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RESEARCH

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The comparison of three dimensional and two dimensional evaluation of varus/valgus stress X-rays following total knee arthroplasty

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Abstract

Purpose The purpose of this study was to compare three-dimensional (3D) and two-dimensional (2D) evaluation of the stress X-rays following total knee arthroplasty (TKA).

Methods This prospective study analyzed 51 consecutive rTKAs (four males and 44 females, both aged 74 ± 6 years). Postoperative varus/valgus stress X-rays were taken at maximum manual varus/valgus stress during knee extension under anesthesia, and were analyzed three-dimensionally using a 3D-2D image matching technique with 3D bone and component models. The 3D models of the femur and tibia, along with component-bone constructs, were reconstructed from CT data using 3D modeling software. The 2D evaluation of varus/valgus stress X-rays were carried out directly on the stress X-rays. The varus/valgus angle (VV angle) between components, Medial joint opening (MJO) and lateral joint opening (LJO) were assessed under conditions of no stress, valgus stress, and varus stress.

Results The VV angles under no stress, valgus stress, and varus stress in 3D and 2D evaluation were 3.6 ± 1.1 / 3.6 ± 1.1°, -0.6 ± 1.6 / -0.6 ± 1.6°, 7.1 ± 1.9 / 6.8 ± 2.5°, respectively. The MJO in the non-stress condition and under valgus stress in 3D and 2D evaluation were 0.0 ± 0.5 / -1.8 ± 0.8 mm,1.4 ± 1.0 / -0.2 ± 1.4 mm, and the LJO in the non-stress condition and under varus stress in 3D and 2D evaluation were 0.9 ± 1.0 / -0.6 ± 1.0 mm, 3.5 ± 1.9 / 2.1 ± 1.9 mm, respectively.

Conclusions This prospective study revealed that the 3D evaluation of varus/valgus stress X-rays following total knee arthroplasty is equivalent to 2D evaluation in VV angles, whereas different from 2Devaluation in MJO and LJO.

Keywords Robotic total knee arthroplasty, Stress x-ray, Comparison between 3D/2D evaluation

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Introduction

Recent reports on robotic-assisted total knee arthroplasty (rTKA) have demonstrated increasingly satisfactory clinical outcomes [1, 2]. There are also reports that patient satisfaction score, which has long been considered an issue with TKA, is improving [3]. A critical determinant of these outcomes is the achievement of excellent postoperative varus/valgus stability, which relies on precise prosthesis positioning tailored to each patient's unique anatomy and soft tissue characteristics. This stability is essential for the overall clinical success of TKA procedures [4].

In our previous study, we documented exceptional postoperative varus/valgus stability following rTKA, assessed three-dimensionally using varus/valgus stress radiographs [5]. However, this three-dimensional (3D) evaluation cannot be directly compared to the numerous prior studies that employed two-dimensional (2D) assessments of postoperative varus/valgus stability [6, 7]. A significant limitation of 3D evaluation is the extensive time required for analysis. Moreover, computed tomography (CT) is not a practical tool for frequent postoperative assessments. To date, no studies have compared the outcomes of complex 3D evaluations with the more accessible 2D evaluations of varus/valgus stress radiographs following rTKA.

Our research group has recently focused on 3D static alignment measurements and dynamic knee motion analysis using a 3D-2D image registration technique [8–15]. In this study, we aimed to assess the utility of 3D evaluation employing the 3D-2D image registration technique for varus/valgus stress radiographs following TKA and compare it with conventional 2D evaluation methods.

The purpose of this study is to reveal significant differences of 3D evaluation using the 3D-2D image registration technique for varus/valgus stress radiographs compared to 2D evaluation.

Materials and methods

The present study was approved by the ethical review board of Niigata University (IRB number: 2020 – 0448). This prospective study included a consecutive series of rTKAs performed on patients aged 60 years or older with advanced varus knee osteoarthritis (OA), classified as grades 3–4 according to the Kellgren–Lawrence (K–L) classification [16]. Of the 55 knees (50 patients) treated between January 2021 and March 2023, 51 knees (48 patients) were included in the analysis, excluding cases with incomplete data. The cohort comprised four males (four knees) and 44 females (47 knees). Their mean age, body hight, body weight, body mass index (BMI) and pre-/post operative femorotibial angles (FTA) were 74 ± 6 years, 153.0 ± 6.1 cm, 59.5 ± 9.1 kg, 25.7 ± 3.6 kg/m^2, and 184.2 ± 7.9/176.9 ± 3.7°, respectively (Table 1).

