ICC) were calculated to obtain reliability, and Bland–Altman analysis was performed to assess systematic errors. The MDC_{95} was calculated according to MDC_{95} = standard error of measurement × 1.96 × $\sqrt{2}$. In the 2D and 3D-CT measurements, intraobserver reliability for coronal and sagittal positions of the tibial component were sufficiently reliable, where ICCs were >0.8. In the coronal plane, the ICCs for interobserver reliability were lower in 2D (ICC, 0.5-0.7) than in 3D-CT (ICC > 0.9). Bland-Altman plots showed systematic bias in sagittal alignment in the 2D assessment. In the 3D assessment of intra- and interobserver reliability, the MDC_{95} of the coronal, sagittal, and axial planes was <2°. In the 2D intra- and interobserver reliability, the MDC_{95} of the coronal and sagittal planes was >2°. The 2D measurement had a risk of misidentifying the tibial component position in UKA.

Keywords: unicompartmental knee arthroplasty, tibia, computed tomography, intra- and interobserver reliabilities, minimal detectable change.

INTRODUCTION

Unicompartmental knee arthroplasty (UKA) is one of the world standard surgery for osteoarthritis and osteonecrosis of the knee joint. In total knee arthroplasty (TKA), postoperative alignment has an impact on longevity and patient satisfaction[1,2]. In UKA, it has also been reported that postoperative alignment affects results[3,4]. In particular, malposition of both the coronal and sagittal planes in the tibial component has been reported as a risk factor for loosening[5]. Iriberri reported that rotation of the tibial component was an important factor in the clinical outcome[6]. Therefore, we believe that tibial component position is an important factor influencing clinical outcomes and longevity. Two-dimensional (2D) radiographic imaging is frequently used to assess preoperative and postoperative leg alignment after UKA. However, previous studies have suggested that a combination of flexion and external rotation progressively alters hip–knee–ankle angles in radiographic assessments[7]. Additionally, the tibial components in UKA have a smaller coronal plane width and a larger posterior slope than those in TKA or the tibia and tibial component rotations are mismatched, which may lead to difficulty in obtaining accurate 2D measurements.

Three-dimensional computed tomography (3D-CT) reconstruction can avoid measurement errors due to rotation. Although 3D-CT has been used to measure the position of components after TKA[8-12], there have been few reports of measuring the position of components after UKA[13].

ZedKnee version 14.5 (LEXI, Tokyo, Japan) is 3D-CT preoperative planning software for UKA that has a function for matching pre- and postoperative CT images, which permits 3D comparison of planned positions with those of implanted components. The intra- and interobserver reliabilities of 3D-CT measurements of the positions of TKA components have previously been reported. Yoshino et al concluded that the intra- and interobserver reliabilities were favorable in all measurements except the sagittal position of the femur[10]. However, to the best of our knowledge, there is no literature on the intra- and interobserver reliabilities of 3D-CT measurements in UKA.

Absolute reliability is statistically determined using the standard error of the mean (SEM). A clinically useful mechanism for examining absolute reliability is minimal detectable change (MDC). MDC represents the magnitude of change necessary to provide confidence that a change is not the result of random variation or measurement error[14]. This study aimed to assess the intra- and interobserver reliabilities of the 2D radiographic and 3D-CT measurements and to assess the MDC scores for the 2D radiographic and 3D-CT assessments of the tibial component position in UKA.

MATERIALS AND METHODS

This retrospective study examined patients who underwent primary UKA performed at two institutions between January 2018 and February 2021. The sample size was 30, as previously reported[15], according to estimates from reliability studies using intraclass correlation coefficients (ICCs). The study population included 23 females and 7 males. The preoperative demographic data of the patients are shown in Table I. Surgeries were performed by three expert orthopedic surgeons using a Persona® Partial Knee system (Zimmer, Warsaw, IN) with a portable navigation system (KneeAlign® 2, OrthAlign, Aliso Viejo, CA). We first used portable navigation to perform osteotomy of the tibia. Then, we cut the distal femoral condyle parallel to the tibial bone-cut surface. This research was approved by the IRB of the authors' affiliated institutions. Informed consent was obtained from all patients.

