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Pre-surgery knee joint loading patterns during walking predict the presence and severity of anterior knee pain after total knee arthroplasty

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Abstract

This study tested if abnormal sagittal knee joint loading patterns after total knee arthroplasty (TKA) were present pre-surgery, and if patterns with higher external knee flexion moments were related to the presence and severity of post-surgery anterior knee pain. Gait analysis and clinical evaluation were performed on 34 patients (41 arthroplasties) both before and 12–18 months after TKA, and on 20 healthy age-matched controls at matched velocities. The majority of knees with abnormal flexor or extensor sagittal knee joint loading patterns post-surgery (18 of 26, 69%) also displayed these patterns pre-surgery. Knee joint loading in the early mid-stance phase of walking prior to surgery was identified by stepwise regression as a significant predictor of the presence ($\exp(\beta) = 2.9$, CI: 1.2–6.8, $p = 0.017$) and severity of post-surgery anterior knee pain ($R^2 = 0.314$, $p = 0.019$). Therefore, the frequency and severity of anterior knee pain after TKA can be partially explained by retained pre-surgery gait patterns that had higher external flexion moments in the early mid-stance phase, which place higher forces on the patellofemoral joint.

Keywords: Total knee arthroplasty; Patellofemoral joint; Gait analysis

Introduction

The pre-surgery detection of those patients at risk of significant anterior knee pain would be desirable for operative planning and early post-surgery management. Recent prospective, randomized trials of total knee arthroplasty (TKA) with patellar resurfacing versus non-resurfacing have failed to find any definitive etiological factors [2,4,26].

Gait patterns have been shown to be predictive of surgical outcome after high tibial osteotomy [17,21] and of component migration after TKA [9,10]. Abnormal knee flexion/extension moment patterns have been identified after TKA [1,5,19,23,24] and also in those about to undergo TKA [9,23]. Even though post-surgical retention of high pre-surgery peak knee flexion moments has been documented [9], the significance of these moment patterns to clinical outcome after TKA has not been determined.

Patients may retain pre-surgery knee flexion/extension moment patterns, and patterns that have high external flexion moments could be expected to exhibit higher patellofemoral joint forces [8,11,15,20]. Post-surgery anterior knee pain after TKA may in part be related to the magnitude of loading at the patellofemoral joint. We hypothesized that higher external knee flexion moments may be related to the retention or development of anterior knee pain after TKA. This prospective study aimed to test the following hypotheses:

(1) abnormal external flexion/extension moment patterns at the knee are present after TKA and are identifiable pre-surgery; and

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(2) higher external flexion moments at the knee may be predictive of the presence or severity of post-surgery anterior knee pain after TKA.

Methods

Thirty-four patients with 41 TKAs and 20 control subjects participated in the study. Patients underwent assessment, which included clinical knee scoring and gait analysis, at two time-points: pre-surgery and 12–18 months post-surgery. Control subjects completed a single gait analysis.

Between March 1999 and 2000 all patients with osteoarthritis undergoing primary TKA from two university affiliated teaching hospitals were evaluated for this study, which was approved by both university and hospital ethics committees. Patients with inflammatory arthritis, prior patella fracture, patellectomy, patellofemoral instability, prior unicondylar knee replacement, or neurological disease were excluded.

A total of 43 patients recruited to the study participated in pre-surgery gait analysis. Nine subjects were unsuitable for post-surgery follow-up, and in total, 34 patients with 41 TKAs (i.e., seven subjects with bilateral TKA) were available for both pre- and post-surgery gait analysis.

Surgery was performed by one of two experienced surgeons or their trainees under supervision using the *Profix* total knee system (Smith and Nephew Richards Inc., Memphis, TN) with cemented components and a medial parapatellar or subvastus approach. TKA was performed on 23 left knees and 18 right knees. Patients for this study were part of a larger prospective, randomized trial in which knees were randomized to TKA with or without patellar resurfacing. Seventeen knees underwent TKA with patellar resurfacing and 24 without, and there was no difference in patellar disease severity between these two groups ($p = 0.168$) assessed using the Outerbridge classification system [16]. Twenty-nine of the 41 (70.7%) knees were in varus alignment pre-surgery, three (7.3%) were in valgus alignment, and nine (12.0%) knees were in neutral (5–10° valgus) alignment.