Table 1 The demographic data

Total	**51**	**knees**
Male/Female	3/45	
	Mean ± SD	95%CI
age, years	74 ± 6	72–75
Body height, cm	153.0 ± 6.1	151.3-154.8
Body weight, kg	59.5 ± 9.1	57.0-62.1
Body mass index (BMI), kg/m^2	25.7 ± 3.6	24.7–26.7
Pre operative FTA, °	184.2 ± 7.9	182.0-186.5
Post operative FTA, °	176.9 ± 3.7	175.8-177.9

FTA = femorotibial angle

All surgeries were performed using the Navio® and CORI® surgical systems (Smith & Nephew, Memphis, TN, USA), which are handheld, imageless, semi-active robotic platforms [17, 18]. Compared to the Navio system, the CORI system features an enhanced workflow efficiency enabled by higher-speed camera technology. Both systems facilitate image-free mapping of bone geometry, gap assessment, intraoperative planning, and confirmation of alignment and knee balance. In all cases, the bi-cruciate substituting (BCS)-TKA prosthesis (Journey II BCS®; Smith & Nephew, Memphis, TN, USA) was utilized.

Preoperative planning was conducted using 3D software (JIGEN®; LEXI, Inc., Tokyo, Japan) to determine the size and default positioning of the femoral and tibial components based on anatomical coordinate systems. The preoperative plan included the selection of component size and condylar twist angle, defined as the angle between the posterior condyle axis (PCA) and the surgical epicondylar axis (SEA) [13]. Default femoral component positioning was set to 0° relative to the mechanical axis (MA) in the coronal plane, 3° flexion to the MA in the sagittal plane, and 0° relative to the SEA in the horizontal plane. Similarly, the tibial component was positioned at 0° relative to the MA in the coronal plane, 3° posterior inclination to the MA in the sagittal plane, and 0° relative to the Akagi line in the horizontal plane [19].

During surgery, component positions and overall limb alignment were adjusted to account for soft tissue balance. Adjustments to the femoral component included a range of 0° to 3° varus relative to the MA (coronal plane), 0° to 6° flexion relative to the MA (sagittal plane), and ± 3° external rotation relative to the SEA (rotational alignment). Tibial component positions were fixed based on preoperative plans at 0° relative to the MA in the coronal plane, 3° inclination in the sagittal plane, and 0° relative to the Akagi line. The final lower limb alignment was set within 0° to 3° varus to the MA in the coronal plane. Intraoperative adjustments were made following resection of the anterior cruciate ligament, posterior cruciate ligament, and osteophytes, excluding the posterior femoral condyles where feasible. The procedure included medial parapatellar exposure with minimum collateral release, identification of bony reference points, intraoperative 3D imaging, initial component placement, manual assessment of soft tissue balance under maximum stress, fine-tuning of components, and bone resection using a handheld end-cutting burr. All components were secured using cement. The patellar components were not used in all cases. Furthermore, the thickness of the insert is basically 9 mm, but we adjusted it 9–11 mm depending on the ligament tension.

Postoperative evaluation involved varus/valgus stress radiographs under maximum manual stress with the knee in extension under anesthesia. Preoperative and postoperative 3D models of the femur and tibia, along with component-bone constructs, were reconstructed automatically from CT data using 3D modeling software (ZedView®; LEXI, Inc., Tokyo, Japan). Postoperative component positioning relative to the bone was calculated using a 3D-3D image matching technique (JIGEN®; LEXI, Inc., Tokyo, Japan). The spatial relationships between femoral and tibial components were determined using a 3D-2D image registration technique (Zed Motion®; LEXI, Inc., Tokyo, Japan) with aligning the 3D models to varus/valgus stress radiographs (Figure 1). Coordinate systems for bone and components were established based on prior studies [9, 10], enabling automated calculation of relative femoral and tibial positions (Figure 2).

The primary evaluation parameter, the varus/valgus (VV) angle between components, was defined as the angle between the medial and lateral most distal points of the femoral component and the x-axis of the tibial component coordinate system (Figure 3). The BCS-TKA design incorporates a 3° valgus angle into the femoral component; however, this angle was not subtracted for simplicity. VV angles were assessed under no stress (non-stress VV angle), valgus stress (valgus VV angle), and varus stress (varus VV angle). The joint gap was calculated by subtracting the thinnest insert thickness from the distance between the femoral component's distal points and the tibial component's surface. This gap was reported as the medial joint opening (MJO) and lateral joint opening (LJO) under respective stress conditions (Figure 4). For 2D evaluation, varus/valgus stress X-rays were assessed directly.

Statistical analysis

The Shapiro-Wilk test was applied to assess data normality. Wilcoxon signed-rank tests were used for statistical comparisons. All analyses were performed using SPSS software (version 27; SPSS Inc., Chicago, IL, USA), with statistical significance set at $p < 0.05$ (Statistical power is 0.78 with 51 samples in 0.4 effect size).

