



## Evaluation of implant alignment in navigated unicompartmental knee arthroplasty : a comparison of 2D and 3D imaging

Kazunari ISHIDA, Akihiko TODA, Nao SHIBANUMA, Tomoyuki MATSUMOTO, Ryosuke KURODA, Masahiro KUROSACA

*From Department of Orthopaedic Surgery, Kobe Kaisei Hospital, Nada, Kobe, Japan*

**This study aimed to compare two-dimensional (2D) and three-dimensional (3D) methods for evaluating implant alignment in navigated UKA. Nineteen UKAs in 18 subjects (7 men) were performed using an image-free navigation system. Coronal and sagittal implant alignments were assessed using radiographs (2D evaluation) and 3D image-matching software. The accuracy of 2D evaluation was compared with that of 3D evaluation. A deviation  $> 3^\circ$  from the 3D evaluation was defined as an outlier. In the 2D evaluation, outliers for the femoral component were observed in both the coronal plane (6/19 subjects) and the sagittal plane (3/19 subjects). In UKA, assessment of the implant position might be misjudged because of the design of the implant, especially for the femoral component ; 3D methods are ideal for assessment of implant alignment.**

**Keywords :** unicompartmental knee arthroplasty ; implant alignment ; three-dimensional evaluation ; radiographic evaluation.

### INTRODUCTION

Unicompartmental knee arthroplasty (UKA) has been performed for the treatment of isolated unicompartmental knee disease for more than 3 decades. The long-term outcome of UKA depends on patient selection, age, sex, and level of activity (9,12). In order to obtain a satisfactory outcome after UKA, proper surgical technique and optimal implant posi-

tioning are essential (11,13). Although the optimal alignment still remains controversial, it is accepted that inaccurate implantation is a factor for early failure. Thus, it is generally agreed that accuracy of implant positioning and reconstruction of the mechanical leg axis are major requirements for achieving good long-term results following UKA (2,3,18).

Recent advancements in computer-assisted surgery (CAS) make it possible to plan the operation preoperatively, in detail, in 3 dimensions (3D) ; CAS is also used intraoperatively. However, most postoperative evaluations of implant positioning are still undertaken in 2 dimensions (2D). In fact, most studies reporting improved accuracy and decreased variability in implant placement position and postoperative limb alignment following CAS undertook

---

■ Kazunari Ishida, MD.

■ Akihiko Toda, MD.

■ Nao Shibamura, MD.

*Department of Orthopaedic Surgery, Kobe Kaisei Hospital, Nada, Kobe, Japan.*

■ Tomoyuki Matsumoto, MD.

■ Ryosuke Kuroda, MD.

■ Masahiro Kurosaka, MD.

*Department of Orthopaedic Surgery, Kobe University Graduate School of Medicine, Chuo, Kobe, Japan.*

Correspondence : Kazunari Ishida, Department of Orthopaedic Surgery, Kobe Kaisei Hospital, 3-11-15, Shinohara-Kita, Nada, Kobe, 657-0068, Japan.

E-mail : wavedreamer17@yahoo.co.jp

© 2015, Acta Orthopædica Belgica.

the evaluation using plain radiography (7,8,12,18). Only a few studies have assessed implant position in 3D, using computed tomography (CT) or magnetic resonance imaging (5,16,19). Radiographic evaluation has limitations; radiographs cannot provide information on component rotation. In addition, when using radiographs to assess UKA it can be difficult to evaluate the coronal and sagittal implant position due to features of the component, in contrast to total knee arthroplasty (TKA). Therefore it is hypothesized that the radiograph is an inaccurate and inappropriate method for evaluating component position in UKA. The aim of the present study was to compare 2D and 3D methods of evaluating component alignment in navigated UKA, and explore the difficulties involved in evaluating component alignment, particularly relating to the femoral component.

