Original article

Inaccurate rotational component position in image-free navigated unicompartmental knee arthroplasty

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Abstract

Background/Objective: The success of unicompartmental knee arthroplasty (UKA) is highly dependent on the accuracy of component and leg alignment. Computer-assisted surgery is gaining popularity in total knee arthroplasty with numerous studies reporting improved accuracy and decreased variability in implant position and postoperative limb alignment compared with conventional techniques. However, literature evaluating the accuracy of computer-navigated UKA is limited. Therefore, this study aimed to investigate the accuracy of component positions in navigated UKA using a three-dimensional (3D) image-matching system. To the best of our knowledge, this study is the first to evaluate the accuracy of implant-placement position in UKA using 3D image-matching systems.

Methods: Twenty-three knees in 22 patients (9 men, 13 women) underwent computer-assisted UKA performed by a senior surgeon from 2011 to 2013. All surgeries were performed with measured resection techniques using an image-free-navigation system. We recorded the coronal, sagittal, and rotational bone-resection angles towards the mechanical axis in the distal femur and proximal tibia using image-free navigation intraoperatively. The coronal, sagittal, and rotational alignments of the femoral and tibial components were also measured using the 3D image-matching system, and the accuracy of the navigated UKA was evaluated. The rotational alignment of the femur and tibia was defined as surgical epicondylar axis and Akagi's line, and a deviation over 3° from the AA was defined as an outlier.

Results: We observed coronal outliers for the femoral component in four of the 23 patients, and for the tibial component in three of the 23 patients. We also observed sagittal outliers for the femoral component in five of 23 patients, and for the tibial component in three of the 23 patients. Twenty-two tibial components were placed in external rotation relative to the rotational reference line.

Conclusion: In both coronal and sagittal alignments, there were a definite proportion of outliers. The ratio of outliers in rotational alignment was especially higher than that in coronal and sagittal alignments. In UKA, the identification of bony landmarks is difficult because of the small operation field. Therefore, careful surface mapping of particular bony landmarks is necessary, and it is not enough to use image-free navigation system in UKA.

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Keywords: navigation accuracy; rotational mismatch; three-dimensional evaluation; unicompartmental knee arthroplasty

Introduction

Unicompartmental knee arthroplasty (UKA) has been performed for the treatment of isolated unicompartmental knee disease for more than three decades. The long-term outcomes of UKA depend on patient selection, age, sex, and level of

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activity.[1,2] In order to obtain a satisfactory outcome after UKA, proper surgical technique and optimal implant positioning are essential.[3,4] Since an inaccurate implantation is considered a factor for early failure, 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 after UKA.[5–7] Recently, computer-assisted surgery has been gaining popularity for UKA, with several studies reporting improved accuracy and decreased variability in implant positioning and postoperative limb alignment.[2,7–9] However, most studies have evaluated implant position and limb alignment using radiography, which cannot assess component rotation. Furthermore, it is difficult to evaluate coronal and sagittal implant positions due to features of the component. Few studies have assessed three-dimensional (3D) implant position using computed tomography (CT) or magnetic resonance imaging,[10–12] and none has used a 3D digital templating system. The aim of this study was to investigate the accuracy of component positioning in navigated UKA using a 3D image-matching system. This study also discusses the difficulties associated with navigated UKA.

Materials and methods

This study included 23 consecutive UKAs in 22 patients (9 men, 13 women; average age, 72.6 years ± 5.99 years; age range, 61–80 years). Two types of UKA prosthesis [Unicompartmental High-Flex Knee System; Zimmer, Warsaw, IN, USA ($n = 10$); Triathlon Partial Knee Resurfacing System; Stryker Orthopaedics, Mahwah, NJ, USA ($n = 13$)] were implanted with measured resection techniques using an image-free navigation system (Stryker 4.0 image-free computer navigation system; Stryker Orthopaedics). After medial parapatellar arthrotomy and placement of the tracker pin, anatomical landmarks were digitised to determine the leg axis. The landmarks were as follows: (1) femur: hip-joint centre, centre of the distal femur, Whiteside's line,[13] articular femorotibial joint surface, and anterior surface of the femur; and (2) tibia: centre of the proximal femur, articular femorotibial joint surface, Akagi's line,[14] and medial and lateral malleoli. The hip-joint centre 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. After registration, the tibial extramedullary cutting guides were attached and adjusted to match the coronal and sagittal alignments. Then, a sagittal cut of the tibia was performed along a line parallel to Akagi's line, in the most lateral rim of the medial plateau. The femoral distal cutting block was also adjusted to match the coronal and sagittal alignments by using navigation. When the femoral posterior bone cut was performed, the femoral rotational angle was aligned. We recorded the femoral and tibial bone-resection angles with respect to the mechanical axis intraoperatively by using the navigation system.

