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Comparison of MRI- and CT-based patient-specific guides for total knee arthroplasty

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ABSTRACT

Background: The patient-specific guide for total knee arthroplasty (TKA) is created from the data provided by magnetic resonance imaging (MRI) or computed tomography (CT) scans. It remains unknown which imaging technology is suitable for the patient-specific guide. The purpose of this study was to compare the accuracy of implant positioning and operative times between the two types of patient-specific guides for TKA.
Methods: Forty arthritic knees were divided into two treatment groups using MRI-based (PS-MRI group) or CT-based (PS-CT group) patient-specific guides in this prospective, comparative study. The guide in the PS-MRI group had a cutting slot, whereas that in the PS-CT group only had a pin locator. The operative times were compared between the two groups. The angular error and number of outliers (deviations >3°) of the implant position using pre- and postoperative CT were investigated in both groups.
Results: The mean operative time was significantly shorter in the PS-MRI group (109.2 ± 16.5 min) than in the PS-CT group (129.5 ± 19.4 min) ($p < 0.001$). There were no significant differences in the accuracy of the implant position regarding the coronal, sagittal, and axial planes between the groups ($p > 0.05$).
Conclusions: To reduce the operative time, guides with additional functions, such as cutting and positioning, should be used. Both CT- and MRI-based-guides would result in the same accuracy in three planes but high inaccuracy in the sagittal plane. The use of patient-specific guide based on MRI might not be cost-effective.
Level of evidence: level 2.

1. Introduction

The purpose of total knee arthroplasty (TKA) is to achieve long-term implant survival and successful functional outcomes. Long-term results and the survival rate following TKA have been reported to be over 90% 15 years after TKA [1,2]. Fang et al. measured the knee alignment in 6070 TKAs and found a lower revision rate in patients with well-aligned TKAs [3]. Conversely, it was reported that up to 19% of patients remained dissatisfied after TKA [4,5]. Choong et al. reported that malalignment following TKA results in poor function and quality of life [6]. Nicoll et al. described that rotational error of the component is a major cause of pain after TKA [7]. Thus, malalignments, including component malpositioning, are major factors leading to deteriorating functional outcomes as well as revision of TKA.

Accuracy of the alignment depends on the precision of the surgical technique. Computer-assisted surgery (CAS) was developed in an attempt to improve surgical accuracy and avoid outliers, and numerous studies with CAS have demonstrated improved accuracy in coronal implant positioning in TKA [8–10]. Mason et al. performed a meta-analysis of 29 studies comparing CAS with conventional methods and demonstrated that outliers of more than 3° from the neutral alignment were observed in only 9.0% of patients who received CAS and 31.8% of those who received conventional methods for TKA [9]. However, clinical outcomes did not differ significantly after an early and mid-term follow-up study [8,11]. The problems of CAS include increasing capital cost, additional skin incision, longer operative time, and the learning curve associated with using the CAS technique. In addition, the CAS system has not been accepted worldwide; in the United States, the CAS technique is used only less than 3% of the time in TKA [12]. Therefore, the strategy to overcome the disadvantages of the CAS technique has led to the development of the patient-specific guide. The use of a patient-specific guide results in a significant reduction in operative time compared with conventional methods [13,14]. Ng et al. reported that, in a retrospective study of 569 TKAs performed using the patient-specific guide, outliers of more than 3° from the neutral alignment are observed in 14.4% of the procedures, suggesting that the accuracy of the patient-specific guide is superior to conventional methods and inferior to CAS [15].

The present technology for providing data to create the patient-specific guide uses magnetic resonance imaging (MRI) or computed tomography (CT) scans. Two main types of guides are commonly

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used: one has only a pin locator, and the other has a cutting slot in addition to a pin locator. In this study, we used the following hypotheses: 1) a patient-specific guide with an integrated cutting block would decrease the surgical time, 2) there would be no difference in accuracy between a MRI- and CT-based patient-specific guide and 3) both MRI- and CT-based patient-specific guide would avoid outliers of >3° in the coronal overall limb alignment, in the tibial sagittal plane and avoid internal rotation of the femoral component. The purpose of this study was to compare the accuracy of the component position between using MRI- and CT-based patient-specific guides and the operative time between the two types of guides.