Table I. — Characteristics of the cohort.

Parameter	Mean (SD), or n (%)
Age (years)	75.7 (7.7)
Female	23(76.7)
Height (cm)	153.1 (8.1)
Body weight (kg)	57.7(8.9)
Body mass index (kg/m^2)	24.6(2.9)
Diagnosis	
OA	22 (73.3)
ON	8 (26.7)
Postoperative FTA (degree)	174.7 (2.4)
Postoperative HKA angle (degree)	179.5 (2.2)

SD: Standard Deviation, OA: osteoarthritis, ON: osteonecrosis, FTA: femoro-tibial angle, HKA: hip-knee-ankle angle.

The 2D and 3D measurements of the component positions were compared and the inter- and intraobserver reliabilities were obtained. Two orthopedic surgeons measured the position of the component twice at intervals of ≥3 weeks. The surgeons did not know the result of the previous measurements or each other's measurements at the time of measurement. One of the orthopedic surgeons who performed the measurements was an expert surgeon (observer A: KS), and the other was an orthopedic surgeon (observer B: TY) with <5 years of experience. Intraclass and interclass correlation coefficients were used to measure the reliability of the measurements[15].

In all patients, a 3D-CT scan of the whole leg was preoperatively obtained. The slice thickness of CT was 2 mm. CT data were reconstructed using ZedKnee into 3D models and used for preoperative planning by each surgeon. From 1-3 weeks postoperatively, a similar CT scan was performed and ZedKnee's image-matching function was used to measure and the coronal, sagittal, and axial alignments of the tibial components. Reference points were defined on the CT images to overlap the pre- and postoperative tibial-axis coordinates (Fig. 1, 2). To automatically fuse the preoperative CT image with the postoperative image, these points were used to match the bone surface. After matching, the template of the tibial component was manually overlaid on the implant image to match the contours (Fig. 3). We referred to two pegs and one keel for determining the tibial component position. Once the images were overlain, we used ZedKnee to measure the coronal, sagittal, and axial alignments of the tibial component.

The tibial shaft axis was used to determine the respective coordinate systems. The tibial shaft axis was determined by the medullary centers at the proximal one-third and distal one-third (Fig. 4). Akagi's antero-posterior axis was defined as the baseline tibial component rotational axis[16]. The sagittal plane was set parallel to the Akagi line through the tibial shaft axis (Fig. 4) and the coronal plane was set vertical to the Akagi line. The axial plane was defined as perpendicular to these two planes. Tibial varus alignments were expressed as positive and valgus alignments as negative. The tibial posterior slope was expressed as positive and the anterior as negative. In rotational alignment, internal rotation was expressed as positive and external rotation as negative for the tibial component.