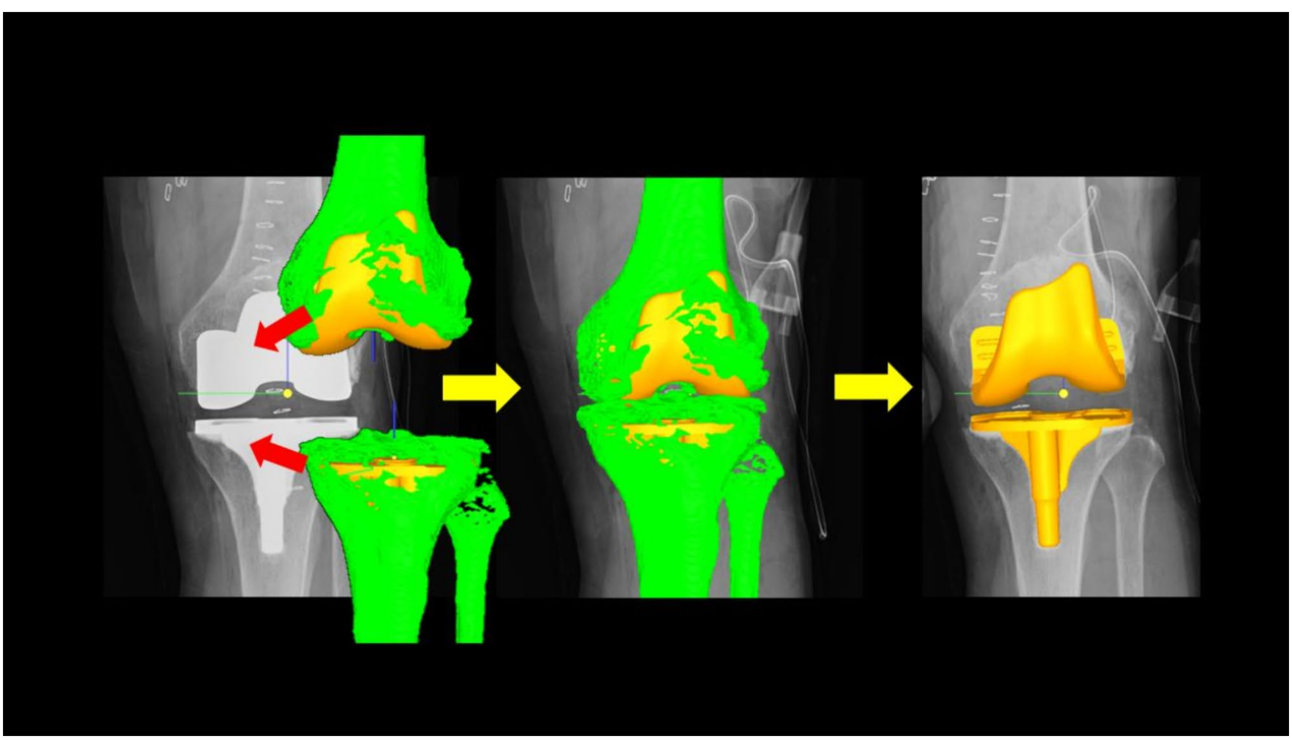

Fig. 1 3D-2D image matching technique with the 3D complex and stress X-rays. The contours of 3D complex in postoperative component positions (yellow) and preoperative bone models (green) were manually detected in stress X-rays under anesthesia regarding femur and tibia separately. After composited the images of femur and tibia into single image, the component was extracted removing preoperative bone models

