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Analysis of the factors that correlate with increased knee adduction moment during gait in the early postoperative period following total knee arthroplasty

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ABSTRACT

Background: Analysis of dynamic knee loading during gait is essential to prevent mechanical failures following total knee arthroplasty. External knee adduction moment during gait is the primary factor producing medial joint reaction force, and an increase in the moment is directly related to an increase in the medial compartment load on the knee.
Methods: Knee adduction moment during gait in 39 knees of 32 female patients following a posterior stabilized knee replacement with a single surgeon was evaluated at 1.3 months following surgery. A cut-off moment was determined as mean + 1 standard deviation (SD) of the moment from 10 healthy subjects, and patients' knees were divided into high- and normal-moment groups. Significant differences in clinical assessments and gait parameters between the two groups were assessed.
Results: Based on the cut-off moment, 23 knees were grouped into normal knees and 16 knees were grouped into high-moment knees. High-moment knees showed identical femorotibial angles and knee society scores but had greater toe-out angles and medially directed ground reaction forces compared to normal-moment knees. High-moment knees showed strong correlations between peak moment and knee adduction angle, and frontal plain moment arm.
Conclusions: The clinical significance of a high knee adduction moment following total knee arthroplasty remains unclear, but dynamic frontal alignment during gait is one of the key factors for residual high-moment knees following surgery.
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1. Introduction

Total knee arthroplasty (TKA) provides long-term pain relief and patient satisfaction for moderate to end-stage knee osteoarthritis (OA). Despite good clinical satisfaction and improvements in surgical techniques, there is concern regarding mechanical failures following primary TKA, such as aseptic loosening, instability, and polyethylene wear [1,2]. These mechanical failures become major reasons for revision surgery, and revision TKA is still required in eight to 10% of primary TKA cases [3]. To prevent and detect such mechanically induced failures, analysis of dynamic knee loading during functional activities is essential.

External knee adduction moment during gait is known to be a key variable in understanding frontal knee mechanics. The knee adduction moment is closely related to frontal limb alignment, and is the primary factor producing the medial joint reaction force;

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thus, an increase in knee adduction moment is directly related to an increase in the medial compartment load in the knee [4–7]. For this reason, the knee adduction moment has been used as the 'gold standard' dynamic index for knee OA patients, and various nonsurgical and surgical treatments are targeted to reduce the knee adduction moment [8–14]. Several studies have examined changes in the knee adduction moment during gait before and after TKA [15–18]. A recent systematic review highlighted the importance of evaluating the knee adduction moment following the surgery [19]. Overall, TKA significantly corrected static knee alignment and reduced the knee adduction moment during gait, but some still had a high knee adduction moment, which presumably predisposes to mechanical failure such as polyethylene wear [18]. However, these gait studies included different implants and surgeons in their patient series; such a study design adds biases due to the implant and the surgeon, and limits the discussion of the factors that affect the level of the knee adduction moment following surgery.

The knee adduction moment is primarily calculated as the product of the resultant ground reaction force in the frontal plane and the perpendicular distance from the ground reaction force to the knee joint center (frontal plane lever arm). The ground reaction force and frontal plane lever arm are independent variables, and modification of either variable can alter the knee adduction moment. An association between peak knee adduction moment and peak frontal plane lever arm in OA knees has been reported [19], but no study has examined the contributions of these variables to the knee adduction moment following TKA. If a high knee adduction moment remains following TKA, it is important to analyze which component is dominant since modification of the ground reaction force or frontal plane lever arm can be achieved by nonsurgical interventions such as walking shoes or gait training [8–12].

The purposes of this study were: (1) to measure early postoperative knee adduction moment to determine whether there are high-moment knees following TKA with a single implant and surgeon, and (2) to analyze the factors that affect the level of knee adduction moment. Our hypotheses were: (1) that there are knees with a high knee adduction moment following surgery, and (2) that there are gait parameter(s) that relate to high knee adduction moment.

2. Materials and methods

2.1. Subjects

Fifty patients underwent primary TKA and postoperative gait analysis between 2009 and 2011 at our institutions. Patients who had a previous arthroplasty (hip or ankle) or high tibial osteotomy of the involved limb, or could not walk without an assistive device, were not included. We excluded the cases with osteonecrosis, rheumatoid arthritis, or OA of the lateral compartment (valgus knee deformity) (10 cases), male patients (five cases), and the patients who had a postoperative period of less than one month or greater than six months (two cases). The final cohort involved only female patients with the primary diagnosis of OA in the medial compartment. There were 41 knees of 33 cases, including eight cases with simultaneous bilateral surgery. The surgery was performed by a single surgeon (Y.N.) using a standard medial incision (quad-sparing or sub-vastus approach). A posterior stabilized type implant (LPS-flex, Zimmer, Warsaw, IN) was used in all cases. All study protocols were approved by the Institutional Review Board of our institution, and informed consent was obtained from each subject prior to initiation of the study.

2.2. Gait analysis

Gait analysis was performed at a mean postoperative period of 1.3 months (range, one to four months). Six retro-reflective markers were placed directly onto the skin of the subject as previously reported, i.e., at the most superolateral aspect of the iliac ring, greater trochanter, lateral joint line of the knee, lateral malleolus, lateral aspect of the calcaneus, and head of the fifth metatarsal bone [21,22]. After a few practice trials, all subjects performed trials of 10 m level walking at a comfortable walking speed in a gait laboratory without shoes. Two successful gait trials of each knee were used for the analysis. Knee kinematics and ground reaction force were measured using a Pro-reflex system (120 frames/s; Qualysis, Savedalen, Sweden) and an AM6110 force plate (frequency 600 Hz, sample frequency synchronized to 120 Hz; Bertec, Columbus, OH).

2.3. Gait parameters and clinical assessments

Direct measurements of limb segment size and height were used to approximate the joint correction factors of the hip, knee, and ankle, and the positions of the joint centers were estimated from the position of each marker at the greater trochanter, the lateral joint line of the knee, and the lateral malleolus, respectively. All gait variables were calculated by an original software (Q-gait, CFTC, IL). Knee adduction moment and knee flexion moment were calculated using an inverse dynamics approach [21,22]. Knee adduction moment and knee flexion moment of all subjects were normalized by percent body weight times height (%BW × Ht) [21,22]. Knee adduction angle was obtained from the positions of the joint centers of the hip, knee, and ankle on the frontal plane, and the angle was defined as >180° indicates varus. Toe-out angle at the peak knee adduction moment was determined by the angle between the line of progression and the line that connected the fifth metatarsal bone and heel. Maximum ground reaction force in the medial–lateral direction (ground reaction force-ml) and the vertical direction (ground reaction force-v) were normalized by percent body weight (%BW) and evaluated. Ground reaction force frontal plane lever arm was determined as the distance between the knee joint center and the ground reaction force vector when the peak knee adduction moment was obtained. Clinical

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