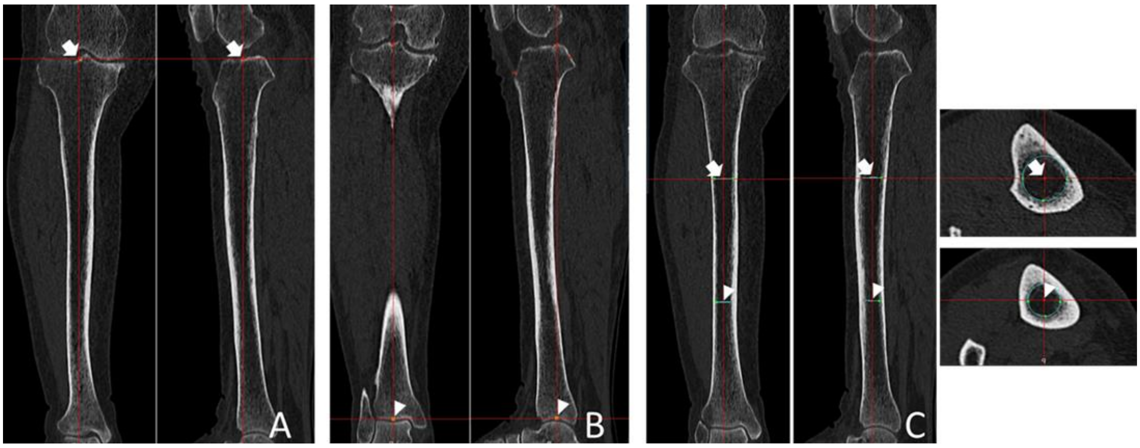

Fig. 1. — Reference points for the right tibia. A: the proximal most point of the temporary mechanical axis (arrow), B: the distal most point of the temporary mechanical axis (arrowhead), C: the medullary centers at the proximal one-third (arrow) and distal one-third (arrowhead).

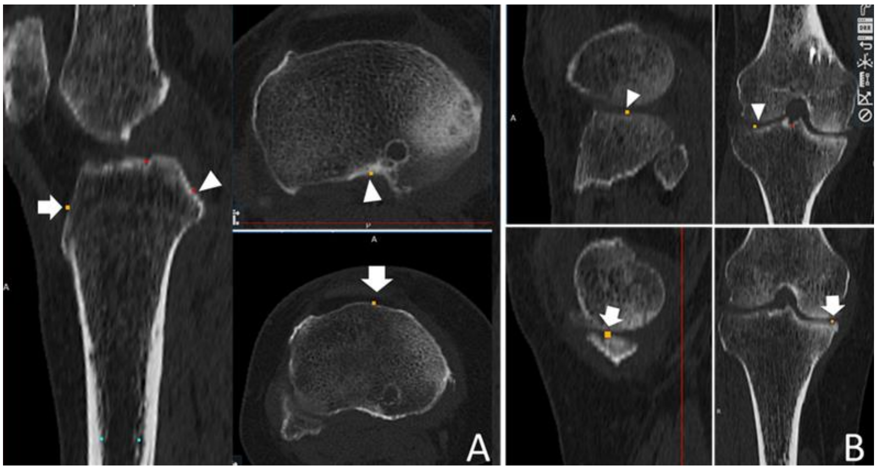

Fig. 2. — Reference points for the right tibia. A: medial edge of the tibial tubercle (arrow) and the enthesis of the posterior cruciate ligament (arrowhead).B: the medial (arrow) and lateral (arrowhead) articular surfaces.

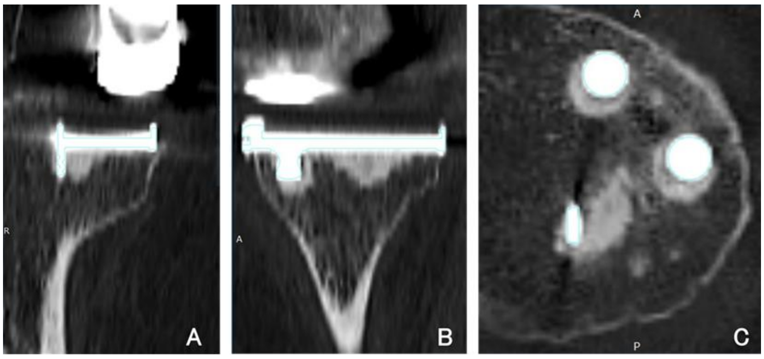

Fig. 3. — (A) tibial coronal, (B) tibial sagittal, (C) tibial axial. Component templates overlaid on images of implants.

Fig. 4-A. — Tibial shaft axis is determined by the medullary centers at proximal one-third and at distal one-third in 3D-CT. B. — The anteroposterior axis of the tibia was determined using the 'Akagi line', a line connecting the middle of the posterior cruciate ligament to the medial border of the patellar tendon attachment in 3D-CT.

Fig. 5. — The Radiographs of the whole tibia in coronal and sagittal planes were taken. Tibial shaft axis is determined by the medullary centers at proximal one-third and at distal one-third.