The knee society clinical rating system [12], knee pain scale [18] and a knee pain diagram were used at each clinical evaluation. Knee pain location was recorded on a diagram of the knee by the patients. Criteria for classification of a knee as having anterior knee pain were: anterior knee pain was indicated on the knee diagram; frequency of pain was scored as at least three out of five for activities assessed by the knee pain scale; and the pain had not been diagnosed as arising from a referred pain source, infection, metabolic, vascular or neurological disease, patellar subluxation, dislocation, or fracture.

Control subjects reported no history of diagnosed lower limb or lower back pathology and had been pain-free in the lower limbs and back over the past two years. There was an equal distribution of males and females in the patient and control group. The patient and control group were comparable in age (69 ± 7 and 67 ± 7 years, respectively) and height (169 ± 8 and 170 ± 6 cm, respectively), but the patient group was significantly heavier (86.9 ± 17.6 and 72.2 ± 10.5 kg, respectively, $p = 0.001$) and had a significantly higher BMI (30.5 ± 5.8 and 24.9 ± 2.9, respectively, $p < 0.001$).

Gait analysis was performed using a VICON 370 motion analysis system (Oxford Metrics, Oxford, UK) with six, 50 Hz cameras. Ground reaction force data were simultaneously obtained using two AMTI force platforms (AMTI, Watertown, MA) at 2000 Hz. Subjects wore tight fitting gym shorts, and passive reflective markers were fixed with adhesive tape to anatomical landmarks identified by an experienced physiotherapist (AS). A standard marker set was used to define joint centers and axes of rotation [6,13]. A knee alignment device was used to estimate the three-dimensional alignment of the knee flexion axis during a static trial. Patients walked at their naturally selected walking speed in comfortable, habitual footwear with a low heel. A minimum of five (5–8) trials were obtained for the affected leg and used in the further analyses. To enable walking speed of the control subjects to be matched to the patient group, control subjects were asked to walk at slow, medium, and fast pace, and the data from the speed closest to the patient group was used for comparison. Gait data were normalized to 51 time-points over stance using VICON Clinical Manager (VCM) Version 1.37. External knee joint moments in the frontal and sagittal plane were calculated from the kinematics data and force platform measures in VCM using standard inverse dynamics [6,13] and anthropometric values from Winter [25]. All moments are reported normalized to body weight.

Peak values of the external knee moment (early mid-stance peak flexion moment and the terminal-stance peak extension moment) were identified using Microsoft Excel (Microsoft, Redmond, CA) from each trial, and the average determined across trials for each person (Fig. 2).

Since analysis of peak values potentially involves loss of information, a principal components analysis (PCA) was used to characterize and classify the entire external flexion/extension moment curve. A PCA model with varimax rotation was developed in Statistical Package for Social Sciences Version 8.0 for Windows (SPSS Inc. 1997, Chicago, IL) using the 30 time-points in the stance phase of the average flexion/extension moment curve of the controls and post-surgery patients. Principal component (PC) scores for each subject were calculated using the regression method [7]. Data from the pre-surgery analysis was applied to the model and scores for each PC generated. K-means cluster analysis of the first two PC scores was used to identify three groups within the post-surgery and control dataset. Each pre-surgery case was then clustered in turn within this model (this allowed a classification of the pre-surgery data based on the post-surgery classification criterion).

A students t-test or the Mann–Whitney U test was used to analyze differences in continuous variables between the pain and no pain groups, and the chi-squared test was used to test differences in proportions. A paired t-test or the Wilcoxon sign rank test was used to analyze pre- to post-surgery changes. When performing independent t-tests, Levene's test for unequal variances was performed and, if significant, the unequal variance independent t-test was used. In addition, non-parametric statistics were used when data were not normally distributed. For these multiple comparisons, a full Bonferroni correction was not used as this method is known to be conservative. Instead, a significance level of a $\alpha = 0.017$ (i.e., $0.05 \div 3$) was used and considered a good compromise between accounting for multiple comparisons with a moderate sample size without increasing the risk of Type II errors. A two factor repeated measures ANOVA was used to analyze pre- to post-surgery changes between groups with and without anterior knee pain, with significance set at $\alpha = 0.05$.

