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Frontal plane biomechanics of the operated and non-operated knees before and after unilateral total knee arthroplasty

Eytan M. Debbi [a,*], Benjamin Bernfeld [b], Amir Herman [c], Yocheved Laufer [d], Arnan Greental [e], Amit Sigal [e], Yaron Zaulan [b], Moshe Salai [f], Amir Haim [a], Alon Wolf [a]

[a] Biorobotics and Biomechanics Lab, Faculty of Mechanical Engineering, Technion Israel Institute of Technology, Haifa, Israel
[b] Department of Orthopedic Surgery, Carmel Medical Center, Haifa, Israel
[c] Department of Orthopedics and Talpiot Medical Leadership program, Sheba Medical Center, Tel Aviv, Israel
[d] Department of Physical Therapy, Faculty of Social Welfare and Health Studies, University of Haifa, Haifa, Israel
[e] Department of Orthopedics, Rambam Health Care Campus, Haifa, Israel
[f] Division of Orthopedics, Sourasky Medical Center, Tel Aviv, Israel

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ABSTRACT

Background: After unilateral total knee arthroplasty, frontal plane loading patterns on the operated knee remain pathological in the long term, but it is unclear how they change in the early postoperative period. Additionally, researchers have suggested that the non-operated knee bears greater frontal plane loads postoperatively, but this effect is unclear. The objective of the present study was to compare the preoperative and early postoperative frontal plane loading patterns of both knees after unilateral total knee arthroplasty.
Methods: Fifty patients with end-stage knee osteoarthritis were examined prior to and six weeks after surgery. Patients underwent a three-dimensional gait analysis that determined the frontal plane loading patterns of knee varus angle and knee adduction moment during gait, and completed self-evaluative questionnaires and functional tests.
Findings: There were no significant loading differences between limbs preoperatively. The operated knee showed large reductions in varus angle and adduction moment after surgery (all $p < 0.001$). The non-operated knee showed no increases in varus angle or adduction moment, but did show a small reduction in the adduction moment ($p < 0.001$). Both knees showed reduction in pain after surgery ($p < 0.001$) and the operated Knee Society Score improved after surgery ($p = 0.01$).
Interpretation: Total knee arthroplasty reduces frontal plane loading in the operated knee and does not worsen frontal plane loading in the non-operated knee. Therapy after surgery should focus on retaining the reduction in knee adduction moment in the operated knee and preventing further worsening loading patterns in the non-operated knee.

1. Introduction

Osteoarthritis (OA) of the knee is one of the leadings causes of disability in the adult population. Total knee arthroplasty (TKA) is the most common treatment for end-stage knee OA, with approximately 500,000 procedures performed each year in the United States. The number of procedures is expected to rise to over three million by 2030 due to population growth, increasing longevity and a rise in obesity (Bade et al., 2010; Kurtz et al., 2007; Kurtz et al., 2009).

Kinetic and kinematic gait parameters in the frontal plane, specifically knee varus angle (KVA) and knee adduction moment (KAM), have been shown to have a strong association with disease progression in knee OA (Baliunas et al., 2002; Miyazaki et al., 2002; Sharma et al., 2001). A varus alignment of the femur and tibia compresses the medial compartment of the knee (Andriacchi et al., 2004; Tanamas et al., 2009). KAM results from the medially directed vector of the ground reaction force (GRF) relative to the knee during the stance phase of gait, and results in greater compressive loads on the medial compartment relative to the lateral compartment (Andriacchi, 1994; Andriacchi et al., 1986). Abnormal loading patterns and increases in KAM are often associated with abnormal gait patterns, such as high KVA, and increased muscle co-contraction (Andriacchi, 1994; Andriacchi et al., 1986; Andriacchi et al., 2004; Baliunas et al., 2002; Sharma et al., 2001). Patients with knee OA have a higher KAM relative to the normal population, which is believed to drive the rapid progression of the disease (Baliunas et al., 2002; Miyazaki et al., 2002).

Currently, there is no cure for knee OA, and most cases of end-stage knee OA are referred for TKA (Lewek et al., 2005; NIH Panel, 2004),

* Corresponding author at: Biorobotics and Biomechanics Lab, Faculty of Mechanical Engineering, Technion Israel Institute of Technology, Technion City, Haifa 32000, Israel.
E-mail addresses: eytan.debbi@aya.yale.edu, edebbi@technion.ac.il (E.M. Debbi).