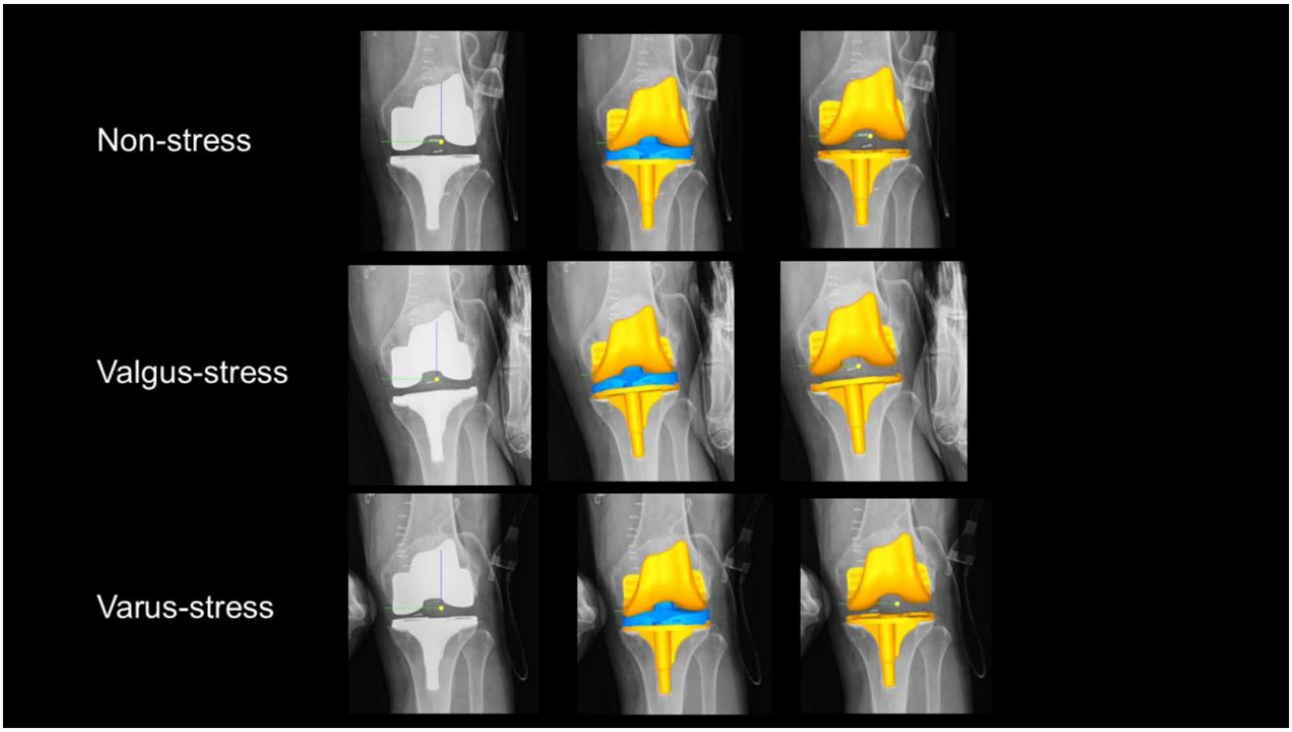

Fig. 2 Analysis of femoral component position relative to the tibial component. Left pictures were varus/valgus stress and non-stress x-rays, and central pictures were result of components position after 3D-2D image matching. As result, the position of femoral components was calculated in the coordinate system of the tibial component (right pictures)

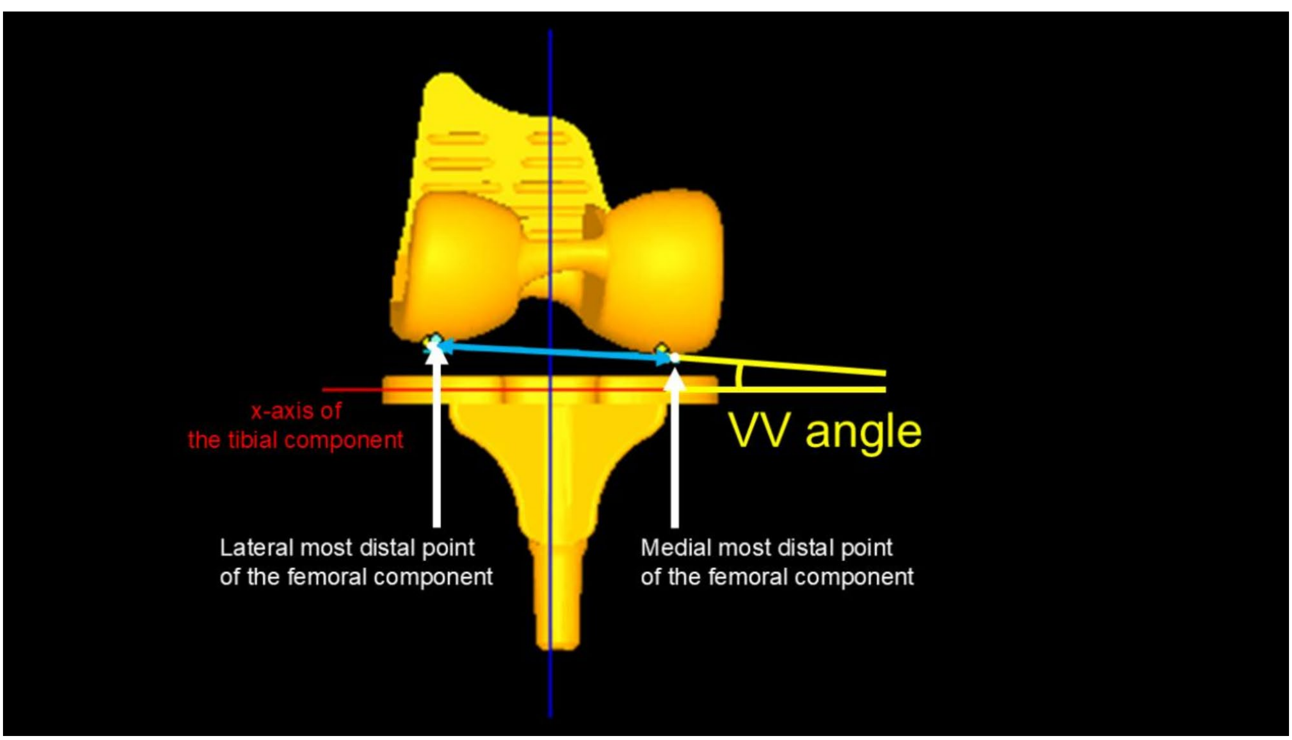

Fig. 3 The angle between femoral and tibial components (Varus/valgus angle: VV angle). The line connecting the medial and lateral most distal points of the femoral component projected onto the coronal plane of tibial implant coordination system and the x-axes of tibial component was defined as varus/valgus angle (VV angle)