## MATERIALS AND METHODS

This study included 19 consecutive UKAs, undertaken in 18 subjects (7 men, 11 women; mean age [SD], 73 (6) years; range, 61-80 years). Two types of UKA prosthesis (Unicompartmental High-Flex Knee System, Zimmer, Warsaw, IN (10 cases); Triathlon Partial Knee Resurfacing System; Stryker Orthopedics, Mahwah, NJ (9 cases)) were implanted with measured resection techniques, using an image-free navigation (NA) system (Stryker 4.0 image-free computer navigation system; Stryker). After medial parapatellar arthrotomy and placement of the tracker pins, anatomical landmarks were digitalized to determine the leg axis. Landmarks for the femur (hip joint center, center of distal femur, Whiteside's line (24), articular femorotibial joint surface, and anterior surface of femur) and tibia (center of proximal tibia, articular femorotibial joint surface, Akagi's line (1), medial and lateral malleolus) were ascertained. The hip joint center was calculated kinematically, by tracking the position of the femoral reference frame during hip motion. The rotational axes of the femur and tibia were determined using Whiteside's line and Akagi's line, respectively. In general the surgeon attempted to implant the tibial component perpendicular to the tibial mechanical axis in the coronal plane, sloped 5-7° posterior, toward the sagittal mechanical axis, and parallel to Akagi's line in rotation. The surgeon also attempted to implant the femoral component perpendicular to the femoral mechanical axis in the coronal plane, allowing few degrees

of sagittal flexion according to the surgeon's judgment, and parallel to the surgical epicondylar axis in rotation.

## Evaluation of implant positioning

### *Evaluation in 2D with conventional radiography*

Four weeks postoperatively, anteroposterior and lateral long leg weight-bearing radiographs (320 mA, 0.03 s exposure at 80-100 kV, depending on soft tissue thickness) were obtained, and component alignment was evaluated, as described below. In addition to the assessment of alignment in TKA, component alignment was defined as: femoral coronal alignment (Fig. 1a), the angle between the femoral coronal mechanical axis and the distal line of the femoral component; tibial coronal alignment (Fig. 1b), the angle between the tibial coronal mechanical axis and the distal line of the tibial component in coronal anteroposterior radiographs; femoral sagittal alignment (Fig. 1c), the angle between the femoral sagittal mechanical axis and the distal line of the femoral component; and tibial sagittal alignment (Fig. 1d), the angle between the tibial sagittal mechanical axis and the distal line of the tibial component. As there is no rigorous definition of the sagittal mechanical axis at present, it was determined according to previous reports (6,20,21). The femoral sagittal mechanical axis is the line connecting the femoral head and the insertion point of the intramedullary rod, when conventional TKA is performed (21). The tibial sagittal mechanical axis is the line connecting the most anterior point on the tibial plateau, and the most anterior and most distally available point of the tibia. The longitudinal axis of the tibia was assumed to be parallel to the tibial sagittal mechanical axis (6,20).

### *Evaluation in 3D with 3D templating software*

In addition to the 2D evaluation, a 3D evaluation was performed using Athena Knee® 3D image-matching software (Soft cube, Osaka Japan), again at 4 weeks postoperatively (15,23). A 3D marker was attached to the surface of the patient's lower leg, and the silhouettes of the marker on the images were used to couple the 2 radiographic images to the 3D. Next, the implanted components were matched to the images using a computer-aided design program. Preoperative CT images were also matched to the coupled radiographic images. In this process, continuous CT data could be divided into femoral and tibial sequencing. Using the matched image, we measured the 3D alignment of the femoral component (Fig. 2a) and tibial component (Fig. 2b). The same