Multiple linear and logistic regression models to predict post-surgery anterior knee pain using gait and other variables were identified by a stepwise backward method with a probability value for entry of $p = 0.05$ and for removal of $p = 0.10$. Residual analysis was performed and confirmed the validity of these models. As with the PC analysis, all statistical analyses were performed using SPSS Version 8.0 for Windows.

Results

Pre- and post-surgery clinical scores

Knee society knee score increased significantly from pre-surgery (38.6 ± 14.9) to post-surgery (83.4 ± 12.0, Wilcoxon sign rank test; $p < 0.001$). The knee society function score also increased significantly from pre-surgery (58.1 ± 11.8) to post-surgery (82.3 ± 15.4, Wilcoxon sign rank test; $p < 0.001$), while the knee pain scale decreased significantly from pre-surgery (55.4 ± 15.2) to post-surgery (16.5 ± 18.5, Wilcoxon sign rank test; $p < 0.001$).

At 12–18 months follow-up, 17 of 41 (41.5%) knees had anterior knee pain, and there were equal proportions of knees with anterior knee pain in the groups with patellar resurfacing (7 of 17, 41.2%) and without patellar resurfacing (10 of 24, 41.7%). Five knees were painful in other areas. Of the 20 knees with anterior knee pain before surgery, nine (45%) had TKA with resurfacing and 11 had TKA without resurfacing (55%). Of the 21 knees without anterior knee pain pre-surgery, six (28.6%) developed anterior knee pain post-surgery. Of the six knees that developed post-surgery anterior knee pain but did not have pre-surgery anterior knee pain, two of these had patellar resurfacing.

Temporal–spatial gait parameters

TKA patients significantly increased their self-selected walking speed from a mean of 0.97 ± 0.16 pre-surgery to 1.05 ± 0.12 m s^{-1} post-surgery ($p < 0.001$, Table 1). All temporal–spatial parameters significantly improved after TKA ($p < 0.001$–0.013, Table 1). The mean walking speed of the control subjects, when matched to post-surgery subjects, was 1.08 ± 0.14 m s^{-1}. Control subjects displayed similar values to post-surgery TKA patients in all temporal–spatial parameters except for significantly greater single limb support ($p = 0.002$), less double limb support ($p = 0.001$) and lower stance phase times ($p = 0.014$) as a proportion of the gait cycle.

Sagittal plane knee joint moment patterns

The four PCs (PC1, PC2, PC3, PC4) that accounted for 93.6% of the variance were retained from PCA (Fig. 1). PC1 describes the peak of the external extensor moment at mid to late stance (terminal stance knee moment, Fig. 2) and accounted for 39.2% of the variance. PC2 describes the peak of the external flexor moment during early mid-stance (early mid-stance flexor moment, Fig. 2), and accounted for 27.7% of the total variance of the data. PC3 describes terminal stance (21.4% of variance, pre-swing knee flexion moment) and PC4 describes the few time-points immediately after heel-strike (5.3%) (initial knee extension moment).

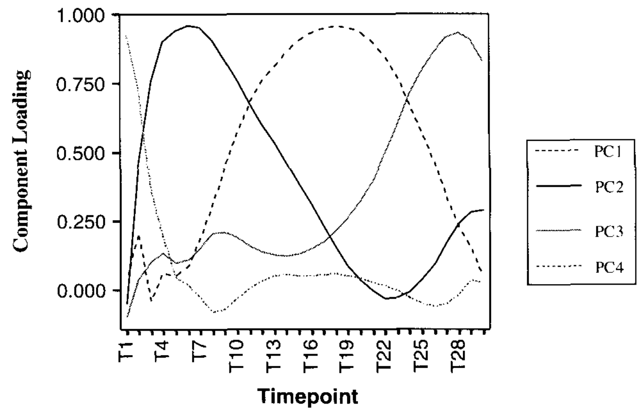

Fig. 1. Component loadings of stance phase time-points on four retained principal components.

