The Journal of Arthroplasty Vol. 28 No. 2 2013

Isocentric 3-Dimensional C-Arm Imaging of Component Alignments in Total Knee Arthroplasty With Potential Intraoperative and Postoperative Applications

Shahram Amiri, PhD,* David R. Wilson, PhD,* Carolyn Anglin, PhD,†‡§
Andrew Van Houwelingen, MD,* and Bassam A. Masri, MD*

Abstract: An intraoperative imaging tool for total knee arthroplasty could help avoid poor clinical outcomes related to malalignment. We investigated the feasibility of using isocentric (ISO-C) fluoroscopic imaging for this purpose. Three-dimensional ISO-C and computed tomographic (CT) images were acquired from 6 cadaveric specimens implanted with standard knee arthroplasty components and analyzed to determine rotational alignments. In comparison with standard CT measures, the ISO-C–based measures had overall accuracies (determined as root mean square error) of 0.8° and 1.3° and corresponding SDs of 1.3° and 1.4° for the femoral and tibial components, respectively. With ISO-C imaging, it is possible to measure rotational alignment in knee arthroplasty with accuracy and repeatability comparable with CT. Isocentric imaging has strong potential as an intraoperative tool to accurately align arthroplasty components. **Keywords:** knee arthroplasty, ISO-C, isocentric, intraoperative, rotational alignment, knee replacement.

Component malalignment in total knee arthroplasty has been linked to patellar maltracking [1-3], improper soft tissue balance [4-6], abnormal kinematics [7], premature wear of the polyethylene inlay [8,9], and subsequent clinical complications such as anterior knee pain [4,10]. It has been demonstrated that malrotation of the femoral component by 5° from the transepicondylar axis (TEA) changes the tibiofemoral kinematics [11] and increases shear forces applied to the patellar component [11-13]. It has also been shown that combined femoral and tibial internal rotation of 1° to 4° can cause lateral tracking and tilting of the patella, whereas larger amounts can cause dislocation or failure of the patellar component [14]. There is significant variability associated with rotational alignment of the components: femoral component rotation ranged from 13° internal rotation to 16° external rotation in one study [15] and tibial component ranged from 44° internal rotation to 46° external rotation in another study [16].

Component alignment, when investigated, is generally measured postoperatively using computed tomographic (CT) scans based on the method suggested by Berger et al [14]. A recent study suggests that early revision of the total arthroplasty can be highly beneficial when component malrotation is demonstrated [17]. However, if diagnosis is done postoperatively, the components are well fixed, and a difficult decision has to be made for revision surgery to bring the components to correct alignments.

The use of preoperative CT has been recommended for more accurate alignment of the components [18], especially for patients with severe valgus deformity or severe hypertrophic osteoarthritis [19]. For the femur, this includes finding the angular relationship between a reliable intraoperative reference line of the posterior condylar line and the TEA identified on the CT image. The corresponding tibial alignment is defined by the relationship between the TEA and a tibial reference obtained from the preoperative CT acquired at full extension [20,21]. It has been shown that these methods can reduce the interobserver variability [22] and

*From the *Department of Orthopaedics, University of British Columbia, Vancouver, British Columbia, Canada; †Biomedical Engineering, University of Calgary, Calgary, Alberta, Canada; ‡Department of Civil Engineering, University of Calgary, Calgary, Alberta, Canada; and §McCaig Institute for Bone and Joint Health, University of Calgary, Calgary, Alberta, Canada.*

Submitted January 13, 2012; accepted May 6, 2012.

The Conflict of Interest statement associated with this article can be found at http://dx.doi.org/10.1016/j.arth.2012.05.007.

Reprint requests: Shahram Amiri, PhD, Centre for Hip Health and Mobility, Robert HN Ho Research Center, Room 686F, 2635, Laurel St, Vancouver, BC, Canada V6H 2K2.

0883-5403/2802-0008$36.00/0
http://dx.doi.org/10.1016/j.arth.2012.05.007

increase the accuracy of rotational alignment of the components [23,24]. However, because CT measures do not account for cartilage thickness, referencing the posterior paddles of the surgical femoral rotation jigs off the posterior condyles can lead to improper alignment of the component in cases where different amounts of posterior cartilage remain on the medial and lateral sides [25]. In the case of full-thickness posterior cartilage on one side and severely worn cartilage on the other, large rotational alignment errors of up to $\pm 3.5°$ can be induced in the axial alignment of the femoral component, assuming maximum 2.5 mm of worn cartilage [26] and 40-mm distance between the condyles.