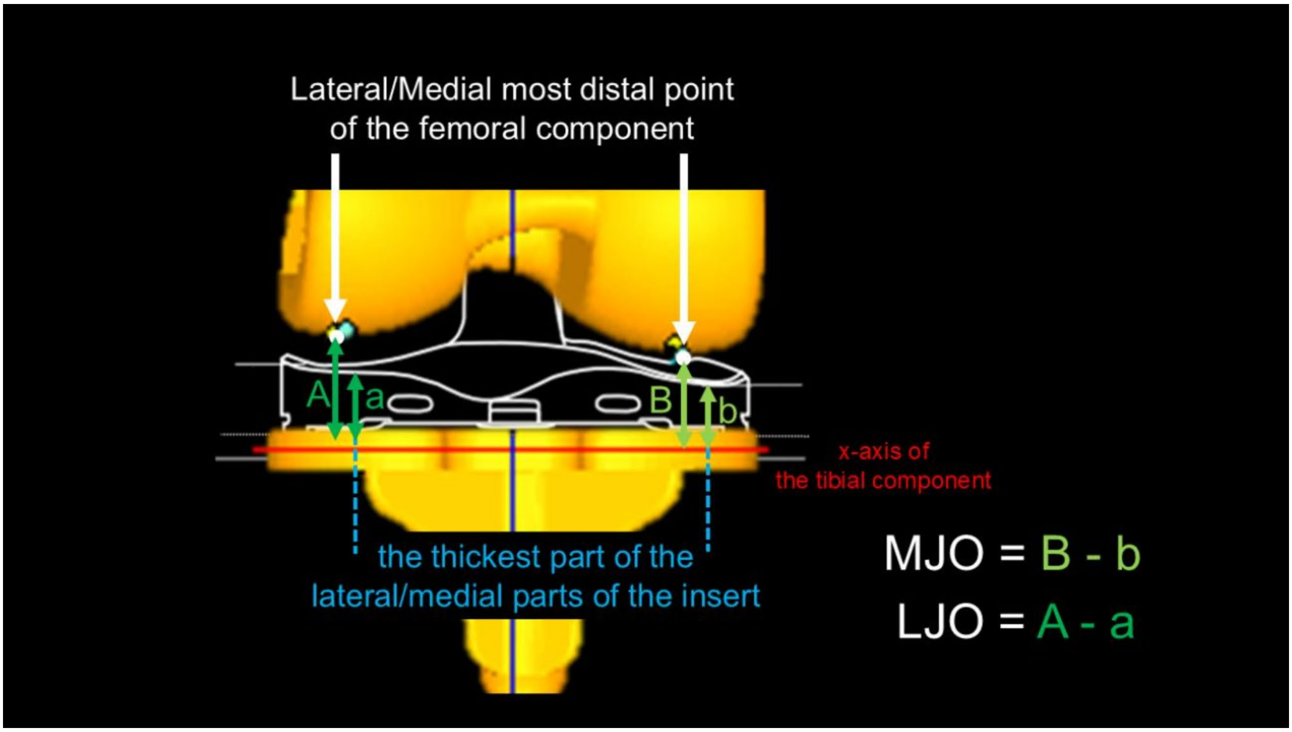

Fig. 4 The separation distance between femoral components and inserts: the medial joint opening (MJO) and lateral joint opening (LJO). The distance of most distal point of the femoral component from the x-axis of the tibial component was calculated in lateral (**A**) and medial (**B**). Medial joint opening (MJO) and lateral joint opening (LJO) as joint gap were calculated by subtracting thickness of thickest part of the insert in lateral (**a**) and medial (**b**) from the distance (**A** and **B**)

Table 2 Evaluation parameters

	3D		2D		
	Mean ± SD	**95%CI**	**Mean ± SD**	**95%CI**	***p* value**
non-stress VV angle, °	3.6 ± 1.1	3.3–3.9	3.6 ± 1.1	3.3–3.9	0.63
valgus VV angle, °	-0.6 ± 1.6	0.2–1.1	-0.6 ± 1.6	0.2–1.1	0.43
varus VV angle, °	7.1 ± 1.9	6.6–7.7	6.8 ± 2.5	6.1–7.5	0.11
MJO in no stress, mm	0.0 ± 0.5	-0.1–0.2	-1.8 ± 0.8	-2.0–1.5	< 0.05*
MJO in valgus stress, mm	1.4 ± 1.0	1.1–1.6	-0.2 ± 1.4	-0.6–0.2	< 0.05*
LJO in no stress, mm	0.9 ± 1.0	0.7–1.2	-0.6 ± 1.0	-0.9 - -0.3	< 0.05*
LJO in varus stress, mm	3.5 ± 1.9	2.1–3.7	2.1 ± 1.9	1.6–2.6	< 0.05*

