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Pre-operative Muscle Activation Patterns during Walking are Associated with TKA Tibial Implant Migration

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Abstract

Background: Gait biomechanical variables have been associated with total knee arthroplasty tibial implant migration measured with Radiostereometric Analysis (RSA), but no studies have examined the role of the periarticular musculature, which is responsible for a high proportion of the forces on the joint. The purpose of this study was to measure the pre-operative electromyography (EMG) patterns of the periarticular knee muscles during gait and determine the association of these patterns with the post-operative tibial implant migration measured with RSA. We hypothesized that pre-operative muscle activation patterns (specifically the activation patterns of the vastus and gastrocnemius muscle groups) measured with EMG are associated with migration at 6 months.

Methods: Electromyographic data were collected from 6 periarticular knee joint muscles on 37 patients pre-operatively during gait. Radiostereometric exams were performed immediately and at 6 months post-operatively. Relationships between the pre-operative patterns of muscle activation and micromotion of the implant were examined using Pearson correlation and regression models.

Findings: Statistically significant correlations were found between the pattern of the quadriceps and gastrocnemius muscle activations during gait and implant translation in the posterior direction. Regression analysis illustrated that a substantial proportion of the variance in the post-operative tibial component posterior translation (R2 = 0.49) was explained by a prolonged activation of the vastus medialis muscle and higher activation of the lateral gastrocnemius muscle during early stance.

Interpretation: The variability in migration explained by the muscle activation patterns supports the hypothesis that pre-operative functional characteristics can contribute to predicting implant migration following total knee arthroplasty surgery.

Keywords: Total knee arthroplasty; Electromyography; Radiostereometric Analysis; Gait analysis

Introduction

Total knee arthroplasty (TKA) is considered an effective treatment for severe knee arthritis based on self-reported measures of pain and function (Robertsson and Dunbar, 2001). However, the longevity of implants is variable and the most common cause of failure of TKA is aseptic loosening (CIHI, 2006). One of the proposed causative factors of aseptic loosening is cyclic micromotion of the implant relative to the underlying bone (Aspenberg and Van der Vis, 1998 and Ryd et al., 1995). Over time, this micromotion results in migration of the implant as the surrounding bone and soft tissue negatively respond to the adverse loading. TKA evaluation tools commonly employ subjective outcome measures, such as patient satisfaction and pain, which do not have the sensitivity to detect early changes of detrimental loosening. Although previous work has shown that there are changes in biomechanics and neuromuscular patterns during gait from the pre to post-operative state (Hatfield et al., 2011 and Hubley-Kozey et al., 2010), objective measures of pre and post-operative joint and muscle function are not widely employed. Since not all post-operative patterns returned to typical asymptomatic patterns even after one-year (Hatfield et al., 2011 and Hubley-Kozey et al., 2010), the patient's pre-operative dynamic function may be predictive of TKA outcome. Given the increasing number of younger and more functionally demanding individuals receiving TKA (Jain et al., 2005), there is a need to understand the relationship between pre and post-operative function and implant longevity. Early post-operative implant migration measured with Radiostereometric Analysis (RSA) has predictive capabilities for early knee implant failure due to aseptic loosening (Ryd et al., 1995). Thus RSA is used as a viable screening tool for new implant designs and surgical techniques. While implant design and surgical variation may contribute to implant migration, other patient-specific functional characteristics, in particular pre-operative biomechanical variables, have been related to implant migration. High pre-operative flexion moments during gait have been shown to predispose patients after TKA to exhibit continuous implant migration leading to early aseptic loosening (Hilding et al., 1996). Frontal plane loading patterns during pre-operative gait have also been associated with migration. High pre-operative BMI and high knee adduction moments during gait explained 45% of the variability in post-operative migration of the tibial implant (Astephen Wilson et al., 2010). These findings support the contribution of functional joint loading to implant migration, but there are limitations associating net joint moments derived from inverse dynamics (Braune and Fischer, 1987) directly to joint loading. These techniques often underestimate contact loads because they do not incorporate subject-specific force contributions from the musculature surrounding the joint.

Theoretical modeling of knee joint loading including muscle force contributions (Shelburne et al., 2004a, Shelburne et al., 2004b, Shelburne et al., 2005, Shelburne et al., 2006 and Taylor et al., 2004) has estimated that muscle forces during gait can contribute up to 60% of the total joint load (Taylor et al., 2004). Shelburne et al. (2004a)showed that the force in the anterior cruciate ligament (posterior shear) during gait was generated primarily by the force of the vastus muscle group during early stance phase and by the gastrocnemius during late stance. These results highlight the need to understand the muscular contribution to knee joint loading.