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which is performed to correct bone deformities, realign the knee joint and replace the damaged articular surfaces. The primary goal of TKA is to reduce pain and improve function (Andriacchi et al., 1986). While patients generally report reduced pain in the long term after surgery, there is a question of whether the operation improves knee loading patterns, and specifically whether it reduces the KAM (McClelland et al., 2007). This issue is important, since high KAM postoperatively may lead to functional abnormalities as well as deterioration of the TKA tibial insert. Tibial inserts retrieved from patients undergoing TKA revision after many years show significant medial wear, suggesting that medial compartment compressive forces persist after surgery (Cameron, 1994; Collier et al., 2007; Wasielewski et al., 1994).

Two systematic reviews of the literature examining gait patterns after TKA were unable to find any noteworthy improvements in the KAM parameters after surgery (McClelland et al., 2007; Milner, 2009). Most of these studies, however, examined gait patterns after more than a year postoperatively. Studies examining gait six months and one year after surgery found lower KAM values compared to preoperative levels (Hatfield et al., 2011; Mandeville et al., 2008; Orishimo et al., 2012). These findings suggest that KAM values may improve after surgery, but then regress to higher values with time. This rebound pattern is still unclear, due to the lack of evidence on gait patterns during the early postoperative period after TKA. The early postoperative period is particularly unique because this is when patients are most focused on rehabilitation and when they begin to walk independently and experience walking with a new knee implant. This is the most ideal time to attempt to rehabilitate gait patterns.

Aside from changes in the operated knee, there is evidence of OA progression in the other major joints of the lower limbs after unilateral TKA surgery. The non-operated knee appears to undergo the most deterioration, with almost 40% of individuals undergoing a TKA revision within 10 years of their first TKA (McMahon and Block, 2003; Shakoor et al., 2002). Previous studies have suggested that the cause for worse OA in the non-operated knee postoperatively is due to increased loading patterns on the non-operated limb after surgery (Alnahdi et al., 2011; Milner and O'Bryan, 2008). Researchers believe that this may due to limb asymmetry postoperatively, with the non-operated limb compensating for the operated limb that is still debilitated postoperatively (Milner and O'Bryan, 2008). In light of this, researchers have examined the frontal plane biomechanics of the non-operated knee after surgery (Alnahdi et al., 2011; Milner and O'Bryan, 2008). These studies showed a greater KAM in the non-operated knee in comparison to the operated knee after surgery, which seems to support the argument of greater loading in the non-operated knee postoperatively (Alnahdi et al., 2011; Milner and O'Bryan, 2008). However, this notion not been examined thoroughly. Previous studies did not examine the differences between limbs preoperatively, nor did they examine patients in the early postoperative period.

The purpose of the present study was to examine gait patterns of both the operated and non-operated knees preoperatively and early postoperatively after TKA surgery in order to determine the changes in the frontal plane biomechanics. We hypothesized that there would be a large improvement in gait patterns, and specifically lower KAM, in the operated knee after surgery and that there would be a worsening in gait patterns, and specifically higher KAM, in the non-operated knee after surgery.

2. Methods

The study cohort was made up of 50 patients (28 females, 22 males). Average (SD) age was 65.9 (8.1) years and BMI was 33.5 (4.4). All patients were diagnosed with end-stage knee OA of the medial compartment and were scheduled for TKA surgery. Patients with previous arthroplasties of the lower limb, other orthopedic disorders aside from OA, neurological disorders and a need for assistive devices for walking the distance required for gait analysis were excluded from the study. The study was approved by our Institutional Review Board and all patients gave written informed consent to participate in the study.

Patients were evaluated within two weeks prior to surgery and six weeks postoperatively. Patients underwent a gait analysis, completed a Time-Up-Go test (TUG) (Podsiadlo and Richardson, 1991) and a Six-Minute-Walk test (6 MW) (Guyatt et al., 1985), and completed the self-evaluative Western Ontario and McMaster Universities Osteoarthritis Index questionnaire (WOMAC) (Roos et al., 1999), the Short-Form 36 survey (SF-36) (Kosinski et al., 1999), and a VAS scale for pain. A Knee Society Score (KSS) was completed for each patient as well (Liow et al., 2000).