*Statistical significance by Wilcoxon signed-rank tests

VV angle = varus/valgus angle; MJO = medial joint opening in valgus stress; LJO = lateral joint opening in varus stress

Results

Table 1 presents the demographic data for this study. The non-stress varus/valgus (VV) angle, valgus VV angle, and varus VV angle in the 3D and 2D evaluations were 3.6 ± 1.1° / 3.6 ± 1.1°, -0.6 ± 1.6° / -0.6 ± 1.6°, and 7.1 ± 1.9° / 6.8 ± 2.5°, respectively. MJO under non-stress and valgus stress conditions in the 3D and 2D evaluations were 0.0 ± 0.5 mm / -1.8 ± 0.8 mm and 1.4 ± 1.0 mm / -0.2 ± 1.4 mm, respectively. Similarly, LJO under non-stress and varus stress conditions in the 3D and 2D evaluations were 0.9 ± 1.0 mm / -0.6 ± 1.0 mm and 3.5 ± 1.9 mm / 2.1 ± 1.9 mm, respectively (Table 2).

While the VV angle showed no statistically significant differences between the 3D and 2D evaluations under non-stress, valgus stress, and varus stress conditions, the MJO and LJO exhibited statistically significant differences between the 3D and 2D evaluations under all stress conditions.

Discussion

The most findings of this study were as follows: (1) MJO and LJO exhibited statistically significant differences between 3D and 2D evaluations under non-stress, valgus stress, and varus stress conditions; and (2) the VV angle showed no statistically significant differences between 3D and 2D evaluations under any of these conditions.

The statistically significant differences observed between 3D and 2D evaluations of MJO and LJO across all stress conditions in this study are considered to be purely due to differences in evaluation methods because we use same images for 3D and 2D evaluations. There have been similar reports in the previous study. Mizuuchi et al. highlighted that postoperative evaluations of TKA should be performed three-dimensionally rather than two-dimensionally [20]. This result shows the importance of 3D assessment and the limitations of 2D evaluation using radiographs after TKA. Especially in the case of measuring distances such as MJO and LJO, it would be preferable to evaluate in 3D rather than 2D. Skowronek et al. emphasized the necessity of 3D evaluation for assessing femoral component rotation [21]. Even among 2D evaluation methods, Petersen and Engh reported a mean difference in anatomical alignment of 1.4° (SD 2.2°, range: −3° to 6°) between the HKA and AP knee radiographs, further indicating the potential influence of rotational alignment on evaluation outcomes [22]. Additionally, Stöbe et al. reported that the joint gaps are determined by the combination of the external femur rotation, appropriate tibial slope and femur rollback [23]. Additionally, Shin et al. reported the effect of posterior tibial slope for the joint gap in TKA [24]. However, accurate assessment of the posterior tibial slope is impossible in 2D evaluation of anterior-posterior (AP) knee radiographs. Therefore, the effect of posterior tibial slope is not included in 2D evaluation. Thus, tibiofemoral rotation and posterior tibial slope were considered as the cause of MJO and LJO differences between 3D and 2D evaluations in this study.

The issue of evaluation accuracy in AP knee radiographs has been discussed in several studies [25, 26]. In this study, certain distance parameters yielded negative values, potentially due to inaccuracies in recognizing the x-axis of the tibial component. Tanifuji et al. noted that AP and lateral views are not always true representations of the femur and tibia [10]. In 2D evaluations, recognition of the x-axis depends on the angle of X-ray projection, whereas this dependency is eliminated in 3D evaluations. This difference underscores the superior accuracy of 3D evaluation for knee X-rays compared to 2D methods.

Conversely, the VV angle showed no statistically significant differences between 3D and 2D evaluations under any of the stress conditions. This result suggests that 2D evaluation may be sufficient for assessing angular parameters. Ishii et al. demonstrated that using landmarks 10 cm away from the joint lines yields accurate and repeatable anatomical axes on standardized AP knee radiographs [27]. The findings of the present study further support the validity of angle evaluation using routine 2D stress radiographs.

This study has several limitations. First, all evaluations were performed by a single researcher, which may introduce bias or limit generalizability. Second, the sample size was relatively small and inequal of gender, necessitating larger-scale studies to strengthen the statistical validity of these findings. Third, the underlying reasons for the observed differences in MJO and LJO between 3D and 2D evaluations remain unclear. Further detailed analyses are required to address this issue comprehensively.

Conclusions

This study demonstrated the following findings: (1) MJO and LJO exhibited statistically significant differences between 3D and 2D evaluations under non-stress, valgus stress, and varus stress conditions; and (2) the VV angle showed no statistically significant differences between 3D and 2D evaluations under any of these conditions.