The tibial component is implanted perpendicular to the tibial mechanical axis in the coronal plane, at a 5° posterior slope to the sagittal mechanical axis, and parallel to Akagi's line in rotation. The femoral component is implanted perpendicular to the femoral mechanical axis in the coronal plane, at a few degrees of sagittal flexion, according to the surgeon's preoperative planning to match the implant with the curvature of the condyle and fully cover the posterior condyle with the implant, and parallel to the surgical epicondylar axis in rotation.

Evaluation of implant positioning

Four weeks postoperatively, anteroposterior and lateral radiographs were obtained and evaluated using Athena Knee 3D image-matching software (Soft Cube, Osaka, Japan).[15,16] Briefly, a 3D marker was attached on the surface of the patient's lower leg, and the silhouettes of the marker were used to couple the two radiographic images three-dimensionally (Figure 1A). Next, the implanted components were matched to the images using a computer-aided design program (Figure 1B). In addition, preoperative CT images were matched to the coupled radiographic images (Figure 1C). In this process, continuous CT data could be divided into femur and tibia. In the matched image, we measured the 3D alignment of the femoral and tibial components (Figure 1D). Lines to determine the component alignment are shown in Table 1.

We compared the bone-resection angles measured intraoperatively using the navigation system with component alignment angles measured postoperatively using Athena Knee. NA with a deviation of > 3° from AA was defined as outliers. Evaluations were performed three times by two authors (Akihiko Toda and Kazunari Ishida) who were blinded to the patients' clinical information, and the averages were used for analysis. The intra- and interobserver reliability showed favourable results for almost all items (Table 2). This study was approved by the Institutional Review Board at Kobe Kaisei Hospital, Kobe, Japan (identification number: 0049).

Statistical analysis

The results were analysed statistically using a statistical software package (Stat Mate III; ATMS Co., Ltd., Tokyo, Japan). Comparisons of the incidence of outliers amongst the coronal, sagittal, and rotational alignments of both components were analysed using the Chi-square test. When the analysis of variance was observed to be significant, a Chi-square *post hoc* analysis was performed to determine which groups were significantly different from one another. A *p* value of < 0.05 was considered statistically significant.

