The Journal of Arthroplasty Vol. 27 No. 6 2012

The Knee Adduction Moment During Gait is Associated With the Adduction Angle Measured During Computer-Assisted Total Knee Arthroplasty

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Abstract: Computer-assisted surgery can be used to measure 3-dimensional knee function during arthroplasty surgery; however, it is unknown if the movement of the knee measured during surgery is related to the in vitro, dynamic state of the knee joint, specifically the knee adduction moment during gait, which has been related to implant migration. The purpose of this study was to determine if the preoperative adduction moment is correlated with the knee abduction/adduction angle measured intraoperatively. A statistically significant correlation was found between the mean (r^2 = 0.59; P = .001) and peak (r^2 = 0.53; P = .003) preoperative knee adduction moment and the mean abduction/adduction angle measured intraoperatively. The association found in this study suggests the potential for incorporating functional information that relates to surgical outcome into surgical decision making using computer-assisted surgery. **Keywords:** total knee arthroplasty, computer-assisted surgery, knee adduction moment, knee kinematics, gait.

Some total knee arthroplasty (TKA) implants continue to fail postoperatively [1,2] and levels of continued postoperative dysfunction and dissatisfaction have been observed [3-5]. Post-TKA implant migration measured with radiostereometric analysis has been associated with implant failure [6], and recent studies have associated the amount of postoperative migration with dynamic measures of knee joint function measured during gait, specifically the knee adduction moment and knee flexion moments [7,8]. This suggests that patient-specific mechanical factors measured during gait may be important considerations for TKA surgical decision making.

Computer-assisted orthopedic surgery can be used to record the 3-dimensional (3D) movement of the knee joint within the operating room before and after component positioning, providing improved and more dynamic knee joint alignment information to surgeons above static radiographs. The pattern of abduction/adduction movement of the knee joint in the frontal plane during a flexion/extension exercise is often recorded, and these patterns tend to be variable over the range of knee flexion [9]. The variability in the passive movement of the knee measured intraoperatively suggests a functional variability in TKA patients and the potential need for joint function-specific surgical decision making. It has been suggested that the pattern of the abduction/adduction angle through the flexion/extension range should be corrected to neutral during surgery for all patients [9]; however, there have been no studies that have related the intraoperative kinematic patterns either to preoperative knee dynamics or postoperative outcome. Because the knee adduction moment during preoperative gait has been associated with post-TKA implant migration [7], the purpose of this study was to determine if the preoperative knee adduction moment and angle during gait are associated with intraoperative abduction/adduction angle measured during a flexion/extension exercise intraoperatively. It was hypothesized that the dynamic knee adduction moment during preoperative gait, which is

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Submitted August 29, 2011; accepted February 6, 2012.

The Conflict of Interest statement associated with this article can be found at doi:10.1016/j.arth.2012.02.009.

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0883-5403/2706-0069$36.00/0
doi:10.1016/j.arth.2012.02.009

reflective of the amount of loading on the medial compartment of the knee joint [10], would be associated with the abduction/adduction angle measured intraoperatively. A secondary purpose of this study was to determine if this adduction angle measured during gait was associated with the passive adduction angle measured intraoperatively. Varus thrust (ie, the range of the knee adduction angle during initial stance phase of gait) was examined because it has been associated with varus deformity and the knee adduction moment [11] and medial compartment knee osteoarthritis (OA) progression [12]. It was hypothesized that varus thrust during gait would also be associated with the abduction/adduction angle measured passively intraoperatively.

Material and Methods

Patients diagnosed with end-stage knee OA were recruited from a TKA wait list. Inclusion criteria included diagnosis of severe knee OA, the ability to walk unaided for 6 m, no indication of cardiovascular disease, joint sepsis, metabolic bone disease or neurologic disease that would affect gait, no previous surgery to other lower extremity joints and body mass index less than or equal to 40. Informed consent was given under the guidelines provided by the institution's research ethics board.

Gait patterns of all patients were tested within the week before TKA surgery. Three-dimensional motion and loading of the lower limb were captured using an Optotrak 3020 motion capture system (Northern Digital, Inc, Waterloo, Ontario, Canada), coupled with a force platform (AMTI, Watertown, Mass). Infrared marker placement followed a previously described protocol [4,7]. Patients were asked to walk along a 6-m walkway at a self-selected walking speed, and 5 walking trials were recorded after a familiarization period. Three-dimensional knee angles were calculated according to a joint coordinate system model [13], and net resultant knee joint moments were calculated using inverse dynamics as described previously [14]. The knee adduction moment was the net resultant knee joint moment in the frontal plane, and both the adduction moment and angle were described about a floating axis of the joint coordinate system. The knee moments were normalized to body mass, and moments and angles were time normalized to 100% gait cycle from first to second heel strike of the affected leg. The mean and peak values of the preoperative knee adduction moment were calculated for each patient over the stance phase of gait. The range of abduction/adduction angle in early stance (0%-20%) was calculated to represent varus thrust during gait for each patient.

All patients received primary computer-assisted TKA surgery performed by 2 surgeons, and all received Stryker PS Triathlon TKA components. The Stryker Precision Knee computer-assisted surgery system was used for all TKA procedures (Stryker Corporation, Kalamazoo, Mich). During the procedure, the surgeon fixed 2 infrared segment trackers (each with 3 embedded noncollinear markers) to the femur and tibia bones using cortical anchoring pins and used a digitization tool to record the position of anatomical landmarks (lateral and medial epicondyles, femoral center, lateral and medial malleolus, tibial center) and morphological surfaces of the tibiofemoral joint. A femoral anterior/posterior axis (the Whiteside line) was digitized along the groove between the lateral and medial epicondyles of the distal femur, and a tibial anterior/posterior axis was digitized along the groove between the lateral and medial compartments of the proximal tibia, superior to the intercondyloid eminence. To mathematically determine the functional hip joint center, the surgeon circumducted the femur about the hip joint [15]. Anatomical landmarks were used to define anatomical coordinate systems (axes in the anterior/posterior, medial/lateral, and distal/proximal directions) within the femur and tibia relative to the femoral and tibial trackers.

Before any surgical cuts were made, the 3D passive movement of the knee joint was recorded. The surgeon supported the affected leg posteriorly by grasping the arch of the foot with the knee in full extension. The leg was moved through full extension/full flexion cycles by gently lifting the thigh, flexing the knee and hip and ensuring that the shank was parallel to the operating table during the passive motion. The computer-assisted orthopedic surgery system recorded the 3D positions of the infrared markers on the femur and tibia trackers during this motion. Three-dimensional knee joint angles were calculated during this exercise as rotational movement between the femur and tibia anatomical coordinate systems, defined by the joint coordinate system [13] and displayed in real-time within the operating room (eg, Fig. 1). The mean abduction/adduction angle recorded during the intraoperative passive motion was calculated over a flexion interval from full extension to 60° of flexion. This interval was selected because during gait, the knee generally does not exceed 60° of flexion. The range of abduction/adduction motion was also calculated over this 0° to 60° flexion interval (Fig. 2).

Two-tailed Pearson correlation coefficients were used to test for significant linear associations between the preoperative and intraoperative variables (mean and peak preoperative adduction moment, varus thrust; mean and range of intraoperative abduction/adduction angle). Bonferroni corrections were used to adjust the statistical significance level to a *P* value of .013.

Results

Fourteen patients met the inclusion criteria of the study and were included in the study. The patients had a mean body mass index of 30.7 (±4.9) and age of 67.1 years (±8.6).