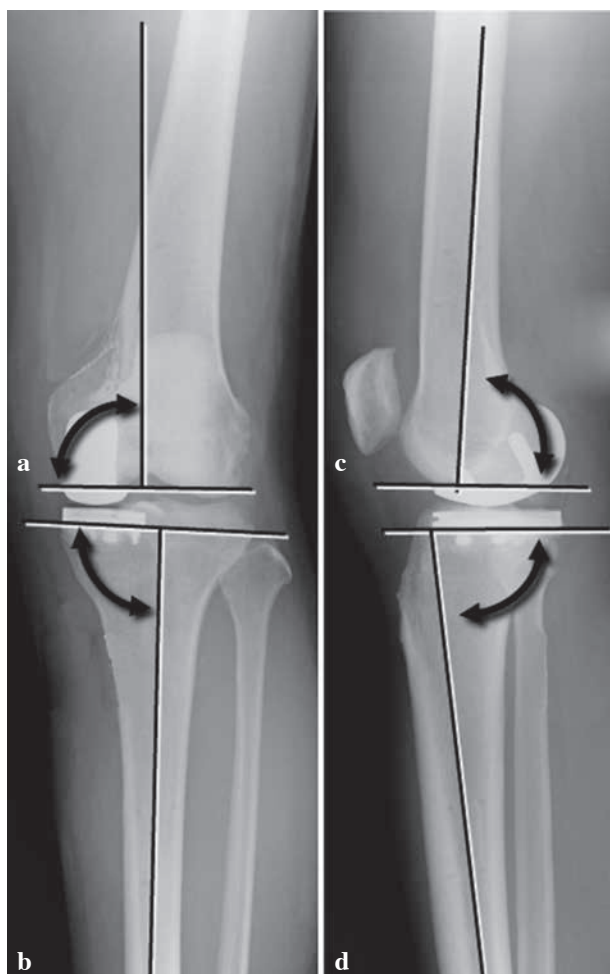


Fig. 1

references points as used in the 2D evaluation were established, and the component alignment was measured.

We compared the angles measured in the 2D and 3D evaluations. The cases in which the angle of the 2D evaluation deviated more than  $3^\circ$  from the angle of the 3D evaluation were defined as outliers. The measurements were repeated at least 3 times, by 2 authors blinded to clinical information, and the mean values were used. This study was approved by the institutional review board at our hospital (identification number : 0057).

### STATISTICAL ANALYSIS

Results were analyzed using a statistical software package (Stat Mate III ; ATMS Co., Ltd., Tokyo, Japan). Differences between 2D and 3D measure-

ments were analyzed using the paired Student t-test. The number of outliers in each component alignment was analyzed using the chi-square test. When the analysis of variance was observed to be significant, chi-square post-hoc analysis were performed to determine which groups were significantly different from one another. Sample size was determined based on the results of the pilot study by power analysis, using G power 3.1 software (alpha = 0.05 ; power level = 80% ; observed effect size = 1.05 ; total sample size = 10). The estimated sample size was 12 subjects and the post-hoc power analysis further confirmed that the power was 0.998.

### RESULTS

The results with intra- and inter-observer reliability showed that both the 3D and 2D methods of measurement were acceptable for measuring the implant position (Table I).

Comparison of the 2D and 3D measurement methods indicated that the measured angles did not differ significantly between the 2 methods, for any of the component alignments (Fig. 3a-d).

The numbers of outliers were as follows : coronal femoral, 6 ; sagittal femoral, 3 ; coronal tibial, 0 ; and sagittal tibial, 0 (Fig. 4a-d).

Statistical analysis found that the number of outliers differed significantly among the 4 measurements ( $p = 0.003$ ). Further post-hoc analysis to compare the measurements found that the number of outliers in the femoral coronal measurement was significantly larger than that of the tibial coronal ( $p = 0.008$ ) and tibial sagittal ( $p = 0.008$ ) measurements.

### DISCUSSION

The most important finding in this study is that the number of outliers in the femoral coronal measurements was significantly larger than that of the other measured alignments. The results suggest that component alignment might be misjudged by radiographic evaluation, especially in terms of the femoral coronal alignment. To the best of our knowledge, this study is the first to compare the 2D and 3D methods of measurement in UKA.

