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Stiff knee gait may increase risk of second total knee arthroplasty

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Abstract

Osteoarthritis (OA) progression in the contralateral limb after unilateral total knee arthroplasty (TKA) may be related to altered and asymmetrical movement patterns that overload the contralateral joints. The purpose of this study was to determine if biomechanical factors after unilateral TKA were associated with future contralateral TKA. 158 individuals who underwent unilateral TKA completed three dimensional motion analysis 6–24 months after unilateral TKA (baseline). Subjects were re-contacted for follow-up (mean 5.89 years after baseline testing) to determine if they had undergone a contralateral TKA. Biomechanical variables from gait at baseline were compared between those who did and did not undergo contralateral TKA at follow-up using one-way ANOVAs. Odds ratios were calculated for variables found to be significant in the ANOVA models. Individuals who underwent contralateral TKA had less knee flexion excursion (10.5 vs 12.1 degrees; p=0.032) and less knee extension excursion (8.2 vs 9.6 degrees; p=0.035) at baseline on the operated side during walking. Individuals who underwent contralateral TKA also had less knee flexion excursion on the contralateral limb at baseline (11.9 vs 14.0 degrees; p=0.017). For every additional degree of knee flexion excursion on the contralateral knee at baseline, there was a 9.1% reduction in risk of future contralateral TKA. Individuals who walked with stiffer gait patterns were more likely to undergo future contralateral TKA.

Keywords

joint replacement; arthroplasty; kinetics; kinematics; gait analysis; osteoarthritis

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Introduction

After unilateral total knee arthroplasty (TKA), there is a non-random evolution of osteoarthritis (OA) progression in other lower extremity joints in which the contralateral knee joint is most likely to be replaced next [1]. An analysis of 5,352 patients who underwent total joint replacement found that 49.5% of patients with TKA underwent a second arthroplasty procedure on a different joint [2] and that 93% of those had a contralateral TKA. While it may be intuitive to think that this incidence is the result of existing underlying joint disease in the contralateral knee at the time of surgery, individuals who planned a subsequent TKA at the time of index surgery were excluded from the study, suggesting that the baseline sample was comprised of unilaterally symptomatic individuals [3]. A separate study found that even individuals with mild OA in the contralateral knee were at risk for needing contralateral TKA in the future [4].

Several risk factors are associated with OA incidence and progression, including female sex [5,6], greater body weight [7–9], and abnormal biomechanics that place excessive or abnormal loads on the joint [10,11]. After unilateral TKA, many individuals move asymmetrically and rely on the non-operated limb to complete dynamic tasks, such as walking. While this is an expected outcome early after surgery, it can be problematic when these asymmetries are not resolved in the long term. This asymmetry increases adduction moments on the contralateral limb [12]. Greater adduction moments are related to greater joint loading in the medial compartment and have been directly linked to initial OA progression [13].

Biomechanical factors other than adduction moments have been suggested to play a role in OA incidence and progression. Stiff-legged gait patterns, in which there is reduced knee excursions in the sagittal plane, are an inherent aspect of gait in individuals with knee OA [14]. Knee stiffness during walking is greater in individuals with knee OA compared to controls [15] and the magnitude of knee stiffness increases as the severity of OA increases [16]. It is possible that stiff knee gait patterns increase the internal joint stresses due to reduced joint motion and a smaller area of load distribution and may play a role in the symptomatic or radiographic progression of OA. However, there have been no prospective studies to evaluate whether these abnormal movement patterns are associated with symptomatic OA progression.

While much effort has gone into identifying risk factors for primary OA incidence and progression, there is limited research to identify risk factors for contralateral OA after index TKA. This is particularly important as gait mechanics, body mass, and other characteristics change after unilateral TKA, potentially altering the course trajectory of disease progression in the non-operated limb. It is conceivable that abnormal movement patterns in the operated knee amplify asymmetrical loading and abnormal movement in the non-operated knee, Therefore, the purpose of this study was to determine if abnormal kinetics or kinematics after unilateral TKA were different between those who did or did not require contralateral TKA in the future.

Methods

Level of Evidence:

Case-control study Level III

Subjects—Subjects were recruited from a previous cross-sectional study that evaluated movement patterns within two years of unilateral TKA. In the parent study, subjects were eligible to participate if they underwent unilateral TKA for end-stage OA and were between the ages of 40 and 85. Subjects were excluded if they had neurological condition that impaired their movement ability, had decreased sensation in their feet, had musculoskeletal conditions that affected their walking ability, had a body mass index (BMI) greater than 50, or had undergone a previous joint replacement other than the most recent surgery. To establish a unilaterally symptomatic sample, subjects were also excluded in the parent study if they were undergoing a simultaneous or staged TKA, had plans for a future contralateral TKA, or had pain greater than 4 out of 10 on a verbal analog score. All potential subjects underwent TKA at a single Joint Replacement Center with one of six surgeons who performed tricompartmental cemented TKA with medial parapatellar approach and used either posterior stabilized or posterior cruciate retaining prostheses. This project was approved by the Human Subjects Review Board at the University of Delaware and all subjects signed an informed consent form prior to beginning any aspect of the study.

