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Basic Science

Differential Effect of Total Knee Arthroplasty on Valgus and Varus Knee Biomechanics During Gait

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ABSTRACT

Background: Total knee arthroplasty and its relation to gait abduction or adduction moment has not been fully described.

Methods: Gait analysis was performed on 25 patients (27 knees) preoperatively, 6 months and 1 year after total knee arthroplasty. Reflective markers were placed on the lower extremity, and motion data were collected at 60 Hz using 6 infrared cameras. Ground reaction forces were recorded at 960 Hz with a force plate. Stance phase was divided into braking and propulsive phases. Coronal knee angles and moments were calculated. Repeated-measures analysis of variance was used to compare frontal plane knee impulse over time and between the braking and propulsive phases of stance.

Results: In varus knees, static alignment was corrected from 2.2° varus to 3.3° valgus and in valgus knees from 15.2° valgus to 2.7° valgus ($P < .010$). Braking phase adduction impulse decreased from 0.145 to 0.111 at 6 months but increased to 0.126 Nm/kg s ($P > .05$) at 1 year. Propulsive phase impulse changed from 0.129 to 0.085 and persisted at 1 year. Impulse changed from 0.01 (abduction) to 0.11 Nm/kg s (adduction) at 6 months and persisted ($P = .01$).

Conclusion: Restoration of anatomic alignment and soft tissue balancing changes the lateral loading conditions of valgus knees. Both cases, between 6 months and 1 year, increased peak moment.

Knee biomechanics have been well studied and documented [1-17]. Ground reaction forces (GRFs) work by exerting force from the ground onto the body in contact with it. This force acts on the normally aligned knee by passing medially from the foot toward the body's center of mass; as such, a characteristic adduction moment, typical of human gait, occurs.

Patients with knee osteoarthritis (OA) and medial compartment narrowing walk with a higher knee adduction moment were compared to control subjects [5]. For every 1% increase in knee moment above baseline, the risk of OA progression increases 6.5 times [11]. Consequently, many interventions for knee OA center on the reduction of this knee moment [10,12,18-20]. Although less prevalent, as many as 9%-17% of patients with valgus type deformity end up requiring total knee arthroplasty (TKA) [21].

Gait analysis studies have been performed to examine the dynamic loading patterns in postoperative TKA patients, with the purpose of comparing different implant designs [17,20]. However, an inherent lack of literature comparing valgus and varus knee patient performance pre- and post-TKA prompts for more studies allowing us to determine the effectiveness of the arthroplasty in restoring normal knee loading patterns, and it may also provide important information regarding potential wear-related complications.

By 6 months, it has been proposed that the correction of knee deformity and reaction forces accomplished by TKA can be equated to that of healthy subjects [22]. Yet, even though this suggests improved mechanics, retrieval studies of tibial inserts have shown a predominance of medial compartment wear after TKA. These results imply that the preoperative loading conditions (ie, high peak knee moment) might have returned [23-25].

Investigation performed at Lenox Hill Hospital, New York, NY.

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Basic definitions used in this analysis include moment, defined as the angular or rotational effect of a force about the joint. In this specific case, we are examining the adduction moment about the knee. This means, how much moment the GRF exerts on the knee to rotate it into varus. An abduction moment would be the same idea, except it would rotate the knee into valgus. Impulse, or more specifically, rotational impulse, is the area under the moment-time curve. It represents the moment multiplied by the amount of time it is applied to the joint. The dynamic knee angle represents the position of the knee (in the frontal plane) as it progresses from heel strike to toe off. This data point is measured during movement (ie, walking), and it is not just a static measurement of alignment such as a full-length X-ray.

The purpose of this study was 3-fold. First, to determine whether the changes in dynamic knee gait angle and frontal knee moment remained at long-term follow-up (6 months and 1 year) post TKA. Second, to assess whether the changes in frontal knee moment are in fact related to the static and dynamic knee angular correction at the 6-month and 1-year post-TKA follow-up. Third, determine if these biomechanical changes are related to changes in the Knee Society (KS) scores.

Our primary hypothesis was that the observed preoperative moment would be reduced after TKA. The secondary hypothesis was that the magnitude of reduction in observed moment would be proportionate to the tibiofemoral correction.

Methods

In a 2-year period, 25 patients (27 knees) were recruited from the practice of 2 fellowship-trained orthopedic surgeons (J.A.R. and S.J.N.). All patients were subjected to a standardized gait analysis protocol performed preoperatively, 6 months and 1 year after TKA. There were 9 men and 16 women; of those, 15 patients had varus type deformity and 10 patients had valgus type deformity. The valgus deformity group had a mean height of 168 cm (range, 152-180 cm) and mean weight of 75 kg (59-117 kg) with a mean age of 63.7 years (56-72 years). The varus deformity group had a mean height of 171 cm (range, 151-185 cm) and mean weight of 84 kg (range, 62-91 kg), with a mean age of 65 years (range, 56-70 years).