A number of studies have shown that the electromyographic (EMG) patterns of the periarticular muscles of the knee joint during walking differ in those with knee osteoarthritis (OA) compared to asymptomatic controls (Childs et al., 2004, Hubley-Kozey et al., 2006 and Hubley-Kozey et al., 2009), and alterations also related to OA severity. Higher co-activation of the knee musculature in early stance has been demonstrated in those with medial joint instability (Lewek et al., 2004a) and in those with severe knee OA (Hubley-Kozey et al., 2009). Individuals with severe knee OA just prior to TKA surgery also have increased lateral muscle site activity, reduced medial muscle site activity, and prolonged activity and phase shifts among muscles (Hubley-Kozey et al., 2009), all of which have the potential to alter the joint loading environment. General improvement toward more asymptomatic EMG patterns at one-year post-TKA has been shown (Hubley-Kozey et al., 2010), but features remain altered. Therefore we assumed that pre-operative patterns that persist in the early post-operative period would affect the integrity of the mechanical environment of the joint. There has not yet been any investigation into the effect of pre-operative neuromuscular patterns on post-operative implant migration. The purpose of this study was to measure the EMG patterns of the periarticular knee muscles during gait in individuals undergoing TKA surgery and determine the association of these patterns with the post-operative migration of the tibial implant as measured with RSA. We hypothesized that pre-operative muscle activation patterns (specifically the activation patterns of the vastus muscle group and the gastrocnemius muscle group) measured with EMG are associated with migration of the total knee arthroplasty tibial implant measured with RSA.

Methods

Patients

This study involved a subset of patients who took part in a larger randomized controlled trial (n = 70) (Dunbar et al., 2009). Of these 70 patients, 40 patients (20 Nexgen LPS Trabecular Metal tibial monoblock component (Zimmer, Warsaw, IN, USA), 20 NexGen Option Stemmed tibial component (Zimmer, Warsaw, IN, USA)) were willing to take part in the gait and EMG portion of the study and underwent three-dimensional gait and EMG analysis within the week prior to surgery.

Surgery was performed by 4 experienced knee surgeons using a standardized protocol: posterior cruciate ligament resection, patellar resurfacing with a cemented inlay component, cementing of the femoral component and RSA marker placement of 0.8 mm tantalum beads. Four to 6 beads were placed around the periphery of the polyethylene component and 8 to 20 beads were inserted into the proximal tibia. The standardized post-operative protocol included continuous passive motion as tolerated and patients were allowed immediate full weight bearing.

EMG Methodology

Patients were included in the gait portion of the study if they were able to walk 6 m without a walking aid, and were excluded if they had any neuromuscular disease, cardiovascular disorders or lower limb surgeries (excepting exploratory arthroscopy, knee lavage, or partial menisectomy at least 1 year prior to entry into the study). Informed consent was obtained from all patients.
Gait analysis consisted of collecting three dimensional motion Optotrak™ 3020 (Northern Digital Inc., Waterloo, Canada), ground reaction force (AMTI Force platforms, Advanced Mechanical Technology Inc., Watertown, MA) and surface EMG (Bortec Biomedical Ltd., Calgary, Canada) data from 6 lower limb muscles on the affected limb. Only the EMG methodology is presented in this study.

After standard skin preparation with an alcohol/water solution, silver/silver chloride surface electrodes (0.79 mm^2 contact area, Bortec Inc., Calgary, Alberta, Canada) were placed in a bipolar configuration (20 mm center-to-center) in line with the muscle fibers of vastus lateralis (VL), vastus medialis (VM), lateral (LH) and medial (MH) hamstrings, and the medial (MG) and lateral (LG) gastrocnemius using a standardized procedure (Hubley-Kozey et al., 2006).
Placement was based on palpation of anatomical landmarks, and verified by assessing EMG

signals using isolated movements to activate different muscle groups (Hubley-Kozey et al., 2006 and Kendall et al., 1993). Raw EMG signals were preamplified 500 × then further amplified as required (CMRR = 115 dB (at 60 Hz), input impedance ~ 10 Gohm) using an eight channel surface EMG system (AMT-8 EMG, Bortec Inc., Calgary, Alberta, Canada) (Hubley-Kozey et al., 2006). Analog ground reaction force and EMG data were digitized at 1000 Hz using the Optotrak™ 3020 motion capture system analog data capture feature. Baseline recordings were made in relaxed supine lying.