Using K-means cluster analysis of PC1 and PC2, three patterns of external knee flexion/extension moment were

Table 1
Differences in temporal–spatial parameters, knee flexion/extension kinematics and kinetics for TKA patients pre- and post-surgery and control subjects (knee flexion is a positive angle and an external knee flexion moment is positive)

	Pre-surgery TKA $N = 41$		Post-surgery TKA $N = 41$			Control[a] $N = 41$		
	Mean	SD	Mean	SD	p-value[b]	Mean	SD	p-value[b]
Temporal–spatial parameters								
Velocity (m s^{-1})	0.97	0.16	1.05	0.12	**<0.001**	1.08	0.14	0.804
Cadence (steps/min)	101.0	12.9	103.0	8.8	**0.013**	101.3	11.8	0.361
Stride length (m)	1.15	0.13	1.22	0.13	**<0.001**	1.26	0.12	0.228
Step length (m)	0.58	0.07	0.63	0.06	**<0.001**	0.64	0.06	0.338
Stride time (s)	1.20	0.15	1.17	0.10	**0.004**	1.19	0.13	0.264
Single limb support (% of cycle)	31.6	2.6	33.8	1.8	**<0.001**	35.3	1.4	**0.002**
Double limb support (% of cycle)	36.4	4.9	32.3	3.1	**<0.001**	29.5	2.8	**0.001**
Total stance phase (% of cycle)	68.1	2.9	66.1	1.9	**<0.001**	64.8	1.4	**0.014**
Knee flexion angle (°)								
Minimum angle at heel-strike	10	6	8	4	0.055	7	3	0.418
Maximum mid-stance angle	16	8	15	5	0.712	18	4	0.025
Total flexion during loading	6	5	7	4	0.029	11	3	**<0.001**
Minimum angle at late stance	8	8	5	6	**0.002**	4	4	0.492
Maximum flexion at swing	54	9	55	5	0.772	57	4	0.039
Knee flexion moment (N m kg^{-1})	$N = 38$		$N = 40$					
Initial extension	−0.31	0.09	−0.43	0.10	**<0.001**	−0.38	0.10	0.066
Early mid-stance flexion	0.18	0.20	0.20	0.16	0.574	0.30	0.09	**0.004**
Terminal stance extension	−0.06	0.24	−0.16	0.18	**0.002**	−0.21	0.12	0.231
Pre-swing flexion	0.26	0.11	0.17	0.05	**<0.001**	0.19	0.05	0.399

[a] Control data reported at velocity matched for post-operative patient data.
[b] Statistically significant values in bold.

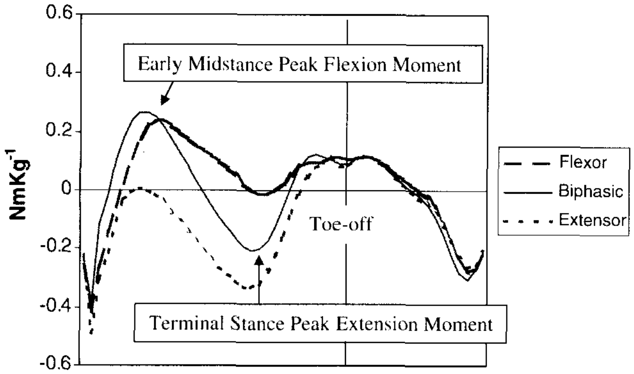

Fig. 2. Average sagittal moment pattern for post-surgery patient and control data.

identified: biphasic, flexor, and extensor (Fig. 2). Post-surgery 12 of 40 (30.3%) knees displayed a biphasic pattern, 16 (40%) knees displayed a flexor pattern, and 12 (30%) displayed an extensor pattern. The kinetics data for one post-surgery knee were excluded due to technical problems. Eight of 17 (47.1%) knees with post-surgery anterior knee pain displayed the biphasic pattern post-surgery, compared to only four of 23 (17.4%) knees without anterior knee pain ($p = 0.043$). Nineteen of the 20 control subjects were classified as biphasic.