Abbreviations

3D	Three-dimensional
2D	Two-dimensional
TKA	Total knee arthroplasty
VV Angle	Varus/valgus angle
MJO	Medial joint opening
LJO	Lateral joint opening
rTKA	Robotic-assisted total knee arthroplasty
CT	Computed tomography
K-L	The Kellgren–Lawrence
BCS	Bi-cruciate substituting
PCA	Posterior condyle axis
SEA	Surgical epicondylar axis
MA	Mechanical axis
FTA	Femorotibial angles
AP	Anterior-posterior

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Author contributions

H.H. and T.M. wrote the main manuscript text. H.H and T.M prepared figures and Tables.H.H., T.M., K.M., O.T., G.O. and N.Y. collected material patients.All authors reviewed the manuscript.

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Data availability

No datasets were generated or analysed during the current study.

Declarations

Ethics approval and consent to participate

This study was approved by the ethical review board of Niigata University (IRB number: 2020 – 0448).

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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References

1. Oussedik S, Abdel MP, Victor J, Pagnano MW, Haddad FS. Alignment in total knee arthroplasty. Bone Joint J. 2020;102–B(3):276–9. https://doi.org/10.1302/0301-620X.102B3.BJJ-2019-1729.
2. Han S, Rodriguez-Quintana D, Freedhand AM, Mathis KB, Boiwka AV, Noble PC. Contemporary robotic systems in total knee arthroplasty: A review of accuracy and outcomes. Orthop Clin North Am. 2021;52(2):83–92. https://doi.org/10.1016/j.ocl.2020.12.001.
3. Stoltz MJ, Smith NS, Abhari S, Whitaker J, Baker JF, Smith LS, Bhimani R, Yakkanti MR, Malkani AL. Patient-Reported outcomes in Robotic-Assisted vs manual cementless total knee arthroplasty. 2024 Oct 12:30101488. https://doi.org/10.1016/j.artd.2024.101488
4. Hossain F, Patel S, Haddad FS. Midterm assessment of causes and results of revision total knee arthroplasty. Clin Orthop Relat Res 2010 May;468(5):1221–8. https://doi.org/10.1007/s11999-009-1204-0
5. Hijikata H, Mochizuki T, Maeda K, Tanifuji O, Omori G, Yamamoto N, Kawashima H. Varus/valgus stability in imageless robotic-assisted total knee arthroplasty applying three-dimensional assessment of varus/valgus stress X-rays. Biomed Mater Eng. 2024;35(2):179–89. https://doi.org/10.3233/BME-230146.
6. Kamenaga T, Muratsu H, Kanda Y, Miya H, Kuroda R, Matsumoto T. The influence of postoperative knee stability on patient satisfaction in Cruciate-Retaining total knee arthroplasty. J Arthroplasty. 2018;33(8):2475–9. https://doi.org/10.1016/j.arth.2018.03.017.
7. Ishii Y, Matsuda Y, Ishii R, Sakata S, Omori G. Coronal laxity in extension in vivo after total knee arthroplasty. J Orthop Sci. 2003;8(4):538–42. https://doi.org/10.1007/s00776-003-0668-0.
8. Sato T, Koga Y, Omori G. Three-dimensional lower extremity alignment assessment system: application to evaluation of component position after total knee arthroplasty. J Arthroplasty. 2004;19(5):620–8. https://doi.org/10.1016/j.arth.2003.12.063.
9. Sato T, Koga Y, Sobue T, Omori G, Tanabe Y, Sakamoto M. Quantitative 3-dimensional analysis of preoperative and postoperative joint lines in total knee arthroplasty: a new concept for evaluation of component alignment. J Arthroplasty. 2007;22(4):560–8. https://doi.org/10.1016/j.arth.2006.06.020.
10. Tanifuji O, Mochizuki T, Yamagiwa H, Sato T, Watanabe S, Hijikata H, Kawashima H. Comparison of post-operative three-dimensional and two-dimensional evaluation of component position for total knee arthroplasty. Knee Surg Relat Res. 2021;33(1):21. https://doi.org/10.1186/s43019-021-00106-2.
11. Mochizuki T, Sato T, Blaha JD, Tanifuji O, Kobayashi K, Yamagiwa H, Watanabe S, Matsueda M, Koga Y, Omori G, Endo N. Kinematics of the knee after unicompartmental arthroplasty is not the same as normal and is similar to the kinematics of the knee with osteoarthritis. Knee Surg Sports Traumatol Arthrosc. 2014;22(8):1911–7. https://doi.org/10.1007/s00167-013-2767-6.