In order to be included in the study, patients were required to have a (1) diagnosis of primary (medial or lateral) compartment OA and voluntary consent for TKA, (2) no previous arthroplasty surgery (hip or knee) or history of high tibial osteotomy in the affected lower extremity, and (3) the ability to walk without an assistive device. Varus knees were enrolled first, and on completion, valgus knees were enrolled. During each recruitment period, all patients meeting the previously mentioned criteria were offered the opportunity to participate in the study. Before participation, subjects provided informed consent in accordance with the institutional review board.

A previously published technique of alignment and soft tissue release was utilized for varus knees [21] and valgus knees, respectively [26]. All varus knees received a posterior-stabilized knee implant (Depuy Sigma PFC, Warsaw, IN or Biomet Vanguard, Warsaw, IN). Valgus knees (Depuy Sigma PFC or Smith Nephew Legion, Memphis, TM) received a posterior-stabilized implant in 7 cases. A mid-level constrained insert was used in 2 knees based on mild lateral condylar liftoff after lateral soft tissue release and a cruciate-retaining implant by patient request in 1.

Preliminary power analysis from previous analyses on gait data from our laboratory [12] determined that in order to detect a change of 5° in peak knee angle and 15% knee moment, 12 patients were needed ($P = .05$, 80% power).

Radiographic follow-up was performed by using preoperative and postoperative (6-month and 1-year follow-up) standing anteroposterior (AP) radiographs. Clinical function surveys (KS and Function Scores) were completed at each laboratory visit (preoperative, 6 months, and 1 year).

For both groups, kinematic and GRF data were recorded as subjects walked initially at a self-selected pace across a 6-m walkway. Reflective markers were placed over the calcaneus, first and fifth metatarsals, medial and lateral malleoli, anterior shank, medial and lateral femoral condyles, anterior thigh, greater trochanter, sacrum and anterior superior iliac spine of the involved leg, and the greater trochanter and anterior superior iliac spine of the contralateral leg. Marker positions were collected at 60 Hz using 6 infrared cameras (Qtrac, Qualisys, Gothenburg, Sweden). The motion data were then filtered with a fourth-order Butterworth low-pass filter with a cutoff frequency of 10 Hz in order to eliminate any high frequency noise. GRFs were recorded at 960 Hz with a multicomponent force plate (Kistler Instrument Corp., Amherst, NY) incorporated into the walkway. Subjects performed 5 gait trials and were instructed to walk as naturally as possible and contacting the force plate with only the involved limb. Trials in which the foot did not land completely on the force plate or the subject altered his or her gait pattern to target the force plate were discarded, and the trial was repeated. Previous reliability analysis for gait data from our laboratory [27] has shown, with 12 subjects, we could detect changes of 55 has shown, with 12 subjects, we could detect changes of The motion data were then.

Sagittal (flexion/extension) and frontal plane (abduction/adduction) knee angles and moments were calculated using specialized computer software (Visual 3D; C-Motion, Inc, Rockville, MD). Based on the anterior/posterior GRF, the stance phase of each trial was divided into a braking phase and a propulsive phase. The area under the knee abduction and/or adduction moment curve (knee moment impulse) was calculated for each phase.

Statistical analyses consisted of separate, single-factor (time) repeated-measures analysis of variance to compare static AP alignment, KS and Functional Scores, gait velocity, and range of motion (ROM) and dynamic knee angle during gait over time. Repeated-measures (time $\times$ phase) analysis of variance was also used to compare changes in knee moment and impulse for the braking and propulsive phases, from preoperatively to postoperatively (6 months and 1 year). Dynamic knee angle and peak moment were defined as the maximum valgus/varus angle or moment observed at a given period. Bonferroni corrections were applied for post hoc comparisons where applicable. Finally, Pearson correlations were done to investigate the association between knee moment and impulse and gait velocity, static alignment, and dynamic gait angle. Additional Pearson correlations were done to investigate the association between the change in knee moment and impulse and the change in either static alignment or change in peak angle during gait. P values less than or equal to .05 were considered significant.

Results

KS and Function scores significantly improved in both groups ($P < .001$ and $P < .001$, respectively) (Table 1). In the valgus group, measured static knee alignment changed from 15.2 degrees valgus (standard deviation: 5.6) to 2 degrees valgus (1.2) ($P < .001$) at 6 months, with nonsignificant change to 2.7 (2.1) degrees valgus at final follow-up. For the varus group, preoperative static knee alignment was 2.2 degrees varus (2.5) and was corrected to 3.5 degrees valgus (2.7), as measured at both 6 months and 1 year ($P < .001$).

In both groups, gait velocity progressively increased following TKA (main effect of time, valgus: $P = .069$; varus: $P = .010$). The valgus group showed an increase of 3% in velocity at 6 months