A three-dimensional gait analysis of each subject was performed using the Vicon motion analysis system (Oxford Metrics Ltd., Oxford, UK) for kinematic data capture. Ground reaction force (GRF) was recorded by two three-dimensional AMTI OR6-7-1000 force plates (Advanced Mechanical Technologies, Inc., Newton MA, USA). The cameras and force plates sampled at 100 Hz and 1000 Hz, respectively. Kinematic and kinetic data were collected simultaneously while the subjects walked over a 10 m walkway. Passive reflective markers were fixed with adhesive tape to anatomical landmarks. A standard marker set was used to define joint centers and axes of rotation (Kadaba et al., 1990). A knee alignment device (Motion Lab Systems Inc., Baton Rouge LA, USA) was utilized to estimate the three-dimensional alignment of the knee flexion axis during a static trial. Knee joint moments in the frontal plane were calculated using inverse dynamic analyses from the kinematic data and force platform measurements using the 'PlugInGait' model (Oxford Metrics Ltd., Oxford, UK). Analyses were performed for both knees. Joint moments were normalized to body mass and height (Moisio et al., 2003). Data were recorded by a computer running the Vicon Nexus and analyzed using the Vicon Polygon program. Six barefoot trials were collected for each subject, per analysis. The kinematic and kinetic parameters of KVA, KVA range of motion, first and second peak KAM, and KAM impulse were evaluated, as well as the spatiotemporal gait outcomes of walking speed, stride length, cadence, step length, single-limb-support, and double-limb-support. As with previous studies on this patient group, gait data were presented to two decimal places since this is the typical accuracy of the surface marker set in this patient population with high BMI (Alnahdi et al., 2011; Hatfield et al., 2011).

All continuous parameters were presented as mean (standard deviation). Comparisons of preoperative and postoperative clinical outcome scores were done by the paired Wilcoxon's rank sign test. Univariate analysis for comparisons of gait parameters in each knee before and after surgery was done by paired Wilcoxon's rank sign test.

Multivariate analysis was done by a two-way mixed effect model ANOVA to compare gait parameters between legs accounting for the operation effect. Each gait parameter was used as the dependent variable for fitting an ANOVA model where the patient was used as a random effect and operated (vs non-operated), preoperative (vs postoperative), and their interaction was used as fixed effect parameters. P value less than 0.05 was considered as statistically significant. All tests were two sided.

3. Results

While no significant changes were seen in WOMAC scores or in most SF-36 scores (Table 1), there was a significant improvement in the SF-36 limitation due to emotional problems scale ($p = 0.0002$). The operated knee showed a significant improvement in the KSS ($p = 0.01$) and a slight, but non-significant improvement in the KSS function score ($p = 0.056$). Both preoperatively and postoperatively, the non-operated limb showed lower pain levels (both $p < 0.0001$; Table 2) than the operated limb. The operated and non-operated knees also showed significant reductions in VAS pain scores after six weeks ($p = 0.0001$, and $p = 0.01$; Table 1).

Table 1
Clinical outcomes and self-reported subjective questionnaires.

	Pre Op	Post Op	Significance
WOMAC (0–10 cm)			
Pain	6.1 (2.3)	5.8 (2.2)	0.565
Stiffness	6.4 (2.2)	6.9 (2.1)	0.210
Function	6.4 (2.3)	5.7 (2.2)	0.186
SF-36 (0–100 score)			
Physical functioning	26.3 (18.9)	31.3 (17.4)	0.313
Limitation due to physical health	14.5 (28.6)	10 (21.4)	0.353
Limitation due to emotional problem	53.3 (48.6)	25.3 (39.0)	<0.001**
Energy/fatigue	43.6 (22.6)	41.1 (19.8)	0.508
Emotional well-being	59.8 (25.1)	54.1 (20.7)	0.071
Social functioning	39.8 (32.6)	39.5 (28.3)	0.902
Pain	18.6 (18.5)	26.0 (18.6)	0.056
General health	52.0 (25.1)	55.2 (19.7)	0.165
Physical Scale	31.0 (16.5)	32.7 (14.3)	0.481
Mental Scale	49.7 (24.3)	43.0 (21.4)	0.088
KSS (0–100 score)			
Knee score	38.2 (9.1)	46.0 (17.7)	0.010*
Knee function score	48.9 (18.3)	44.2 (15.3)	0.056
Functional tests			
TUG (s)	12.4 (3.3)	12 (2.5)	0.398
6 MW (m)	330.7 (102.9)	307.4 (97.5)	0.160
VAS (0–10)			
Operated knee	7.28 (1.86)	5.67 (1.99)	0.0001**
Non-operated knee	3.85 (2.93)	2.99 (2.27)	0.01*