Results

Table 3 shows the femoral- and tibial-component positions, the average differences between the intra- and postoperative measurements, and the rates of outliers. For the coronal alignment, the rates of outliers for the femoral and tibial components were 17.4% (4/23) and 13% (3/23), respectively. For the sagittal alignment, the rates of outliers were 21.7% (5/
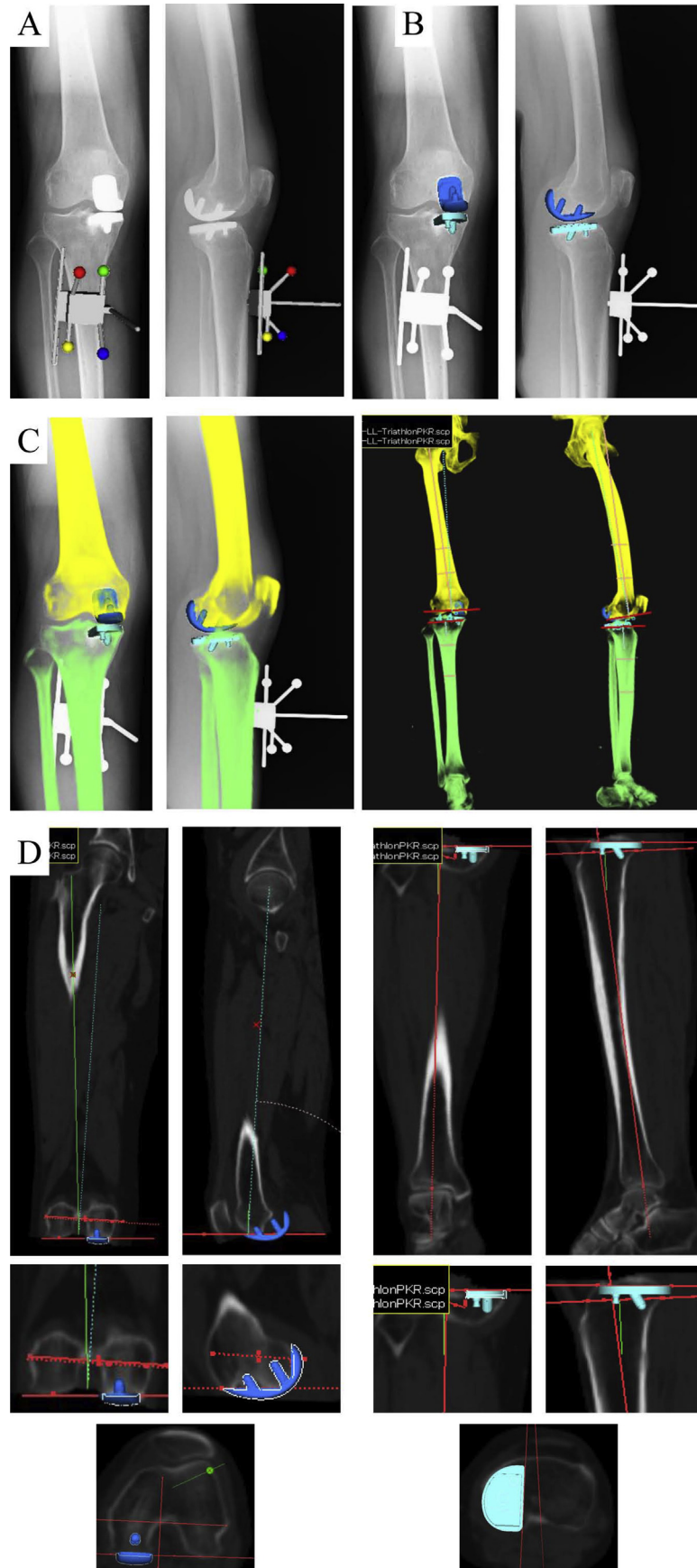
Figure 1. (A) A three-dimensional marker is attached to the surface of the patient's lower leg, and marker silhouettes are used to couple the two radiographic images three-dimensionally. (B) Implanted components are matched to the images using a computer-aided design program. (C) Computed tomographic images (thickness, 2.5 mm) are matched to the coupled radiographic images. (D) Three-dimensional alignment of femoral and tibial components are measured.

Table 1
References for alignment measurement.

	Axis	Component
Femoral coronal alignment	Femoral mechanical axis	Distal line of femoral component
Femoral sagittal alignment	Femoral mechanical axis	Distal line of femoral component
Femoral rotational alignment	Surgical epicondylar axis	Posterior condylar line of femoral component
Tibial coronal alignment	Tibial mechanical axis	Distal line of tibial component
Tibial sagittal alignment	Tibial mechanical axis	Distal line of tibial component
Tibial rotational alignment	Akagi's line	Tangent to anteroposterior tibial component

23) and 8.7% (2/23), respectively. For the rotational alignment, the rates of outliers were 47.8% (11/23) and 100% (23/23), respectively. The detailed results of the component rotation measured by Athena Knee are shown in Figure 2. Except for only one case, 22 tibial components were placed in the external rotation relative to Akagi's line. The statistical analysis found that the number of outliers was significantly different between the coronal, sagittal, and rotational alignments for both the femoral and tibial components ($p = 0.048$ and $p < 0.001$, respectively). Further *post hoc* analysis found

Table 2
Inter- and intraobserver reliability.