All patients underwent plain radiography of the whole tibia in coronal and sagittal planes. The tibial shaft axes of the sagittal and coronal planes were defined as in the 3D assessment. The tibial shaft axis was determined by the medullary centers at the proximal one-third and distal one-third (Fig. 5). These plain radiographs were taken by radiology technicians. The rotation of the plain radiograph was manually adjusted to the position where the patella was centered between the femoral condyles in the coronal plane. ImageJ software (National Institutes of Health, Bethesda, MD) was used for 2D measurements of the coronal and sagittal prosthetic alignments.

Intra- and interobserver reliabilities were determined by calculating ICCs with a confidence interval (CI) of 95%. An ICC value of 1.0 indicates perfect reliability; 0.81-1.0, almost perfect; 0.61–0.80, substantial; 0.41-0.60, moderate; 0.21-0.40, fair; and 0.0-0.20; slight[17]. Before calculating the MDC, the systematic error was determined. Bland-Altman analysis was performed to assess systematic errors[18]. The limits of agreement were calculated as the mean difference ± 1.96 × standard deviation (SD). After statistical analysis of the data, the results were rounded to two decimal places. No systematic bias was considered to be present if the range of the 95% CI included zero. The MDC was calculated if there were no systematic errors.

The MDC at the 95% confidence level (MDC$_{95}$) was calculated according to the following formula: $\text{MDC}_{95} = \text{SEM} / 1.96 \times \sqrt{2}$. The SEM was calculated according to the following formula: $\text{SEM} = \text{SD} / \sqrt{2}$[19]. IBM SPSS Statistics for Windows, Version 25.0. (IBM Corp., Armonk, NY) was used to analyze all data.

RESULTS

Measurement data from the inter- and intraobserver reliability analyses, including the ICC with 95% CI and MDC$_{95}$, are reported in Tables II and III. Intra- and interobserver measurements using 3D-CT reconstruction for the coronal, sagittal, and axial positions of the tibial component were sufficiently reliable (ICCs > 0.9) for all alignments. Intraobserver measurements for the coronal and sagittal positions of the tibial component using 2D radiography were sufficiently reliable (ICCs > 0.8) for all alignments. However, interobserver measurements for the coronal plane of the tibial component were less reliable for 2D radiography than for 3D-CT (ICCs = 0.669). In the 3D-CT assessment, Bland-Altman plots showed no systematic bias for intra- and interobserver reliabilities in all alignments (Figs. 6, 7). In the 2D assessment, Bland-Altman plots showed systematic bias in interobserver reliability for the sagittal alignments (Fig. 7 e). Therefore, the MDC was not calculated for the sagittal alignment in the interobserver reliability assessment. In the 3D-CT assessment of interobserver reliability, the MDC$_{95}$ of the coronal, sagittal, and axial planes was <2°. However, in the 2D assessment, the MDC$_{95}$ of the sagittal planes in the intraobserver reliability were 2.76° (observer A) and 4.10° (observer B). The MDC$_{95}$ of the coronal planes was >4° in the intraobserver reliability and >7° in the interobserver reliability (Tables II and III).

Table II. — Intraobserver reliability of 3D and 2D alignment measurements for tibial components angle.