Notes
Values are presented as mean (SD).
WOMAC = Western Ontario and McMaster Universities Osteoarthritis Index questionnaire (3 subclasses); SF-36 = Short-Form 36 survey (7 subclasses and 2 summary scales); KSS = Knee Society Score (2 scores); TUG = Time-up-go test (seconds); 6 MW = six minute walk test (meters); VAS = visual analogue scale.
* Less than 0.05.
** Less than 0.01.

In spatiotemporal parameters, the non-operated limb showed higher single-limb-support before and after surgery ($p = 0.001$; Table 2) than the operated limb preoperatively and postoperatively. Postoperatively there was a slight reduction in walking speed and cadence ($p = 0.007$; $p = 0.003$).

Kinetic and kinematic parameters preoperatively and postoperatively are presented in Table 3. There were no significant differences between limbs preoperatively. Univariate analysis showed that, at six weeks postoperatively, the operated knee peak KVA decreased by 71% ($p = 0.0006$; Fig. 1) and KVA range of motion decreased by 30% ($p = 0.0065$). First and second peak KAM decreased to 74% and 79% of preoperative values, respectively ($p = 0.0005$; $p = 0.005$; Fig. 2). KAM impulse decreased to 73% of its preoperative value ($p = 0.0005$). In the non-operated knee, only the first peak KAM showed a significant change after surgery, decreasing slightly to 92.3% of its preoperative value ($p = 0.0055$; Fig. 2).

Two way analysis of variance (ANOVA) showed that KVA ROM changed in both knees in a similar way before and after the surgery (p value = 0.018). KAM differed between the two knees and between time points (preop vs postop), but surgery had a similar effect on both knees (p values = 0.0028, 0.021, 0.11 for follow-up time, knee and interaction, respectively). Similar observations were found in regards to the KAM impulse.

4. Discussion

The present study examined and compared operated and non-operated knees before and six weeks after unilateral TKA. This is still an early stage of recovery. Nevertheless, significant changes were seen in knee biomechanics. In the operated knee, a very large improvement was found in both the kinematic and kinetic parameters at six weeks postoperatively. The KVA was reduced dramatically from a high varus alignment to a neutral alignment. This is most likely due to the surgical realignment of the joint and is evident also in the improved KSS score postoperatively. The values for the KAM also decreased dramatically after surgery, suggesting a decrease in loading on the medial compartment of the knee. Much of this is likely due to the reduction in KVA, which reduces the moment arm of the KAM by bringing the GRF vector closer to the knee joint (Andriacchi et al., 2004; Sharma et al., 2001). Furthermore, although a reduction in pain often signifies an increase in joint loading (Hurwitz et al., 2000), the reduction in KAM loading here occurs despite a large reduction in pain.

Previous studies by Mandeville et al. and Hatfield et al. also showed a significant reduction in KAM in operated knees at six months and one year after surgery (Hatfield et al., 2011; Mandeville et al., 2008), but their values for KAM were significantly greater than those found in the present study at six weeks after surgery. This suggests that KAM may worsen over time in the operated knee. This finding is supported by a recent study of Orishimo et al. that suggests that KAM in the operated knee may be decreased at six months postoperatively but that KAM levels will slowly regress to higher levels after one year (Orishimo et al., 2012). Orishimo et al. also acknowledged that a decrease in pain and an increase in velocity contribute to the increase in KAM with time, but explained that the change in pain and velocity does not account for all of

Table 2
Pain and spatiotemporal gait parameters for both knees before and after unilateral TKA.