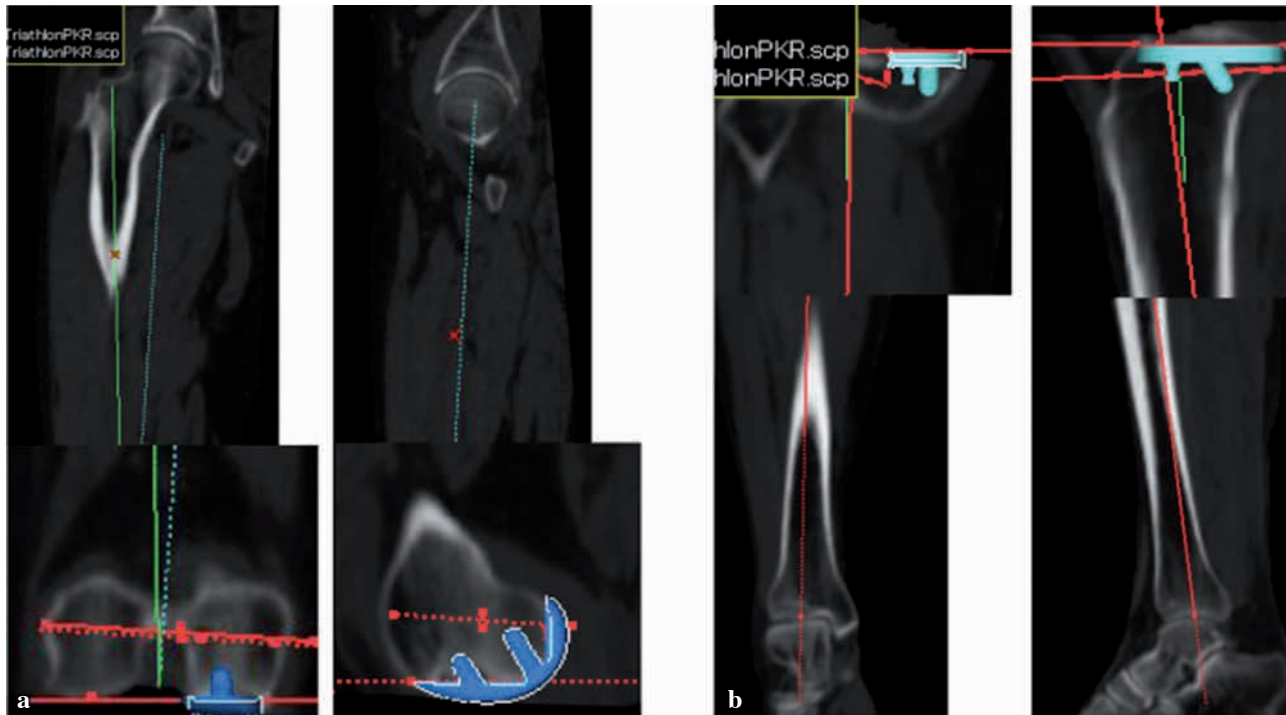


Fig. 2

Table I. — Measurement of intra- and inter-rater reliability

	Intra-rater Reliability		Inter-rater Reliability	Intra-rater Reliability		Inter-rater Reliability
	ATHENA (3D)			Radiograph (2D)		
	Observer 1	Observer 2		Observer 1	Observer 2	
Femoral varus/valgus	0.99	0.99	0.99	0.98	0.93	0.91
Femoral flex/ext	0.99	0.99	0.99	0.99	0.99	0.98
Tibial varus/valgus	0.94	0.93	0.98	0.97	0.97	0.86
Tibial posterior slope	0.93	0.83	0.84	0.91	0.97	0.9

Given the importance of evaluating rotational alignment in TKA, the superiority of 3D evaluation is well established. Although there are several radiographic methods for the evaluation of rotational alignment (10,22), it is generally agreed that CT is a

superior method. Although the importance of rotational alignment in UKA with a fixed-bearing insert remains unresolved, radiographic methods may not be useful for assessing rotational alignment in UKA. Indeed, previous reports found that there were rela-