Observer	Measurement	Intra-rater reliability	3D	2D
A	coronal	Mean difference (range)	0.03(-1.12-1.24)	-0.46(-4.96-4.84)
		ICC (95%CI)	0.986 (0.970-0.993)	0.886(0.764-0.946)
		SEM	0.56°	1.47°
		MDC$_{95}$	1.51°	4.07°
	sagittal	Mean difference (range)	0.09(-1.20-2.13)	0.00(-3.43-2.55)
		ICC (95%CI)	0.956(0.908-0.979)	0.925(0.842-0.964)
		SEM	0.56°	0.99°
		MDC$_{95}$	1.54°	2.76°
	axial	Mean difference (range)	-0.09(-1.06-0.94)	
		ICC (95%CI)	0.999(0.998-0.999)	
		SEM	0.31°	
		MDC$_{95}$	0.88°	
B	coronal	Mean difference (range)	-0.21(-0.19-2.09)	-1.02(-9.16-3.47)
		ICC (95%CI)	0.999(0.998-0.999)	0.839(0.661-0.924)
		SEM	0.58°	2.10°
		MDC$_{95}$	1.62°	5.84°
	sagittal	Mean difference (range)	0.05(-0.63-0.74)	0.05(-3.35-7.78)
		ICC (95%CI)	0.981(0.960-0.991)	0.852(0.668-0.930)
		SEM	0.254°	1.48°
		MDC$_{95}$	0.71°	4.10°
	axial	Mean difference (range)	-0.09(-1.03-0.85)	
		ICC (95%CI)	0.997(0.995-0.999)	
		SEM	0.35°	
		MDC$_{95}$	0.98°	

ICC: Intraclass correlation coefficient, CI: Confidence interval, SEM: Standard error of measurement, MDC95: Minimum detectable change at the 95% confidence level.

Table III. — Interobserver reliability of 3D and 2D alignment measurements for tibial components angle.

Measurement	Inter-rater reliability	3D	2D
coronal	Mean difference (range)	-0.05 (-1.75 - 1.97)	-1.00 (-6.98 - 7.95)
	ICC (95%CI)	0.980 (0.959 - 0.991)	0.669 (0.318 - 0.841)
	SEM	0.58°	2.71°
	MDC_{95}	1.62°	7.52°
sagittal	Mean difference (range)	0.17 (-1.13 - 1.53)	-1.29 (-4.41 - 1.28)
	ICC (95%CI)	0.954 (0.904 - 0.978)	0.927 (0.847 - 0.965)
	SEM	0.54°	0.97°
	MDC_{95}	1.51°	
axial	Mean difference (range)	-0.00 (-1.01 - 2.18)	
	ICC (95%CI)	0.998 (0.995 - 0.999)	
	SEM	0.47°	
	MDC_{95}	1.32°	

ICC: Intraclass correlation coefficient, CI: Confidence interval, SEM: Standard error of measurement, MDC_{95}: Minimum detectable change at the 95% confidence level.

DISCUSSION

In this study, only the tibial components were measured and not the femur components. Also, only a single implant was evaluated. We recognize that these are the weaknesses of this study. However, this is the first study of intra- and interobserver reliabilities and MDC of 3D-CT measurements. The 3D-CT intra- and interobserver measurements for positions of the tibial component were sufficiently reliable (ICCs > 0.9) for all alignments. The MDC_{95} of the 3D-CT assessment of the intra- and interobserver reliabilities was <2° for all tibial component alignments. On the contrary, the interobserver measurements for the coronal plane of the tibial component were less reliable for 2D radiography than for 3D-CT, and the MDC of coronal planes was >4° in the intra- and interobserver reliabilities. An outlier of prosthetic alignment is often defined as a case in which the alignment error is >2° or 3° from baseline[13,20]. For this reason, we suggest that 2D assessment has misread the results. Therefore we recommend using 3D-CT for measurement of the positions of the tibial component after UKA.

Several previous studies have reported intra- and interobserver reliabilities of measurements of component positions using 3D-CT images in TKA. Hirschmann et al.[9] evaluated the intra- and interobserver reliabilities of tibial and femoral component measurements in patients after TKA using 3D-CT, and reported excellent intraobserver (ICC, 0.96-0.99) and interobserver (ICC, 0.89-0.97) reliability. They recommended 3D-CT as the preferred technique. Boonen assessed the reliability and validity of measurements on long-leg radiographs using 3D-CT as a gold standard[21]. They reported that surgeons should be aware of potential measurement errors when performing measurements on long-leg radiographs and concluded that 3D-CT measurement of component positions in TKA should be performed. Yoshino et al.[10] reported inter- and intraobserver reliabilities after TKA using the image-matching process of ZedKnee preoperative planning software. They reported very good ICCs for the inter- and intraobserver reliabilities. In addition, Bland-Altman plots were produced for the first- and second-alignment measurements to examine intraobserver reliability, which showed systematic bias only for the sagittal position of the femoral component and no systematic bias for the tibial component. They also concluded that 3D-CT measurements of component positions after TKA have sufficient intra- and interobserver reliability.