Pre-surgery only six of 38 (15.8%) knees displayed a biphasic pattern, while 15 of 38 (39.5%) were classified as a flexor pattern and 17 of 38 (44.7%) as an extensor pattern. The kinetics data for three pre-surgery knees were excluded due to technical problems. In the majority of cases, abnormal post-surgery moment patterns could be identified pre-surgery. Ten of the 15 knees (66.7%) with the abnormal flexor pattern post-surgery demonstrated this pattern pre-surgery, and eight of the 11 knees (72.7%) with an extensor pattern post-surgery demonstrated this pattern pre-surgery.

Knee joint kinematics and kinetics

The peak early mid-stance knee flexion moment did not alter significantly post-surgery ($p = 0.574$). The peak early mid-stance knee flexion moment in the patient group post-surgery was significantly less than that of the control group ($p = 0.004$, Table 1).

The knees that were painful post-surgery had similar pre-surgery and post-surgery peak flexion moment at early mid-stance ($p = 0.643$). However, at pre-surgery, the knees that developed post-surgery anterior knee pain had a mean peak knee flexion moment of 0.27 ± 0.19 $\mathrm{N\,m\,kg^{-1}}$, which was significantly higher than the mean pre-surgery value of 0.11 ± 0.19 $\mathrm{N\,m\,kg^{-1}}$ in the group without anterior knee pain ($p = 0.015$, Table 2). The findings were similar for PC2 that described the loading phase. Pre-surgery the PC2 scores were different between knees with and without post-surgery anterior knee pain ($p = 0.007$, Table 2), while no significant difference was found in post-surgery PC2 ($p = 0.267$).

The pre-surgery peak knee flexion moment and PC2 were comparable in the knees with and without pre-surgery anterior knee pain ($p = 0.967$ and 0.722 respectively). However, the patients with and without post-surgery anterior knee pain displayed different patterns of change in the peak knee flexion/extension moment from pre- to post-surgery ($p = 0.046$, Fig. 3). In the knees without anterior knee pain peak knee flexion moment increased from 0.11 to 0.19 $\mathrm{N\,m\,kg^{-1}}$ ($p = 0.043$), while in the knees with anterior knee pain the peak knee flexion moment decreased from 0.27 to 0.21 $\mathrm{N\,m\,kg^{-1}}$, but this was not significant ($p = 0.337$).

A significant interaction was found between the change in peak terminal stance knee extension moment and the presence of post-surgery anterior knee pain ($p = 0.014$). Knees with post-surgery anterior knee pain significantly decreased the peak extension moment pre- to post-surgery (0.01 to −0.18 $\mathrm{N\,m\,kg^{-1}}$, $p = 0.002$),

Table 2
Differences in knee flexion/extension kinematics and kinetics for knees with and without post-operative AKP (knee flexion is a positive angle and an external knee flexion moment is positive)

	Pre-surgery					Post-surgery				
	AKP		No AKP		p-value[a]	AKP		No AKP		p-value[a]
	Mean	SD	Mean	SD		Mean	SD	Mean	SD	
Knee flexion angle (°)										
Minimum angle at heel-strike	12.7	6.3	8.0	5.2	**0.012**	8.9	6.0	7.6	3.0	0.375
Maximum mid-stance angle	18.3	6.8	14.0	7.9	0.078	14.9	6.0	15.7	4.0	0.593
Total flexion during loading	5.6	2.9	6.0	5.6	0.762	6.0	3.1	8.1	3.9	0.073
Minimum angle at late stance	9.2	8.0	7.1	8.1	0.416	3.8	6.2	5.3	5.7	0.420
Knee flexion moment ($\mathrm{N\,m\,kg^{-1}}$)										
Early mid-stance flexion	0.27	0.19	0.11	0.19	**0.015**	0.21	0.20	0.19	0.13	0.643
Terminal stance extension	0.01	0.24	−0.11	0.22	0.100	−0.18	0.18	−0.14	0.19	0.512
PC2	−0.25	0.97	−1.13	0.94	**0.007**	−0.10	1.33	−0.47	0.72	0.267

[a] Statistically significant values in bold.