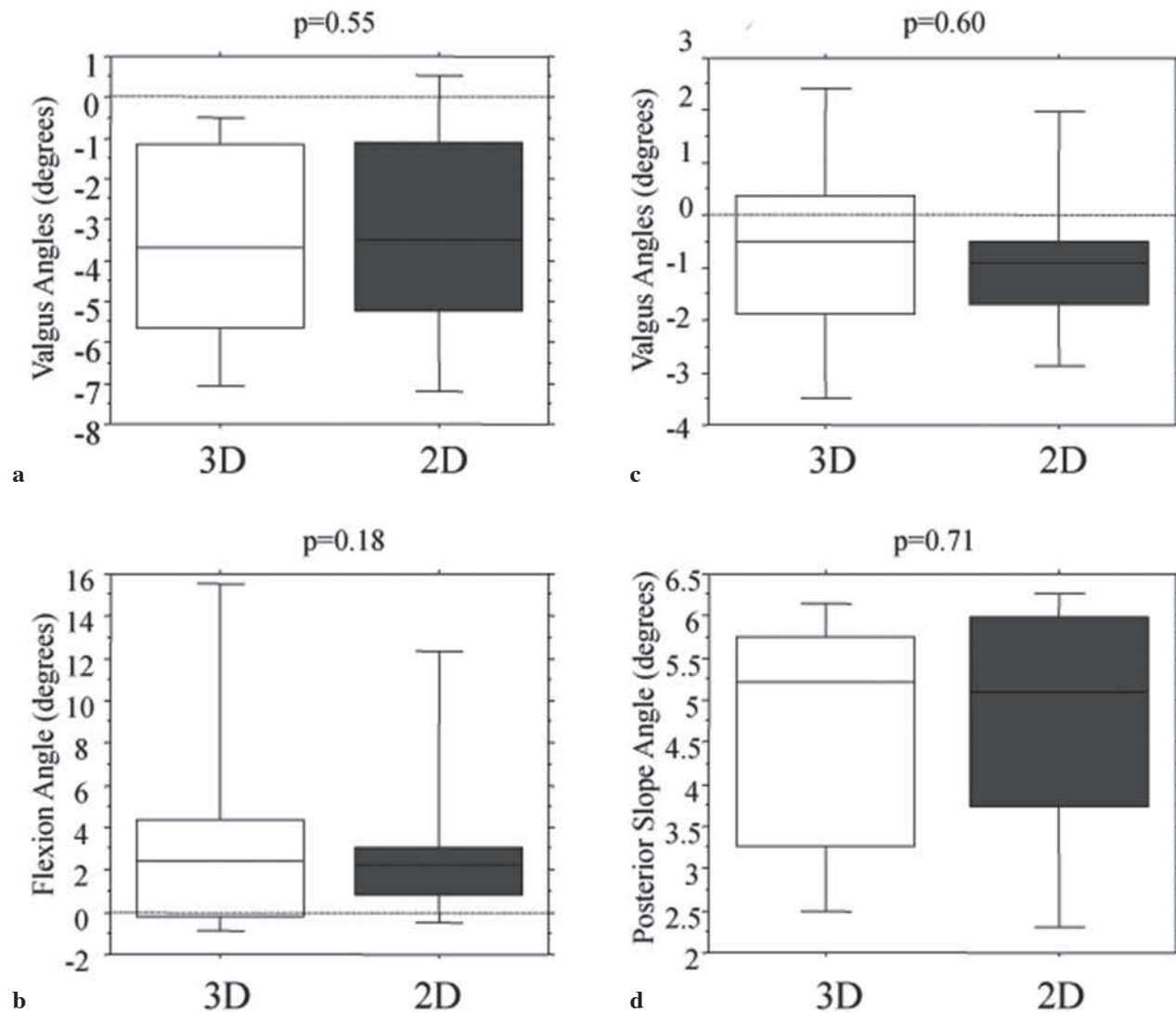


Fig. 3

tively high rates of outliers for both femoral and tibial rotational alignment (16,19). Results of unpublished data also found that the ratio of outliers in rotational alignment was higher than that of coronal and sagittal alignment in navigated UKA, because identification of bony landmarks is difficult in the context of a small operating field. These results suggested that rotational alignment should be carefully assessed in UKA.