	Operated knee		Non-operated knee		P-value		
	PreOp	PostOp	PreOp	PostOp	FU	Knee	Interaction
VAS for pain	7.28 (1.86)	5.67 (1.99)	3.85 (2.93)	2.99 (2.27)	0.0002**	0.0001**	0.2514
Walking speed (m/s)	0.81 (0.18)	0.73 (0.21)	0.81 (0.19)	0.736 (0.21)	0.0071**	0.9012	0.9546
Stride length (cm)	97.92 (15.23)	93.21 (19.17)	97.95 (16.47)	92.98 (19.02)	0.0632	0.967	0.9611
Cadence (s^{-1})	0.98 (0.13)	0.93 (0.12)	0.99 (0.13)	0.93 (0.12)	0.0034**	0.8333	0.9879
Single limb support (%GC)	34.03 (4.09)	33.30 (3.97)	36.25 (2.90)	36.65 (3.511)	0.7578	0.001**	0.2895
Double limb support (%GC)	29.23 (5.31)	30.05 (6.39)	29.49 (5.81)	29.83 (6.79)	0.5264	0.9889	0.7828
Step length (cm)	47.95 (7.95)	46.62 (9.99)	48.597 (8.00)	45.09 (9.89)	0.0707	0.7108	0.4121
Step length normalized to LL	0.56 (0.09)	0.55 (0.11)	0.57 (0.09)	0.53 (0.11)	0.0591	0.6793	0.476

Notes
Values are presented as mean (SD).
Analysis was performed by two-way ANOVA with interaction term as fixed effect and patient effect as random effect.
VAS = visual analogue scale; GC = gait cycle; LL = leg length; FU = follow-up time (pre vs post operation effect); knee = operated vs non operated knee.
P-value-FU < 0.05 means that there is a statistically significant difference between the values before and after surgery in both knees.
P-value-knee < 0.05 means that there is a statistically significant difference between the operated and non-operated knees regardless of the time effect.
P-value-interaction < 0.05 means that there is a statistically significant difference between the operated and non-operated knees, before and after the surgery (i.e. the surgery effect is different between knees).
** Less than 0.01.

Table 3
Kinematic and kinetic gait parameters and pain scale.

	Operated Knee		Non-operated knee		P-value		
	PreOp	PostOp	PreOp	PostOp	FU	Knee	Interaction
Knee varus angle (°)	4.22 (8.50)	1.20 (4.94)	3.02 (5.87)	3.57 (5.44)	0.1791	0.4964	0.0526
Varus angle ROM (°)	4.26 (2.86)	2.99 (2.01)	3.94 (3.01)	3.59 (1.61)	0.0181*	0.6919	0.1712
KAM Peak 1 (%BW × Ht)	3.11 (1.47)	2.30 (0.92)	3.21 (1.10)	2.97 (1.05)	0.0028**	0.021*	0.1104
KAM Peak 2 (%BW × Ht)	2.57 (1.42)	2.04 (0.99)	2.55 (1.11)	2.64 (0.97)	0.1935	0.0749	0.0698
KAM Impulse (%BW × Ht × GC)	120.14 (58.89)	88.18 (42.55)	128.24 (51.61)	122.75 (48.62)	0.0147*	0.004**	0.0839

Notes
Values are presented as mean (SD).
Analysis was performed by two-way ANOVA with interaction term as fixed effect and patient effect as random effect.
KAM = knee adduction moment; BW = body weight; Ht = height; GC = gait cycle; FU = follow-up time, (pre vs post operation effect); Knee = operated vs non operated knee.
P-value-FU < 0.05 means that there is a statistically significant difference between the values before and after surgery in both knees.
P-value-knee < 0.05 means that there is a statistically significant difference between the operated and non-operated knees regardless of the time effect.
P-value-interaction < 0.05 means that there is a statistically significant difference between the operated and non-operated knees, before and after the surgery (i.e. the surgery effect is different between knees). Here, knee adduction moment peak 1 is different between the knees and before and after surgery (P values knee and P-value-FU < 0.05). However, in both knees the surgery effect is similar—reduction in KAM peak 1 (P-value-interaction = 0.11).
* Less than 0.05.
** Less than 0.01.

the increase in KAM with time (Orishimo et al., 2012). Furthermore, longer-term studies of this patient population have difficulty finding significant improvements in KAM after one year (McClelland et al., 2007; Milner, 2009).