Baseline testing—Subjects completed baseline testing 6 to 24 months after unilateral TKA. All testing took place between 2003 and 2013. Biomechanical testing consisted of shod walking over level ground at a self-selected speed. A three dimensional kinematic and kinetic evaluation was performed using an 8-camera motion capture system (VICON, Oxford Metrics, London, England) and two force platforms (Bertec Corp., Worthington, OH, USA). Retro-reflective markers were placed bilaterally directly on the skin over anatomical landmarks that included the iliac crest, greater trochanter, lateral femoral condyle, and lateral malleolus. The head of the 5th metatarsal and two markers on the heel were placed on the shoe over the landmarks. Rigid tracking shells were secured on the lower legs, thighs, and posterior pelvis. Five successful walking trials were collected for each subject. A successful walking trial occurred when a subject walked within 5% of the self-selected walking speed, and there was no obvious targeting of the force plates. Marker data were low pass filtered at 6 Hz, and force platforms data were filtered at 40 Hz using a second order phase-corrected butterworth filter. Joint moments were normalized to body mass and height using Visual 3D software (C-motion, Inc, Rockville, MD).

From the walking data, several variables of interest were extracted from the stance phase of the gait cycle. Kinematic variables included: 1) knee angle at initial contact, 2) peak knee flexion, 3) peak knee extension, 4) knee flexion excursion during loading response, and 5) knee extension excursion at midstance. Kinetic variables included: 1) Peak vertical ground reaction force, 2) peak external knee flexion moment, and 3) peak adduction moment. All variables were assessed on the operated and non-operated limbs. Knee flexion excursion was defined as the difference between peak knee flexion during stance, which typically occurred around 20% of the stance cycle, and knee position at initial contact. Knee extension excursion was the difference in joint angle between peak knee flexion during stance and peak knee extension during midstance. Walking speed was calculated for all trials.

Follow-up Testing—All subjects were re-contacted between 2014 and 2015 by telephone to determine if they had undergone contralateral TKA. If the individual did undergo contralateral TKA, the date of the surgery was recorded. The time between the initial surgery and follow-up was recorded, as was the time between initial surgery and contralateral TKA, when applicable.

Data Analysis—Subjects were dichotomized into two groups: those who underwent contralateral TKA at the time of follow-up (TKA group), or those who did not (No TKA group). Comparisons between groups were made for all of the biomechanical variables in using independent t-tests. Walking speed and time from baseline to follow-up were also compared using independent t-tests. All comparisons were made without adjusting for multiple comparisons.. Odds ratios were also calculated for variables found to be significant in the between group comparisons. In the presence of a significant difference in age, BMI, or walking speed between the TKA and No TKA groups, these variables were to be used as covariates in the comparative and associative analyses.

Results

Of the 199 subjects in the parent study with biomechanical data, 157 (79 males, 78 females) were able to be re-contacted to determine their contralateral knee status (Table 1). Thirty-seven (23.4%) subjects underwent contralateral TKA. The mean time between initial and contralateral surgery was 3.5 years [95%CI 2.9–4.1]. There was no difference in time between surgery and follow-up between those who did and did not undergo contralateral TKA (5.7 vs. 5.9 years; $p=0.46$). There was no difference between groups for walking speed (1.29 ± 0.16 vs. 1.29 ± 0.17 m/s; $p=0.96$). There were also no differences in age or BMI between the groups. The average age in TKA group was 67.4 (SD 7.2), while the average age in the No TKA group was 68.0 (SD 7.3) years ($p=0.62$). Mean BMI in the No TKA group was 31.7 (SD 5.8) and 30.0 (SD 4.0) for the TKA group ($p=0.095$). Therefore, no covariates were used in the comparative statistical models.

The individuals who underwent contralateral TKA had 1.6 degrees less knee flexion excursion ($p=0.032$) and 1.4 degrees less knee extension excursion ($p=0.035$) at baseline on the operated side during walking (Table 2). Individuals who underwent contralateral TKA also had 2.1 degrees less of knee flexion excursion on the contralateral limb at baseline ($p=0.017$). There was no difference in any other kinematic (Table 2) or kinetic (Table 3) gait variable at baseline.