As well as the fact that the ideal mechanical coronal and sagittal axes have not been fully identified, the ideal implant position in UKA is also poorly understood. Implant position alone cannot determine the mechanical axis, because of the intact opposite compartment and surrounding tissues. The mechanical axis is affected by multiple factors, including the size of the osteotomy and the insert. Although it has been hypothesized that a varus/

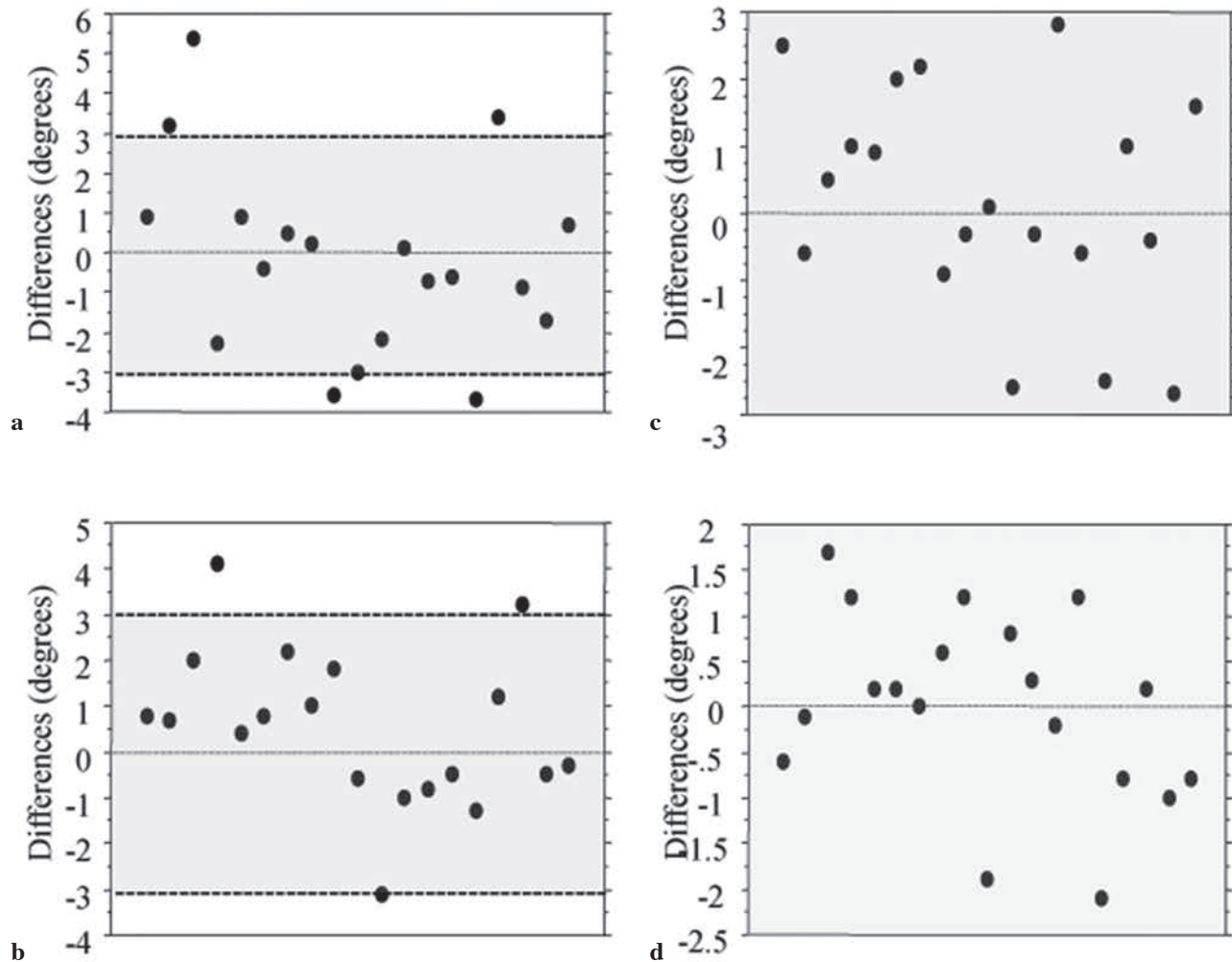


Fig. 4

valgus malposition of the implants did not significantly affect limb alignment, Kim et al. suggested that varying the prosthetic alignment has indirect implications for the postoperative mechanical axis (14). On the other hand, UKA has the concept of surface replacement surgery, and recent reports suggest that the tibia should be cut parallel to the joint line, to correct only the intra-articular deformity (4). A recent study found that kinematics after UKA are not the same as normal, and may be similar to preoperative kinematics if the tibial cut is perpendicular to the tibial mechanical axis (17). The authors suggested that improvements to the implant design

and surgical technique are necessary to achieve normal knee kinematics in the future (17). This indicates that precise implant placement is required if reconstruction of the normal joint surface and kinematic alignment is to be achieved. The present study adds to this research, by providing evidence that (i) 2D evaluation is inappropriate for assessment of component alignment; and (ii) 3D evaluation may be more appropriate for use in future UKA studies.

In contrast to our expectations, the present study found that inter- and intra-observer reliability is high in 2D evaluation. The 2D measurement evaluation was undertaken using a single radiograph,