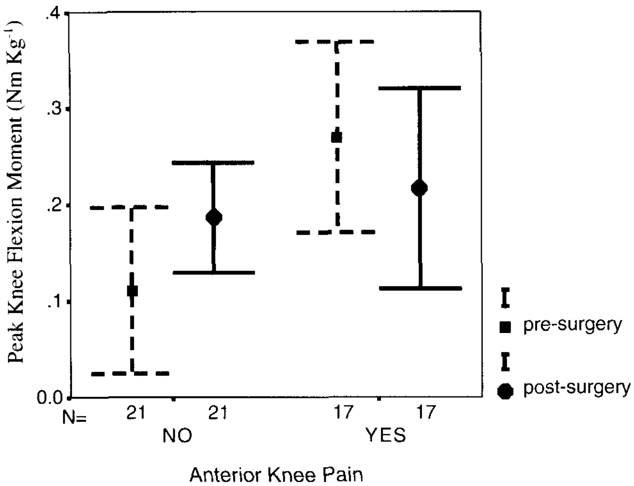

Fig. 3. Pre- to post-surgery change in early mid-stance peak flexion moment of knees with and without anterior knee pain (mean and 95% confidence intervals).

while those without anterior knee pain did not (−0.11 to −0.14 N m kg^{-1}, $p = 0.281$).

No significant differences were found between those knees with and without post-surgery anterior knee pain in terms of post-surgery knee flexion kinematics (Table 2). However, patients with post-surgery anterior knee pain had a significantly more flexed knee at heel-strike pre-surgery ($p = 0.012$).

Predictors of outcome

Of the gait parameters, the single best predictor for the presence of post-surgery anterior knee pain from univariate logistic regression models was the pre-surgery value of PC2 ($p = 0.017$), and this was chosen over peak external flexion moment ($p = 0.026$) for consideration in the final model. Controlling for walking velocity had no effect on the relationship between pre-surgery PC2 or peak knee flexion moment and post-surgery anterior knee pain. The next best predictor was the knee flexion angle at heel-strike ($p = 0.021$). Of the other variables considered as possible predictors of post-surgery anterior knee pain, the presence of other lower limb/lower back symptoms was the best single predictor ($p = 0.033$). The next best single predictors were gender, with females being more likely to develop anterior knee pain ($p = 0.051$), then next the presence of pre-surgery anterior knee pain ($p = 0.090$). TKA without patellar resurfacing and patellar disease severity were not associated with post-surgery anterior knee pain ($p = 0.975$ and 0.143 respectively). Neither weight nor BMI were associated with post-surgery anterior knee pain ($p = 0.792$ and 0.595 respectively). The gait variables and presence of other lower limb/lower back symptoms, gender and pre-surgery anterior knee pain were included in a stepwise logistic regression model (Backward Likelihood Ratio method). PC2 was a significant predictor of post-surgery anterior knee pain (Wald statistic = 4.63, $p = 0.031$, $\exp(\beta) = 2.7$, CI: 1.1–6.4) after retaining gender (Wald statistic = 3.69, $p = 0.055$, $\exp(\beta) = 5.1$, CI: 1.0–26.6) and pre-surgery anterior knee pain (Wald statistic = 3.65, $p = 0.056$, $\exp(\beta) = 5.1$, CI: 1.0–26.9) in the backwards model. The presence of other lower limb/lower back symptoms was not significant in the model ($p = 0.455$) and was significantly associated with the pre-surgery loading phase PC ($p = 0.008$).

Using data from those knees with post-surgery anterior knee pain, a linear regression model showed that pre-surgery PC2 was a significant predictor of the knee pain scale ($B = 11.4$, CI: 3.0–19.8, $t = 2.891$, $p = 0.011$, $R^2 = 0.358$). Similarly, a linear regression model revealed pre-surgery loading phase PC as a significant predictor of the Knee Society Knee Score ($B = -6.8$, CI: −12.4 to −1.3, $t = 2.623$, $p = 0.019$, $R^2 = 0.314$) in those knees with post-surgery anterior knee pain.

Discussion

In this study, a similar pre-surgery pattern was observed in 18 of the 26 (69.2%) knees exhibiting an abnormal flexor or extensor moment pattern post-surgery, despite the highly significant improvements in clinical scores. This study confirms the hypothesis arising from previous studies [1,9,19,24] that the retention of pre-surgery gait patterns accounts for the abnormal sagittal moment patterns observed post-surgery.