For every additional degree of knee flexion excursion on the operated limb at baseline, there was a 10.2% [95% CI 0.8%−18.8%] reduction in risk of future contralateral TKA ($p=0.035$). For every additional degree of knee flexion excursion on the contralateral knee at baseline, there was a 9.1% [95% CI 1.5%−16%] reduction in risk of future contralateral TKA ($p=0.019$). The regression model for knee extension excursion on the operated limb was not significant (Odds ratio 7.5; 95%CI −1.2–15.5%; $p=0.088$).

Discussion

Although TKA is a successful procedure that reduces knee pain and improves self-reported functional ability, the contralateral knee often experiences a progressive decline after the index procedure. There is a high incidence of contralateral TKA after unilateral surgery [3] and many patients experience a progressive deterioration of function and biomechanics of the non-operated knee within 3 years of surgery [17,18]. This is likely the result of OA progression in the contralateral knee, but to date, there is little known about associated risks of this progression. Our results reveal that abnormal biomechanics after unilateral TKA in the operated and non-operated sides are associated with utilization of a future contralateral TKA. In particular, individuals who walk with a more stiff-legged gait pattern may be at the greatest risk of undergoing a contralateral TKA within several years of their first surgery.

Stiff-legged patterns are characterized by reduced knee flexion and extension excursion during stance [16,19]. While the underlying cause for adopting a stiff-legged gait pattern is not clear, it may be an attempt to reduce the use of the operated limb during the shock absorption and propulsion phases of stance, which may result in greater reliance on the non-operated side to complete bilateral weight bearing tasks. [20,21]. However, lower joint excursions were also found in the contralateral knees of individuals who went on to have second TKA. Decreased knee motion also alters the internal loads at the joint surfaces and reduced knee flexion during gait has been a proposed mechanism of OA progression [22]. Given our findings, it is possible that lack of full joint excursion on the operated knee, coupled with altered loading in the non-operated knee as a result of attenuated flexion angles, expedites the progression of contralateral OA. It is hard to quantify the effects of kinematics on internal joint loads and future studies that estimate joint contact force through muscle modeling may provide a better understanding of the mechanism of action in these patients.

Even in a sample of patients who were largely unilaterally symptomatic at baseline, a nearly one-quarter of the subjects underwent contralateral TKA by follow-up. There are numerous factors that motivate the decision to undergo TKA, but progressive pain that substantially interferes with activities of daily living and radiographic evidence of end-stage OA remain the standard indicators for TKA. At baseline, none of the subjects in our sample had pain greater than 4 out of 10, nor did any have plans for a subsequent procedure on the opposite knee. This suggests that there was a progressive worsening in pain, structure, and/or function between baseline and follow-up. It also suggests that this decline happens quickly, as the average time to surgery was 3.5 years. Given the preliminary evidence from this study that stiff knee gait patterns are associated with rapid decline to second TKA, strategies that improve knee motion after surgery should be a target for post-operative rehabilitation..

Despite the differences in joint biomechanics between groups, there are some limitations to our methods. Baseline radiographs of the non-operated knee were not available, so we are not able to account for potentially confounding effect of baseline OA status or radiographic alignment in the contralateral knee. It is known that greater OA severity at the time of the first procedure is associated with future contralateral TKA, but even patients with mild disease undergo contralateral TKA in the future [4]. It is also known that biomechanical changes, including reduced knee flexion excursion, worsen as OA progresses [23]. Therefore, it is possible that the differences observed in the non-operated knees of individuals who underwent contralateral TKA reflect a greater level of structural disease at baseline. That is to say, less knee motion on the non-operated side was indicative of an existing disease process, not just a progressive cause of OA. Our measure of OA progression was also TKA use by follow-up. While this likely captures the symptomatic progression, the decision to undergo TKA is multifactorial and cannot be said to be the result of symptom progression alone. There are a variety of socio-economic factors that influence the decision to undergo TKA [24]. However, the baseline sample was derived from a group of individuals who underwent an initial TKA, making it more likely that the individuals had access and means to undergo a surgical procedure.

The differences between groups for knee flexion and extension excursions were relatively small and ranged from 1.4 to 2.1 degrees. To date, there is no clear consensus on how large of a difference is meaningful. The differences in knee flexion excursion between individuals with and without OA was 3.8 degrees [25], while the difference between individuals with knee OA who did and did not have knee instability was 3.3–3.5 degrees [26,27]. Those differences were larger than the differences in this study, but the former were derived from cross-sectional samples. It is possible that smaller changes in knee motion have a cumulative effect that influences OA progression over a longer period of time. Previous studies, which have included a broader range of biomechanical metrics, have also identified differences in sagittal plane joint angles and segmental positions as being associated with greater severity of OA progression [28]. In particular, this previous study [28] found that individuals with more severe OA had a tibia that was positioned more vertically at heel strike, had greater knee flexion during terminal stance, and overall a knee that was maintained in more flexion during weightbearing portion of the gait cycle. Given these previous findings and our similar results, sagittal plane joint position and knee angles during stance should be the target of future mechanistic studies evaluating the effect of loading on OA severity or progression.