thus the results were constant and independent of the observer. However, given that the accuracy of 2D evaluation is dependent on leg position, it is likely that the results would be more variable and inaccurate if multiple radiographs, taken at different times, were assessed in clinical settings.

There are several limitations to this study. The main limitation is that we did not seek to identify a correlation between the inaccurate measurements and clinical outcome. The relationship between component position and clinical outcome is not understood, and future study relating to this issue in the field of UKA would be invaluable. However, the ability to conduct such work is dependent upon the availability of a valid methodology; the present study has identified methodological inaccuracies associated with the use of 2D imaging, and recommends the use of a 3D method. Another limitation is the relatively small number of cases; however, the power analysis indicates that the study had adequate power, and as such the results of the present study are considered convincing.

This study is clinically relevant, in that it has drawn attention to the risk of misjudging the coronal component alignment when using radiographs to evaluate UKA. The results suggest that postoperative evaluation should be performed using 3D methods.

## CONCLUSION

The 2D evaluations had a significantly greater number of outliers from the 3D evaluations in the coronal femoral implant alignment, compared with either tibial coronal or sagittal alignment. In postoperative evaluation of UKA, assessment of implant position might be misjudged because of the design of the implant, especially in the femoral component. Considering the need for assessment of the rotational alignment, evaluation with 3D methods is an ideal tool for the postoperative evaluation of UKA.