A potential alternative approach is to evaluate the components' positions intraoperatively before cementing. Isocentric (ISO-C) 3-dimensional (3D) imaging is an appropriate intraoperative imaging tool that can reconstruct the 3D image of the joint based on multiple fluoroscopic radiographs and cone-beam reconstruction algorithms using an isocentric C-arm (ie, a mobile C-arm that rotates reliably about a central axis, similar to a CT machine, with motorized rotation through an arc of 190°) [27]. Higher accuracy is expected in this approach compared with preoperative CT planning because posterior condylar cartilage thickness has no effect on the results and preoperative CT information does not need to be transferred to the operating room. The ISO-C 3D also has the potential to measure joint alignment postoperatively within acceptable accuracies at lower radiation doses than CT. The ISO-C 3D imaging has been suggested for intraoperative measurement of the femoral cuts previously [28]. However, the suggested method is limited because it does not directly measure the rotation of the component with respect to the bone, and it does not provide a measure for the rotation of the tibial component. Considering the importance of the combined rotations of the components [14,29] and also the large variability reported in referencing the tibial component [10,16,25], a method that can overcome these limitations will be more useful. One challenge in directly measuring the component location with respect to the bone is the inferior quality of ISO-C imaging compared with CT and the more prominent artifacts in the presence of a metallic device as seen in other orthopedic applications [30].

The objective of this study was to investigate the feasibility of using ISO-C 3D to assess the rotation of the components in knee arthroplasty by comparing accuracy and repeatability of the measures comparing with postoperative CT.

Materials and Methods

Image Acquisition

Six fresh frozen cadaveric knees were thawed overnight. A total knee replacement (Zimmer LPS-Flex; Zimmer, Inc, Warsaw, Ind) was implanted onto the specimens using the manufacturer's recommended procedures and instrumentation. The specimens were secured in a bench vice and prepared by a senior orthopedic surgical fellow (AV). Each specimen was then scanned twice (once for the femur, once for the tibia) using an ISO-C 3D imaging system (ArcadisOrbic ISO-C; Siemens AG, Munich, Germany) in a simulated supine position at full extension. The femoral scan was in slow mode (100 images) with the femoral condyles centered in the field of view and the imaging parameters manually fixed at 40 kV and 2 mA, which optimized the image of the femoral epicondyles and minimized metal artifact. The tibial scan had a field of view covering the tibial component and the tibial tubercle and used the fast scan mode (50 images), with the imaging parameters set automatically (64 kV and 1.8 mA). From each scan, a 120 mm^3 data cube with resolution of 0.46 mm^3 (256 isotropic voxels) was reconstructed. Radiation dose for the ISO-C scans was estimated from previously reported dose values for similar imaging parameters [27].

A CT scan of each specimen was then acquired using a Toshiba Aquilion scanner (TOSHIBA, Tokyo, Japan) with the specimens in an orientation simulating a patient in the supine position. The imaging was done at 120 kV, 160 mA, and a slice thickness of 2.0 mm with 2.0-mm spacing, using the Bone Boost smoothing algorithm (TOSHIBA) for reconstruction. Manual windowing of contrast was used to reduce metal artifact and enhance the image quality. The dose length product (DLP) and effective dose of the ISO-C images were interpolated from published data [27] based on the values of the tube voltage (kilovolts) and tube current (milliamperes) and the governing equation for the absorbed dose, using a conversion factor of 0.0012 mSv/mGy.cm [31].

The average imaging time for the femoral component is 80 seconds, and for the tibial component, is 40 seconds. The estimated extra time added to the operation is approximately 5 to 10 minutes. A radiolucent operating table should be used. However, the imaging is expected to be minimally affected by an operating table that has a narrow metal frame. The knee should be positioned in extension to allow measurement of the combined rotational alignments of the femoral and tibial component and to allow for enough space for rotation of the C-arm around the limb and the table. To minimize the effects of the contralateral leg, it is recommended that the contralateral leg be raised or lowered approximately 10 to 15 cm from the bed level on bolsters before draping.

Image Analysis

To determine the alignment of the femoral and tibial components relative to anatomical landmarks, we developed and applied image analysis procedures that used the 3D images from both ISO-C and CT. The ISO-C 3D reconstructed volumes were analyzed using the