It is also possible that the synergistic effect of less knee flexion excursion, which was significant, and less knee extension excursion, which was 1.4 degrees less but not significant, plays a role in the symptomatic decline. The reduction of the overall arc of motion at the knee, may be clinically relevant to OA progression. Small changes in joint position or excursion can alter the internal loading environment, which may lead to symptomatic and structural changes over the course of years. A clinical study found that for every degree decrease in knee extension range or motion, the odds of undergoing TKA at follow-up increased 23% [29]. Although that was a clinical measure of static knee extension, it does suggest that an association between available motion and symptomatic changes is present. Future studies that include precise quantification of joint motion, such as fluoroscopic measures of knee motion, are needed to better understand the association between small changes in kinematics and the risk for structural or symptomatic decline.

Despite several studies pointing to the adduction moment as a predictor of OA progression, we did not see a difference in adduction between those who did and did not undergo TKA in our study. Because we used progression to TKA as our end-point, we did not stratify progression by medial or lateral compartment disease. Greater adduction moment increases the loads in the medial compartment and can result in medial compartment OA progression [10]. However, it is likely that individuals in our sample had lateral, as well as medial compartment OA. This may be the underlying reason why greater adduction moment in the contralateral knee was not associated with a greater risk of contralateral TKA in our study. Some of the individuals may have had lateral compartment progression, a condition that is associated with lower adduction moments due to the valgus alignment of the lower limb [30]. We also did not find differences in sagittal plane knee moments, despite a difference in sagittal plane knee kinematics. It is not clear why differences emerged in kinematics, but not kinetics. However, greater variability in the measurement of knee moments, or compensatory changes in magnitude and direction of the ground-foot interaction forces may explain this finding. Future work should determine if compensatory changes in joint kinetics occur when kinematic alterations are present.

In summary, we found that individuals who underwent a future contralateral TKA had abnormal movement patterns on the operated and non-operated limbs after unilateral TKA. It is possible that abnormal biomechanical patterns that are characterized by reduced sagittal plane knee excursions play a role in the progression of contralateral knee OA. Future laboratory studies should include mechanistic approaches to determine if and how reduced joint excursion plays a role in cartilage deterioration or symptomatic progression. Prospective longitudinal clinical outcomes studies should be performed to substantiate the findings from this study.

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Clinical Significance:

Altered movement patterns after surgery may increase the risk for contralateral TKA. Knee excursion is an important metric to include in outcome studies and may serve as a target of rehabilitation after TKA.

Table 1.

Subject demographics

	Mean	95% CI
Age (years)	67.5	66.4–68.7
Height (m)	1.69	1.68–1.71
Weight (kg)	90.2	87.1–93.3
BMI	31.3	30.4–32.1
Time to follow-up (years)	5.9	5.7–6.1

Table 2.

Sagittal plane kinematics compared between groups

	TKA	No TKA	p-value
Operated side			
Knee angle initial contact	7.6 (5.2)	6.5 (5.5)	0.249
Peak knee flexion	18.2 (5.1)	18.6 (6.0)	0.733
Peak knee extension	10.0 (6.3)	9.0 (5.8)	0.348
Knee flexion excursion	10.5 (4.3)	12.1 (3.7)	**0.032**
Knee extension excursion	8.2 (3.1)	9.6 (4.7)	**0.035**
Non-operated side			
Knee angle initial contact	5.7 (5.6)	3.6 (5.5)	0.054
Peak knee flexion	17.6 (6.2)	17.6 (6.5)	0.961
Peak knee extension	7.2 (6.7)	5.9 (6.6)	0.283
Knee flexion excursion	11.9 (5.1)	14.0 (4.5)	**0.017**
Knee extension excursion	10.3 (5.1)	11.7 (5.4)	0.162

All data are shown in degrees (standard deviation)

Table 3.

Knee kinetics compared between groups

	TKA	No TKA	p-value
Operated side			
Peak vertical ground reaction force (BW)	1.11 (0.11)	1.12 (0.13)	0.623
Peak external knee flexion moment (Nm/kg*ht)	0.34 (0.13)	0.36 (0.15)	0.655
Peak external knee adduction moment (Nm/kg*ht)	0.29 (.10)	0.27 (0.21)	0.609
Non-operated side			
Peak vertical ground reaction force (BW)	1.15 (0.12)	1.15 (0.12)	0.717
Peak external knee flexion moment (Nm/kg*ht)	0.34 (0.18)	0.33 (0.18)	0.861
Peak external knee adduction moment (Nm/kg*ht)	0.38 (0.14)	0.38 (0.13)	0.758