These findings suggest that KAM will decrease significantly in the early postoperative period, but may increase gradually to higher preoperative levels with time. In the long term, an abnormally high KAM, as well as the high compressive forces it creates on the medial compartment, may persist after surgery. This is critical, because this may lead to a breakdown of the prosthesis in the long-term. Long-term studies have shown that many individuals eventually need to return for TKA revision (Sheng et al., 2006). Studies on the tibial inserts retrieved from these patients have shown high medial compartment wear of the polyethylene insert, further suggesting that the initial TKA many not have adequately corrected for the KAM abnormalities of these individuals (Cameron, 1994; Collier et al., 2007; Wasielewski et al., 1994).

While the present study is limited in its ability to determine how KAM levels change with time, it may be necessary to examine methods of training patients to preserve the healthy loading patterns of their operated knees after surgery. The early postoperative period may be an ideal time to implement such biomechanical training programs. Future studies should examine this trend in KAM in more detail and should also attempt to examine whether biomechanical interventions applied early in postoperative recovery can prevent the regression of KAM to higher levels.

As for the non-operated knee, the results of the present study did not agree with the study hypothesis. Instead of higher values for KAM after surgery, peak two of KAM and the KAM impulse did not change, and peak one of KAM even decreased. As in the operated knee, this occurred despite a large reduction in pain. KVA values also did not change and showed high varus alignment after surgery. The only other change in gait in the non-operated knee was a slight decrease in step length after surgery, but this was mostly likely a way to cope with the overall decrease in velocity and cadence rather than a unique change in the non-operated limb's gait. Patients after TKA have been shown to walk slower and with a lower cadence during the early recovery period after surgery (Bade et al., 2010; McClelland et al., 2007).

When comparing limbs, the results show that there were no kinematic or kinetic differences between the knees preoperatively but, postoperatively, the non-operated knee showed significantly worse gait patterns than the operated knee, specifically higher KVA and higher KAM. This limb asymmetry postoperatively, however, was due entirely to the large reduction in KVA and KAM in the operated knee after surgery, rather than to any changes in the non-operated knee. If at all, the decrease in peak one of KAM in the non-operated knee reduced the differences between limbs. The non-operated knee also showed less pain

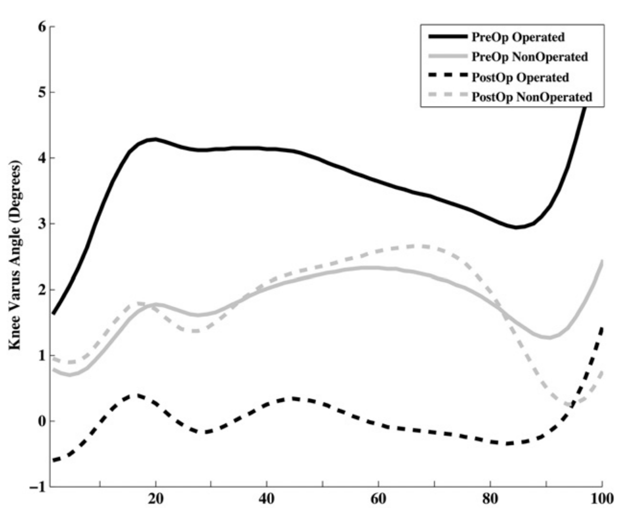

Fig. 1. Ensemble average curves from all subjects showing knee varus angles for the non-operated and operated knees before and after unilateral total knee arthroplasty.

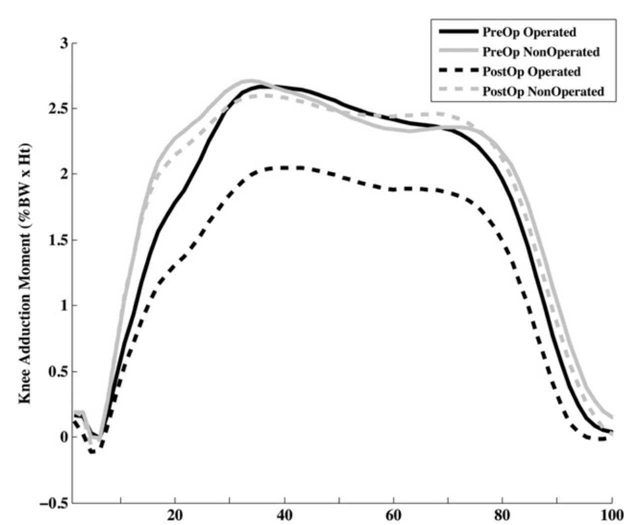

Fig. 2. Ensemble average curves from all subjects showing knee adduction moments for the non-operated and operated knees before and after unilateral total knee arthroplasty.

and higher single-limb support (i.e. less limping) than the operated knee, both preoperatively and postoperatively, which is probably the reason this knee was not chosen for TKA.