## REFERENCES

1. Akagi M, Oh M, Nonaka T *et al.* An anteroposterior axis of the tibia for total knee arthroplasty. *Clin Orthop Relat Res* 2004 ; (420) : 213-219.
2. Bert JM. 10-year survivorship of metal-backed, unicompartmental arthroplasty. *J Arthroplasty* 1998 ; 13 (8) : 901-905.
3. Cartier P, Sanouiller JL, Grelsamer RP. Unicompartmental knee arthroplasty surgery. 10-year minimum follow-up period. *J Arthroplasty* 1996 ; 11 (7) : 782-788.
4. Deschamps G, Chol C. Fixed-bearing unicompartmental knee arthroplasty. Patients' selection and operative technique. *Orthop Traumatol Surg Res* 2011 ; 97 (6) : 648-661.
5. Heyse TJ, Figiel J, Hahnlein U *et al.* MRI after unicompartmental knee arthroplasty : rotational alignment of components. *Arch Orthop Trauma Surg* 2013 ; 133 (11) : 1579-1586.
6. Ishida K, Matsumoto T, Tsumura N *et al.* In vivo comparisons of patellofemoral kinematics before and after ADVANCE Medial-Pivot total knee arthroplasty. *Int Orthop* 2012 ; 36 (10) : 2073-2077.
7. Jenny JY, Boeri C. Unicompartmental knee prosthesis implantation with a non-image-based navigation system : rationale, technique, case-control comparative study with a conventional instrumented implantation. *Knee Surg Sports Traumatol Arthrosc* 2003 ; 11 (1) : 40-45.
8. Jenny JY, Muller PE, Weyer R *et al.* Navigated minimally invasive unicompartmental knee arthroplasty. *Orthopedics* 2006 ; 29 (10 Suppl) : S117-121.
9. Jung KA, Kim SJ, Lee SC *et al.* Accuracy of implantation during computer-assisted minimally invasive Oxford unicompartmental knee arthroplasty : a comparison with a conventional instrumented technique. *Knee* 2010 ; 17 (6) : 387-391.
10. Kanekasu K, Kondo M, Kadoya Y. Axial radiography of the distal femur to assess rotational alignment in total knee arthroplasty. *Clin Orthop Relat Res* 2005 ; (434) : 193-197.
11. Kaya Bicer E, Servien E, Lustig S *et al.* Sagittal flexion angle of the femoral component in unicompartmental knee arthroplasty : is it same for both medial and lateral UKAs ? *Knee Surg Sports Traumatol Arthrosc* 2010 ; 18 (7) : 928-933.
12. Keene G, Simpson D, Kalairajah Y. Limb alignment in computer-assisted minimally-invasive unicompartmental knee replacement. *J Bone Joint Surg Br* 2006 ; 88 (1) : 44-48.
13. Kim JG, Kasat NS, Bae JH *et al.* The radiological parameters correlated with the alignment of the femoral component after Oxford phase 3 unicompartmental knee replacement. *J Bone Joint Surg Br* 2012 ; 94 (11) : 1499-1505.
14. Kim SJ, Bae JH, Lim HC. Factors affecting the postoperative limb alignment and clinical outcome after Oxford unicompartmental knee arthroplasty. *J Arthroplasty* 2012 ; 27 (6) : 1210-1215.
15. Kuroda Y, Ishida K, Matsumoto T *et al.* Fibular axes are not a reliable landmark for tibial mechanical axes of osteoarthritic knees that underwent total knee arthroplasty. *Knee Surg Sports Traumatol Arthrosc* 2015 ; 23 (11) : 3362-3367.
16. Martinez-Carranza N, Weidenhielm L, Crafoord J *et al.* Deviation between navigated and final 3-dimensional

- implant position in mini-invasive unicompartmental knee arthroplasty : a pilot study in 13 patients. *Acta Orthop* 2012 ; 83 (6) : 625-628.
17. **Mochizuki T, Sato T, Blaha JD et al.** 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) : 1911-1917.
18. **Rosenberger RE, Fink C, Quirbach S et al.** The immediate effect of navigation on implant accuracy in primary mini-invasive unicompartmental knee arthroplasty. *Knee Surg Sports Traumatol Arthrosc* 2008 ; 16 (12) : 1133-1140.
19. **Servien E, Fary C, Lustig S et al.** Tibial component rotation assessment using CT scan in medial and lateral unicompartmental knee arthroplasty. *Orthop Traumatol Surg Res* 2011 ; 97 (3) : 272-275.
20. **Stiehl JB, Komistek RD, Dennis DA et al.** Kinematics of the patellofemoral joint in total knee arthroplasty. *J Arthroplasty* 2001 ; 16 (6) : 706-714.
21. **Sugama R, Minoda Y, Kobayashi A et al.** Conventional or navigated total knee arthroplasty affects sagittal component alignment. *Knee Surg Sports Traumatol Arthrosc* 2012 ; 20 (12) : 2454-2459.
22. **Takai S, Yoshino N, Isshiki T et al.** Kneeling view : a new roentgenographic technique to assess rotational deformity and alignment of the distal femur. *J Arthroplasty* 2003 ; 18 (4) : 478-483.
23. **Tei K, Ishida K, Matsumoto T et al.** Novel image-matching software for postoperative evaluation after TKA. *Orthopedics* 2012 ; 35 (12) : e1711-1715.
24. **Whiteside LA, Arima J.** The anteroposterior axis for femoral rotational alignment in valgus total knee arthroplasty. *Clin Orthop Relat Res* 1995 ; (321) : 168-172.