This study found that a high pre-surgery external knee flexion moment during the weight acceptance phase of walking is a predictor of post-surgery anterior knee pain in the 12–18 months after TKA. Furthermore, the pre-surgery loading phase PC was a significant predictor of the knee pain scale and knee society knee score in those knees with post-surgery anterior knee pain. Since the external flexion moments need to be supported by the extension moments generated by the quadriceps, the frequency and severity of anterior knee pain can be partially explained by gait patterns which place greater forces upon the patellofemoral joint in the early mid-stance by increased quadriceps activity in greater degrees of knee flexion.

No difference was found in the peak knee flexion moment or the PC describing the loading phase at post-surgery gait analysis between those knees with and without anterior knee pain. However, a significant interaction was found between the change in peak knee flexion moment and the presence or absence of post-surgery anterior knee pain. The patients without anterior knee pain increased their peak knee flexion moment from pre- to post-surgery, which suggests that by the 12–18 month follow-up patients without painful knees might have already been modifying patellofemoral joint loads.

A significantly greater proportion of knees displaying a biphasic pattern post-surgery had anterior knee pain compared to the other loading patterns. In addition, a significant interaction was found between the decrease in the terminal extension moment and the presence of anterior knee pain. Those people with knees that developed a more biphasic pattern, by retaining a high early midstance knee flexion moment and developing a higher terminal extension moment, appear to be at risk of anterior knee pain.

Although gait parameters describing the weight acceptance phase knee moments were significantly associated with the presence and severity of post-surgery anterior knee pain, the strength of the relationships in the logistic regression (model chi-square/−2 Log Likelihood = 0.294) and the linear regression models ($R^2 = 0.358$ for knee pain scale) were low. Therefore, other factors are involved in the etiology of anterior knee pain after TKA. Assessing the person's exposure to knee loading by monitoring patient walking activity might strengthen the relationship between joint loading and post-surgery outcomes. Variations in patellar tracking will further affect patellofemoral contact pressures, which may occur due to component malrotation [3] or possibly individual differences in the active and/or passive stabilization of the patella in the trochlear groove. However, factors traditionally suspected to contribute to anterior knee pain, such as a non-resurfaced patella and patella disease severity, were not associated with post-surgery anterior knee pain in this study, which supports the recent conclusions from other larger clinical studies [2,22,26].

As there was no association between pre-surgery anterior knee pain and the pre-surgery peak knee flexion moment or PC2, end-stage osteoarthritis of the tibiofemoral joint rather than pathology in the patellofemoral joint could have been driving the abnormal gait patterns observed pre-surgery. The reasons why these gait patterns did not result in anterior knee pain pre-surgery but did post-surgery are the possible low levels of physical activity of the patients pre-surgery due to pain, and the alterations in patellofemoral tracking and contact pressures occurring due to TKA.

The presence of other lower limb or back symptoms was a significant predictor of post-surgery anterior knee pain and was correlated with the pre-surgery loading phase PC. Those patients with other joint involvement might place increased demands on their involved knee, due to other influences driving their gait pattern.

It was difficult to match for weight between groups, as the osteoarthritic patients were heavier than the healthy aged sample, and therefore gait data were normalized to body weight. Since all subjects were of similar height, normalization to weight × height was not performed. Nevertheless, to check if the method of normalization may have affected the results, the association of the pre-surgery peak knee flexion moment with post-surgery anterior knee pain was examined and found to be similar when this parameter was normalized to weight × height ($R = 0.419$, $p = 0.007$) or to height alone ($R = 0.294$, $p = 0.025$). Therefore, irrespective of normalization the same results and conclusions are apparent. Knee adduction moment but not body weight has been identified as a significant predictor of the progression of knee tibial-femoral osteoarthritis [14]. Similarly in the current study neither body weight nor BMI, but knee flexion moment was predictive of the presence and severity of post-surgery anterior knee pain.

In summary, to our knowledge this is the first prospective study to relate pre-surgery knee joint loading to the presence and severity of anterior knee pain after TKA. The study also confirms that abnormal post-surgery gait patterns can be explained in part by the presence of these patterns pre-surgery. As such, this study is further evidence for the value of gait analysis as a tool in the design and evaluation of knee arthroplasty.

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