Previous studies have also shown that postoperatively the non-operated knee demonstrates a higher KAM than the operated knee, even six month to two years after surgery (Alnahdi et al., 2011; Milner and O'Bryan, 2008). This asymmetric loading was considered as a possible cause for the nonrandom evolution of OA after unilateral TKA and for the high incidence of more joint arthroplasties after unilateral TKA (Alnahdi et al., 2011; Milner and O'Bryan, 2008). These studies, however, did not consider preoperative gait data, and the absence of this data was considered as a significant limitation in previous studies (Alnahdi et al., 2011; Milner and O'Bryan, 2008). The results of the present study suggest that, while limb asymmetry does exist after surgery, and occurs even as early as six weeks postoperatively, the high KAM values in the non-operated limb existed even prior to surgery. Furthermore, at least in the short-term, it seems that the surgery itself may not lead to a direct increase in loading in the non-operated limb as previously thought, but may even slightly decrease loading since peak one of KAM decreases at six weeks.

It is outside the scope of the present study to determine whether loading on the non-operated limb will increase with time after surgery, but our findings suggest that the higher incidence of OA and TKA after surgery is more likely due to the development of OA in these joints preoperatively, rather than postoperatively. In fact, the preoperative KAM values of the non-operated knee were just as high as the operated knee, and KVA values showed no significant differences between limbs. It seems that, during the years building up to surgery, both knees underwent deterioration due to OA. One was chosen for TKA, probably due to higher pain levels, but both were suffering biomechanically. In general, it seems that while the surgery may not have a direct role in increasing loading and promoting OA progression in the non-operated knee, the patients undergoing this type of surgery arrive with a propensity for poor biomechanics in their non-operated knee. Unfortunately, although these high levels of KAM and medial compartment loading may not worsen immediately due to surgery, they still persist after surgery. As is known, these high levels of medial compartment loading are correlated with OA progression and, regardless of surgery, this is the likely reason OA in the non-operated knee worsens with time (Miyazaki et al., 2002).

Previous studies have also discussed the possibility of other catalysts by which surgery increases the progression of knee OA in the non-operated knee. Alnahdi et al. suggested that one mechanism by which surgery can worsen OA progression in the non-operated knee is the shorter step length postoperatively, which leads to an increase in the number of steps per distance that the patient takes in comparison to healthy individuals. In addition, we believe that, as a patient begins to experience less pain in the operated knee, there will be an increase in walking speed and activity. An increase in walking speed and activity can increase KAM values by increasing ground impact and increasing the magnitude of the GRF (Robbins and Maly, 2009; Wang et al., 1990). A long-term study is necessary to examine the validity of this argument.

There are some limitations to the present study. The first limitation is from the early postoperative nature of the results. While this was critical to the goal of the project, the recovery process that the patients are still undergoing influences such an assessment. Specifically, reduction in walking speed produces a less dynamic walking pattern and most likely affects some of the kinematic data we obtained. Secondly, there was a high standard deviation of the results as compared to the mean values since the surface modeling system used is not perfectly accuracy. Therefore, while several of results of the study were statistically significant, the magnitudes of the changes are not highly accurate and should be interpreted more as trends. Another limitation is the absence of long-term follow-up postoperative data on this patient population. While several previous studies have examined the frontal plane kinetic and kinematic gait patterns of patients after TKA, it would have been beneficial to know these results in our specific patient population as well.

These findings of the present study are important to consider in a clinical setting because they support previous research that recommends patients undergoing surgery to be mindful not only of their operated knee, but of their non-operated as well (Zeni and Snyder-Mackler, 2010). After surgery, patients should try to protect their non-operated knee from biomechanical changes. There should be a focus on caring for both their operated and non-operated knees using interventions such as physical therapy, gait training and medication. This is especially important considering that patients undergo a significant amount of physical therapy postoperatively, but most is directed towards improving the operated knee (Zeni and Snyder-Mackler, 2010).

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