In UKA, there are some reports of 3D evaluation of component positions[13,22,23]. However, there are few reports on inter- and intraobserver reliabilities in both 2D and 3D, and there are no reports on MDC for both 2D and 3D measurement. Ishida et al. compared 2D and 3D methods for evaluating component alignment in UKA, although their 3D assessment did not use postoperative 3D-CT but rather used radiographic images matched to preoperative CT[24]. They reported excellent intra- and interobserver reliabilities in both 2D and 3D evaluations of tibial coronal and sagittal positions. However, they reported outliers for femoral component observation in the coronal plane (6/19 subjects) when using 2D evaluations. They concluded that in postoperative evaluation of UKA, assessment

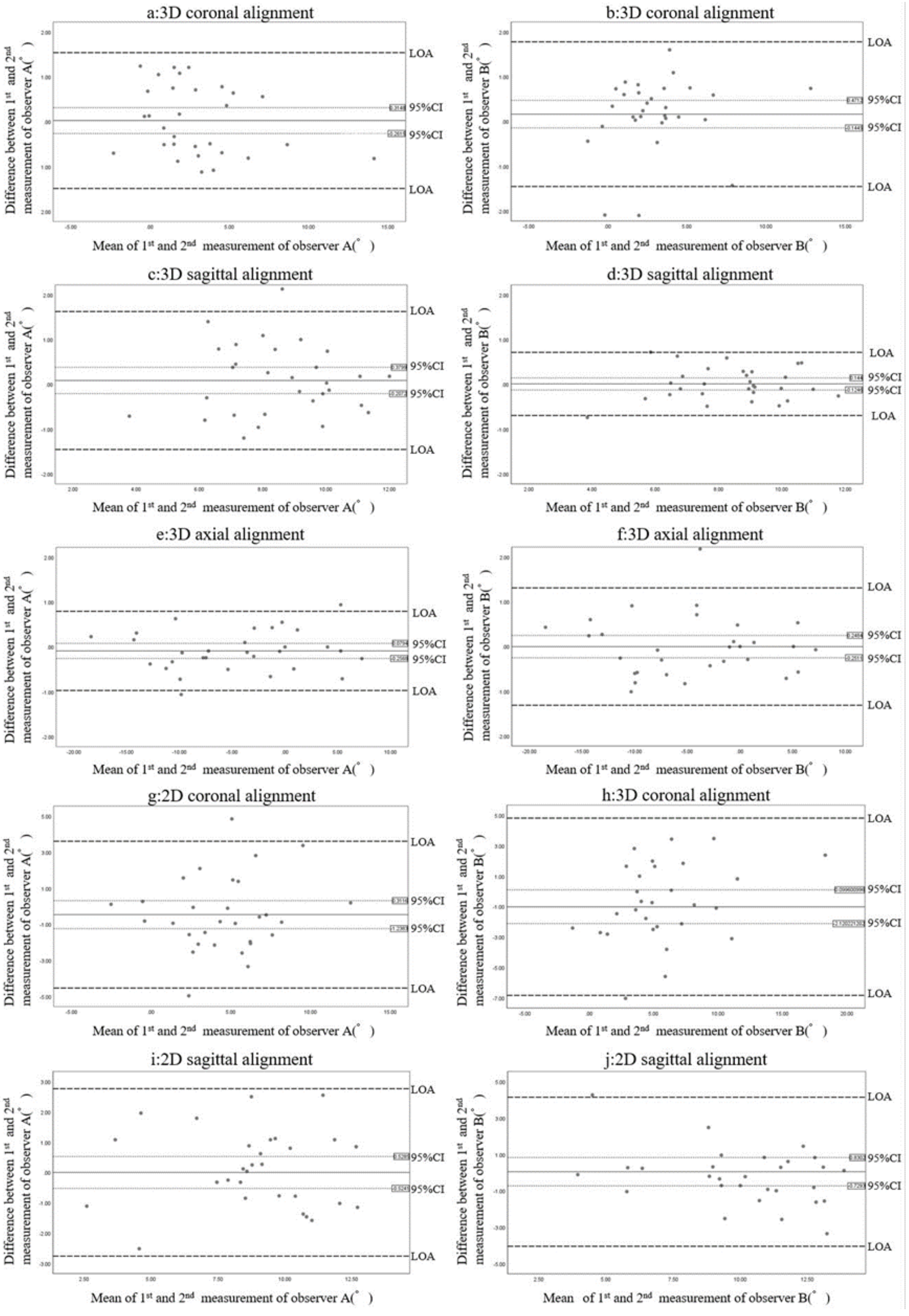

Fig. 6. — Bland-Altman plots for the alignment measurements to examine intraobserver agreement of assessmentThe limits of agreement (LOAs) are represented by the large dotted line. The 95% CI are represented by the small dotted line.