2. Materials and methods

2.1. Patient population

The hospital ethics committee approved the study protocol (22-141, http://www.med.kindai.ac.jp/rinri/). Information disclosure, patients' understanding and voluntariness were emphasized in the written consent form, and all patients agreed to participate in the study. We informed the patients about the adverse effects of radiation exposure by the CT scan. All the patients had disabling knee arthritis, were at an acceptable medical risk, and failed nonoperative management to be candidates for TKA. We evaluated the patients' applicability for the patient-specific guide. The exclusion criteria consisted of a previous fracture around the knee, previous knee surgery, any major flexion contractures (>10°), varus deformity of more than 20° or a valgus deformity, and the necessity for bone grafting on either the femur or tibia. Fifty-five arthritic knees in 51 patients who were scheduled for primary TKA between July 2011 and August 2012 at our institute were enrolled prospectively in this study. All patients were assigned to one of two treatment groups using either the MRI based patient-specific guide (PS-MRI group) or the CT based patient-specific guide (PS-CT group). There were no patients with pacemakers who could not be accepted for MRI. Before TKA, all patients underwent MRI or CT using the manufacturer's protocol. The PS-MRI group was processed using the Visionaire TM system (Smith & Nephew, Inc. Memphis, TN) at the knee MRI and a full-length anterior/posterior radiograph to determine each patient's current and planned mechanical axis. The PS-CT group was processed using the Prophecy TM system (Wright Medical, Inc. Huntsville, AL), which included 1-mm high-resolution slices at the knee and selected spot images at the hip and ankle. The MRI or CT data were uploaded and sent to the respective manufacturer for processing of the patient-specific guide. Although the data of 33 cases receiving MRI were uploaded to the manufacturer, the bone model could not be created in 11 cases (33%) due to motion artifacts. A repeat MRI was not performed. These cases were excluded from the PS-MRI group and underwent conventional surgery. After excluding these cases, the remaining cases were assigned to either group to match the number of cases. Consequently, the subjects comprised 40 knees in 36 patients (29 females and 7 males) with a mean age of 75.2 years (range, 58–90 years), all patients had medial compartment osteoarthritis of the knee (Table 1). The mean body mass index (BMI) was 26.2 kg/m^2 (range, 20.1–38.2 kg/m^2). The hip–knee–ankle (HKA) angle averaged 8.8° (range, 3.6 to 17.8 varus) including 40 varus knees. There were no significant differences in age, BMI, and the HKA angle between the two groups (Student's t test; $p = 0.36$, $p = 0.63$, and $p = 0.73$, respectively).

2.2. Prosthesis and surgical methods

TKA was performed on patients in the PS-MRI group using the Legion implant design and instrumentation (Smith & Nephew, Inc. Memphis, TN), whereas cases in the PS-CT group were subjected to the Advance Medial-Pivot Knee System (Wright Medical, Inc. Huntsville, AL). All surgeries were performed by the senior author (M.A.) using the mid-vastus approach without eversion of the patella (Fig. 1). Patient-specific cutting guides were used in all cases. As each manufacturer supplied patient-specific guides matched to each implant design, some differences between the guides for the PS-MRI and PS-CT groups should be noted. Whereas the guide used in the PS-MRI group had an integral cutting slot, this feature was not present in the PS-CT guide. In cases utilizing PS-MRI guides, distal femoral and proximal tibial resections were performed using the patient-specific guide to direct the surgical saw (Fig. 1A, B). Conversely, in cases utilizing PS-CT guides, pins placed within the distal femur using the patient-specific guide were subsequently used to control the placement of the standard cutting guide supplied with the implant system (Fig. 1C). With both guide designs, secondary femoral cuts, including those of the anterior and posterior femur, were made using a conventional finishing guide positioned on the distal femur using the pre-drilled locating hole. Differences between guides were also present on the tibial side. The PS-MRI tibial guide had peg holes that were positioned to match the tibial keel tray (Fig. 1B). By contrast, the PS-CT tibial guide did not have peg holes to fix the position of the tibial keel tray on the proximal tibia hole (Fig. 1D). In the latter case, once the resection had been performed, the pins using the patient-specific guide were left within the tibia, and the tibial keel tray was positioned manually to align with its pins, and the tibial keel hole was made as a final step.

Table 1
The preoperative demographic data in the PS-MRI and PS-CT groups. OA: osteoarthritis; RA: rheumatoid arthritis; HKA angle: hip–knee–ankle angle; * Not significant (Student's t test).

	PS-MRI group	PS-CT group
Patients/joints (no.)	18/20	18/20
Age (yrs.: mean, range)	76.1 (64–84)	74.4 (59–90) *
Gender (male/female)	4/16	3/17
BMI (kg/m^2)	25.6 (20.1–32.2)	26.9 (20.7–38.2) *
Preoperative HKA angle (°, range)	8.8 (5.0 to 12.8 varus)	8.8 * (3.6 to 17.8 varus)
Manufacturers	Smith & Nephew (Visionaire®)	Wright medical (Prophecy®)
Implant types	Legion PS	Advance CS
Planning images	MRI (knee segment) + radiograph (long leg)	CT (full leg)
Type of the guide	Pin locater with a saw slot	Pin locater

2.3. Measurements using the CT-based Simulation Software

Surgical accuracy was assessed by comparing preoperative and postoperative alignments of the three-dimensional images between the two groups. Multislice CT scanning (Light Speed VCT; GE Healthcare, Milwaukee, WI) was performed using 1-mm thick slices at the knee and selected spot images at the hip and ankle a month before and after operation in all cases. The obtained DICOM data were input into the three-dimensional (3-D) preoperative planning software for TKA (TKA 3-D template; Kyocera Medical Co., Osaka, Japan) [16]. In this software, the operating windows consist of three multiplanar-reformation (MPR) viewers: the frontal, sagittal, and axial planes. The angular error of the coronal overall limb and the component position in each plane was measured as the difference of the angle between the preoperative alignment planned by the manufacturer and postoperative alignment from CT on the software. The planning alignment of the femoral component was a mechanical axis on the frontal plane, a distal anatomical axis on the sagittal plane, and a surgical trans epicondylar axis (TEA) on the axial plane in both groups. The planning alignment of the tibial component was a mechanical axis on the frontal plane and a distal anatomical axis on the sagittal plane. Positive values indicated that the component was made varus relative to the reference axis on the frontal plane, flexion and posterior inclination on the sagittal plane, and internal rotation on the axial plane. The outlier of the component position was defined as a deviation of greater than 3° from the planning