	Femur			Tibia		
	Coronal	Sagittal	Rotational	Coronal	Sagittal	Rotational
Interobserver reliability	0.994	0.995	0.976	0.982	0.836	0.961
Intraobserver reliability (observer: Akihiko Toda)	0.987	0.985	0.939	0.936	0.934	0.875
Intraobserver reliability (observer: Kazunari Ishida)	0.986	0.996	0.984	0.933	0.833	0.960

Table 3
Evaluation of component alignment and number of outliers.

	Femur			Tibia		
	Coronal	Sagittal	Rotational	Coronal	Sagittal	Rotational
Number of outliers	4/23 (17.4%)	5/23 (21.7%)	11/23 (47.8%)	3/23 (13.0%)	2/23 (8.7%)	23/23 (100%)
Difference between NA and AA	1.7° ± 3.0	1.1° ± 1.1	1.6° ± 5.4	0.5° ± 3.3	0.8° ± 1.6	7.5° ± 4.5

Differences are expressed as mean ± standard deviation. NA = intraoperative measurement; AA = postoperative measurement. Differences are AA from NA. Plus means varus in coronal, flexion in sagittal, and external rotation in rotational alignment.
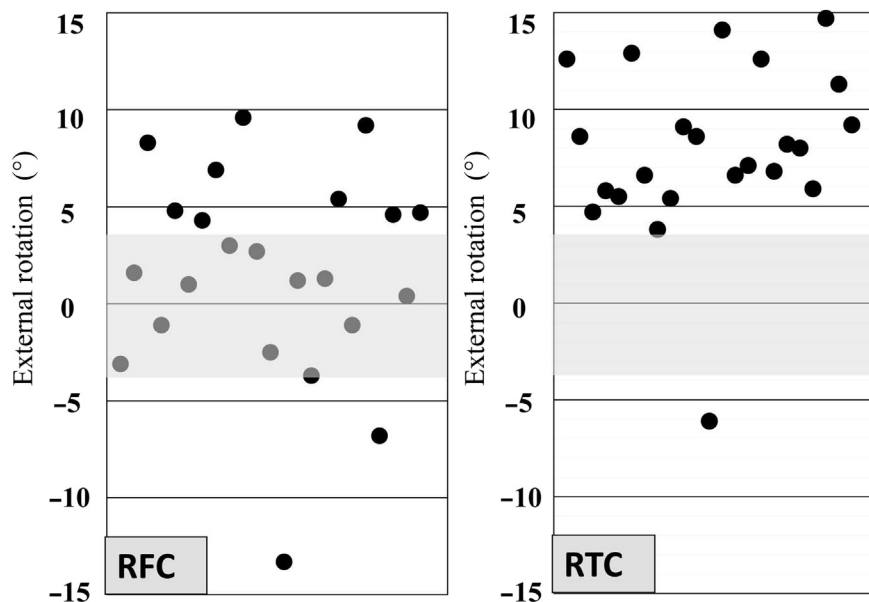

Figure 2. Rotation of femoral and tibial components. Femoral rotational angle is shown on the left. Black points in the white field indicate outliers. Tibial rotational angle is shown on the right. For tibial rotational angle, 22 tibial components are placed in external rotation relative to Akagi's line. RFC = rotation of femoral component; RTC = rotation of tibial component.

that there were no statistically significant differences for the femoral component (coronal vs. sagittal, $p = 0.71$; sagittal vs. rotational, $p = 0.063$; coronal vs. rotational, $p = 0.027$). The *post hoc* analysis of the tibial component found that the number of outliers in the rotational alignment was significantly larger than that in the coronal or sagittal alignment (coronal vs. sagittal, $p = 0.64$; sagittal vs. rotational, $p < 0.001$; coronal vs. rotational, $p < 0.001$).

Discussion

The most important finding in this study is that achieving correct rotation in image-free navigated UKA is difficult, in comparison to achieving relatively accurate coronal and sagittal alignments. The evaluations in this study were performed using a 3D image-matching system. To the best of our knowledge, this study was the first to evaluate the accuracy of implant positioning in UKA using such a system.