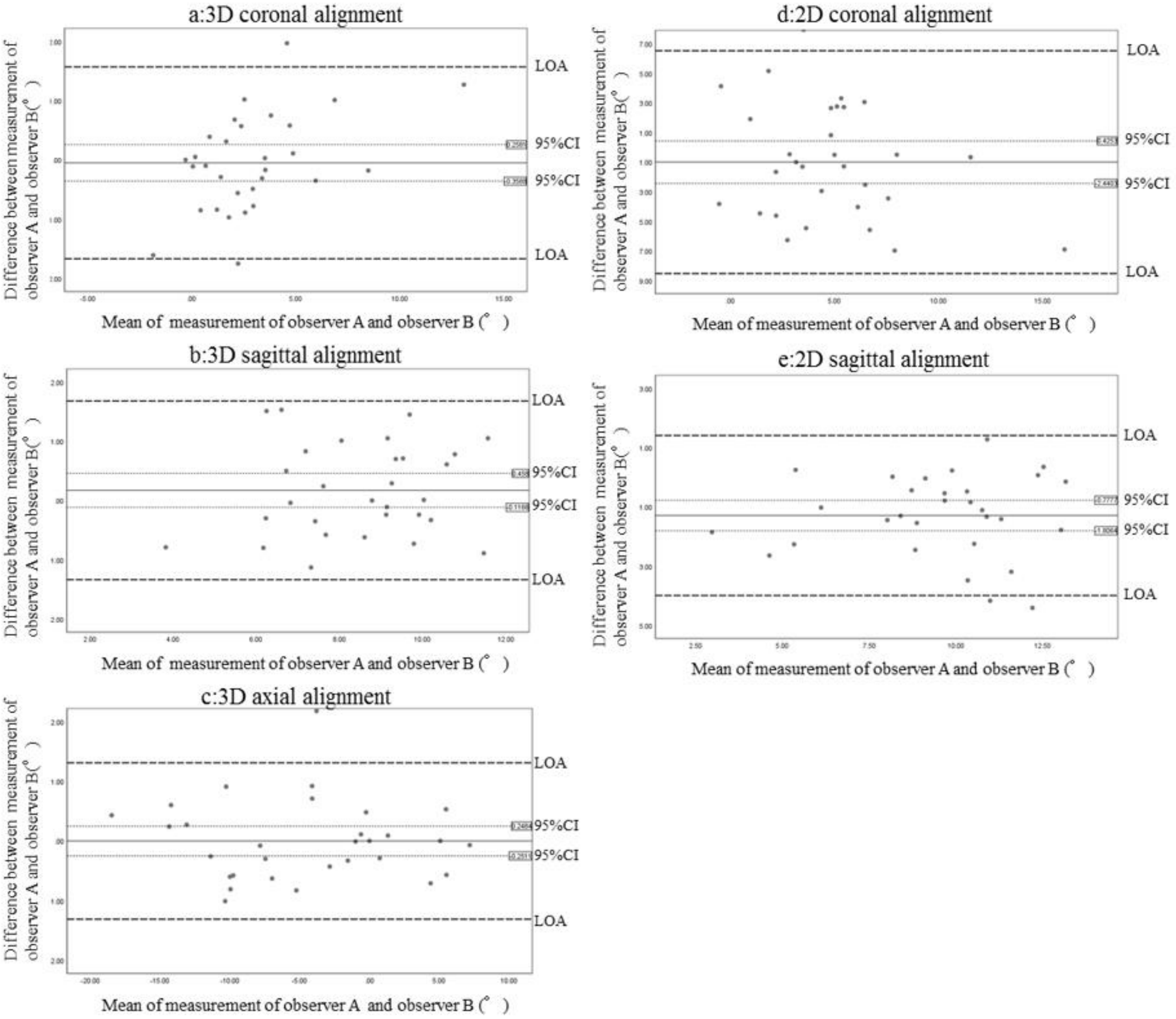

Fig. 7. — Bland-Altman plots for the alignment measurements to examine interobserver agreement. The upper and lower 95% CI for 2D sagittal alignment of measurement were -0.78 and -1.81. Those were, the 95% CI range did not include zero.

of implant position might be misjudged because of the design of the implant.

In this study, intra- and interobserver measurements using 3D-CT reconstruction of the tibial component position were sufficiently reliable with regard to ICCs. On the other hand, the interobserver reliability of the tibial component position in the coronal plane was less reliable for 2D radiography than for 3D-CT with regard to ICCs, and the MDC in the 2D assessment of coronal alignment was >5°. Furthermore Bland-Altman plots showed systematic bias in the 2D assessment. In UKA, the component width in the sagittal plane is sufficient to be evaluated, but the coronal plane is small in component width and can cause measurement errors in 2D assessment due to rotation and posterior slope. The anteroposterior and lateral tibia overall lengths were used in our radiograph evaluations. The cone beam effect of radiographs for 2D measurement is the probable reason for insufficient reliability. Ueyama reported that the cone beam effect deforms images of the femur and tibia, especially when a long film and long focus distance are used[25]. For these reasons, we believe that 2D measurement of the tibia has insufficient interobserver reliability. Therefore, we recommend 3D-CT investigations for accurate evaluation of navigation systems in which an error of ±2 or 3° or more is defined as an outlier[13,20].