12. Mochizuki T, Sato T, Tanifuji O, Kobayashi K, Yamagiwa H, Watanabe S, Koga Y, Omori G, Endo N. Unicompartmental knee arthroplasty cannot restore the functional flexion axis of a living knee to normal. Knee Surg Sports Traumatol Arthrosc. 2015;23(12):3736–42. https://doi.org/10.1007/s00167-014-3296-7.
13. Mochizuki T, Sato T, Tanifuji O, Watanabe S, Kobayashi K, Endo N. Extrinsic factors as component positions to bone and intrinsic factors affecting postoperative rotational limb alignment in total knee arthroplasty. J Arthroplasty. 2018;33(7):2100–10. https://doi.org/10.1016/j.arth.2018.02.009.
14. Mochizuki T, Koga Y, Tanifuji O, Sato T, Watanabe S, Koga H, Kobayashi K, Omori G, Endo N. Effect on inclined medial proximal tibial articulation for varus alignment in advanced knee osteoarthritis. J Exp Orthop. 2019;6(1):14. https://doi.org/10.1186/s40634-019-0180-x.
15. Mochizuki T, Koga Y, Mori T, Nishino K, Kobayashi K, Tanifuji O, Sato T, Katsumi R, Koga H, Omori G, Tanabe Y. Articular surface of the medial proximal tibia is aligned parallel to the ground in three-dimensional space under weight-bearing conditions in healthy and varus Osteoarthritic knees. Knee Surg Sports Traumatol Arthrosc. 2020;28(10):3232–9. https://doi.org/10.1007/s00167-019-05829-0.
16. Kellgren JH, Lawrence JS. Radiological assessment of osteoarthritis. Ann Rheum Dis. 1957;16:494–502. https://doi.org/10.1136/ard.16.4.494.
17. Casper M, Mitra R, Khare R, et al. Accuracy assessment of a novel image-free handheld robot for total knee arthroplasty in a cadaveric study. Comput Assist Surg (Abingdon). 2018 Dec;23(1):14–20. https://doi.org/10.1080/24699322.2018.1519038.
18. Innocenti B, Bori E. Robotics in orthopaedic surgery: why, what and how? Arch Orthop Trauma Surg. 2021;141(12):2035–42. https://doi.org/10.1007/s00402-021-04046-0.
19. Akagi M, Oh M, Nonaka T, Tsujimoto H, Asano T, Hamanishi C. An antero-posterior axis of the tibia for total knee arthroplasty. Clin Orthop Relat Res. 2004;420213–9. https://doi.org/10.1097/00003086-200403000-00030.
20. Mizu-uchi H, Matsuda S, Miura H, Higaki H, Okazaki K, Iwamoto Y. Three-dimensional analysis of computed Tomography–Based navigation system for total knee arthroplasty. J Arthroplasty. 2009;24(7):1103–10. https://doi.org/10.1016/j.arth.2008.07.007.
21. Skowronek P, Arnold M, Starke C, Bartyzel A, Moser LB, Hirschmann MT. European knee associates (EKA). Intra– and postoperative assessment of femoral component rotation in total knee arthroplasty: an EKA knee expert group clinical review. KSSTA. 2021;29(3):772–82. https://doi.org/10.1007/s00167-020-06006-4.
22. Petersen TL, Engh GA. Radiographic assessment of knee alignment after total knee arthroplasty. J Arthroplasty. 1988;3(1):67–72. https://doi.org/10.1016/s0883-5403(88)80054-8.
23. Stöbe C, Hoechel S, Müller-Gerbl M, Nowakowski AM. Systematic effects of femoral component rotation and tibial slope on the medial and lateral tibiofemoral flexion gaps in total knee arthroplasty. J Orthop Translat 2019 Oct 22:24:218–23. https://doi.org/10.1016/j.jot.2019.09.004
24. Shin KH, Kim SB, Jang KM, Lee CS, Han SB. Posterior tibial slope is a modifiable predictor of relatively large extension gaps in total knee arthroplasty for degenerative osteoarthritis. J Orthop Surg (Hong Kong). 2021 Jan-Apr;29(1):23094990211002004.
25. Park A, Stambough JB, Nunley RM, Barrack RL, Nam D. The inadequacy of short knee radiographs in evaluating coronal alignment after total knee arthroplasty. J Arthroplasty. 2016;31(4):878–82. https://doi.org/10.1016/j.arth.2015.08.015.
26. Abu-Rajab RB, Deakin AH, Kandasami M, McGlynn J, Picard F, Kinninmonth AW. Hip–Knee–Ankle radiographs are more appropriate for assessment of Post-Operative mechanical alignment of total knee arthroplasties than standard AP knee radiographs. J Arthroplasty. 2015;30(4):695–700. https://doi.org/10.1016/j.arth.2014.11.024.
27. Ishii Y, Ohmori G, Bechtold JE, Sherman RE, Gustilo RB. Accuracy of the short radiograph in the measurement of the tibiofemoral angle. Knee 2(2):81–4. https://doi.org/10.1016/j.knee.2018.04.015

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