There are several limitations in this study. First, this study did not evaluate clinical outcomes. The influence of component outliers on such variables as maximum flexion angle and kinematics remains unknown, and is beyond the scope of this study. Furthermore, compared with the coronal alignment, the rotational component positioning is less well defined, and the appropriate rotational angles and clinical significance of malrotation are not understood.[17] Although one report recommended a neutral or slight external rotation of the tibial component in UKA,[17] the authors also pointed out that further studies are needed to determine the appropriate tibial rotational angles to achieve excellent clinical results after UKA.[17] In this study, the recommended rotational alignment in UKA could not be determined. Further analysis of the clinical outcome and implant survivorship in relation to the implant rotation may provide us the ideal range of rotation of the tibial component. In the future, with evaluations using 3D image-matching systems, it will be clear how rotational component position affects clinical results. Finally, this study recruited only small numbers of participants and had no control group. There have been only a few reports to mention rotational component alignment in navigated UKA.[11,12] Martinez-Carranza et al[11] reported that eight of 10 patients had rotational deviation of the femoral component of $> 3°$, and that six of 10 patients had rotational deviation of the tibial component of $> 3°$. Servien et al[12] reported that the tibial implant was generally positioned in external rotation in medial UKA. We found a large deviation between intra- and postoperative measurements of rotational position of both the tibial and femoral components. Compared with total knee arthroplasty (TKA), in navigated UKA, the identification of bony landmarks to determine the mechanical axis is difficult due to the small operating field. The lateral epicondyle may not be visible, and pointing out the lateral condyle is impossible if the patella is not retracted sufficiently. Consequently, the surgical epicondylar axis cannot be determined. Therefore, with the navigation system in this study, the femoral rotational axis was determined as the Whiteside's line. Anatomical reference to Whiteside's line only risks misunderstanding the femoral rotational axis. In addition, since the anterior cruciate ligament remains intact, it is difficult to identify the centre of the tibial insertion of the posterior cruciate ligament in order to identify Akagi's line. Therefore, the intraoperative determination of selected landmarks has a high variance, and careful surface mapping of particular bony landmarks is mandatory. By contrast, in the case of image-free navigated TKA, Matziolis et al[18] reported that rotational component alignment was not improved through navigation by solely referencing the epicondylar axis for the femur and the tuberosity for the tibia. On the contrary, in a study on CT-based navigated TKA, Mizuuchi et al[19] reported that accurate rotational alignment was obtained at a significantly higher rate in a navigated group than in a conventional group. In addition, Heyse and Tibesku[20] reported that a patient-specific instrument was effective in significantly reducing outliers of optimal rotational femoral-component alignment during TKA. A CT-based navigation system or patient-specific instrument might achieve more precise implant positioning.

In coronal and sagittal implant positioning, we found similar results compared with Martinez-Carranza et al.[11] However, compared with the results of navigated TKA in previous reports, the rate of outliers in coronal alignment was higher for both the femoral and tibial components.[18] However, a larger study or meta-analysis is required to compare the true accuracy of navigation between TKA and UKA. In two-dimensional (2D) radiographic evaluations, Jung et al[1] reported that the rates of outliers in coronal alignment for the femoral and tibial components were 5% and 8.6%, and the rates of outliers in sagittal alignment were 5% and 22%, respectively. Rosenberger et al[7] also reported that the rates of outliers in coronal alignment were 0% and 30%, and the rates of outliers in sagittal alignment were 20% and 20%, respectively. Compared with these results, the rates of outliers in this study seem higher, except in coronal tibial-component alignment; however, evaluating the component alignment using radiographs is difficult, considering implant design features. Therefore, it is suggested that 2D radiographic evaluation is not sufficient for component alignment in UKA, even in coronal and sagittal planes. Further research is required to clarify the differences between 3D and 2D evaluations.

In conclusion, the ratio of outliers in rotational component position was significantly higher than that in coronal or sagittal component position. The use of an image-free navigation system is not sufficient to obtain accurate rotational component position in UKA.

Conflicts of interest

The authors have no conflicts of interest relevant to this article.

Funding/support

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