Our study had several limitations. First, observers A and B had different years of orthopedic experience. Therefore, there is a possibility that the reliability of the 2D assessments varied. However, in the 3D assessments, intra- and interobserver reliabilities were excellent, even with the less-experienced evaluator. Therefore, we believe our results indicate the high reliability and reproducibility of 3D-CT. Second, the fluoroscopy was not used for obtaining plane radiographs. The intra- and interobserver reliabilities of 2D may have increased if the fluoroscopy was used to adjust the rotation and posterior slope of the tibia. Third, the slice thickness of the CT scans in this study was 2 mm. In previous reports that used ZedKnee's image-matching function, the slice thickness was 1 mm[10]. Although the intra- and interobserver reliabilities were high, we believe that a 1-mm slice thickness is preferable when evaluating the accuracy of implant position. Fourth, the present study did not assess femoral component position. In our surgical procedure, the distal femoral condyles is cut parallel to the tibial bone-cut surface, so tibial osteotomy is very important; therefore, an accelerometer-based portable navigation system is used for tibial osteotomy in UKA. To evaluate the accuracy of the portable navigation system, we must first examine the reliability of the evaluation method. Therefore, the tibial component position was only measured in this study. We will investigate femoral component position in the future study.

CONCLUSION

We found that 2D measurements have a risk of misidentifying the tibial component position in UKA. When evaluating the accuracy of the component position, 2D evaluations may give incorrect results. Therefore, we believe 3D-CT evaluation is desirable.

Conflict of interest and relevant financial agencies: none.

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