Patients walked at their self-selected velocity along a 6-meter walkway. Motion and force data were used to identify one gait cycle (Landry et al., 2007). Following the gait trials, patients completed maximum voluntary isometric contraction exercises to elicit maximum activation for EMG amplitude normalization. Exercises were standardized (Hubley-Kozey et al., 2006) consisting of i) knee extension with the knee at 45° and patient seated, ii) combined hip flexion and knee extension as above in i), iii) knee extension with the knee at 15° and patient supine, iv) knee flexion with the knee at 55° and patient seated, v) knee flexion with the knee at 15° and participant supine, vi) knee flexion with the knee at 55° and patient prone, vii) plantar flexion with patient seated, the knee as close as possible to full extension and the ankle in neutral, and viii) standing plantar flexion. Each normalization exercise was held for 3 s and repeated once after a 90 s rest. Patients were given an opportunity to practice, and visual and verbal feedback was provided as this has been shown to improve maximal activation amplitudes for those with knee OA (Lewek et al., 2004b). Raw EMG data were corrected for bias, converted to microvolts, full wave rectified and low pass filtered at 6 Hz using a Butterworth filter (4th order) (Hubley-Kozey et al., 2006). The highest EMG amplitudes from 0.1 s moving average windows from the normalization exercises for each muscle, regardless of the exercise it occurred in, were used to amplitude-normalize EMG data from gait trials (Hubley-Kozey et al., 2006). EMG waveforms were time-normalized to 100% of one gait cycle. Five walking trials for each muscle were averaged for each patient to create ensemble average profiles (Winter and Yack, 1987).

Radiostereometric Analysis (RSA)

Within 4 days of surgery and at 6 months postoperatively, the knee of every patient was placed within a biplanar calibration box (Tilly Medical Products AB, Lund, Sweden), and simultaneous digital stereo X-rays were taken with the X-ray tubes oriented orthogonally. RSA analysis was performed with MB-RSA (MEDIS, Leiden, Netherlands). RSA results at 6 months were reported as maximum total point motion (MTPM) and 6° of freedom translations and rotations. MTPM is the three-dimensional vector magnitude of the marker that has exhibited the most migration between exams (Valstar et al., 2005). RSA calculations gave the relative motion of the rigid body defined by the beads in the prostheses with respect to the rigid body defined by the beads in the tibia. Rigid body rotations of the prosthesis were calculated about a coordinate system centered at the volumetric center of the implant with axes aligned to the anatomical directions of a right hand coordinate system described previously by Valstar et al. (2005).

MTPM for each implant was calculated using six fictive markers, a set of virtual points defined in the rigid body of the implant. Fictive markers are used to standardize the MTPM calculations in cases where the prosthesis bead placement is not uniform across all subjects (Nilsson et al., 1999). Rotations and translations of the rigid body defined by the tantalum beads in the polyethylene about the volumetric centroid of the prosthesis were then applied to the fictive points to calculate the MTPM for each follow-up. The limit of rigid body fitting was a maximum of 0.2 mm for both the tibial and prosthesis segments (Valstar et al., 2005). In cases where the rigid body errors exceeded the threshold due to a loose bead, that bead was removed from the analysis. The condition number did not exceed 40 at any follow-up examination, indicating adequate distribution of beads in the rigid body (Valstar et al., 2005). The accuracy of the RSA system was assessed with a phantom study protocol. Accuracy was represented as half of the average width of the 95% prediction interval in a regression analysis of true and measured translations of a phantom. Precision was evaluated with double examination analysis, and represented as the 95% confidence interval of the measurements from 11 clinical double examinations performed at the postoperative follow-up.

Statistical Methods

EMG waveforms were used in a principal component analysis (PCA) previously described in detail (Hubley-Kozey et al., 2006), to extract the major patterns of activity of each muscle throughout the gait cycle. These patterns, called principal components (PCs) captured key amplitude and shape features of the EMG waveform data and were determined for each muscle group (gastrocnemius, hamstrings, quadriceps) separately (Hubley-Kozey et al., 2006). A set of *PC scores* for each PC and muscle were calculated that represented weighting coefficients indicating how much a PC contributed to the original EMG pattern for that individual. The higher an individual's PC score for a given pattern, the more dominant that pattern was in the subject's original EMG waveform. The number of PCs retained and examined for each muscle group was based on two criteria: i) number needed to explain 90% of variance (salient characteristics) in the waveforms, and ii) PCs that explained less than 1% of this variance were excluded (Hubley-Kozey et al., 2006). PCs were interpreted by examining the pattern over the gait cycle, as well as by comparing the waveforms of subjects with the top 5 and bottom five PC scores (Deluzio and Astephen, 2007). Custom software (Matlab™ version 7.0.4, The MathWorks, Natick, MA, USA) was used to process all data.

All three muscle groups (gastrocnemius, hamstring and vastus) contribute significantly to the anterior–posterior shear forces at the knee (Shelburne et al., 2004b) and to the ab/aduction moment at the knee (Shelburne et al., 2006). High anterior/posterior shear forces would be associated with anterior/posterior migration of the tibial implant, and high ab/adduction moments would more likely be associated with the medial/lateral tilt of the implant and MTPM. Therefore, Pearson correlation coefficients were used to examine the relationships between the PC scores for the six knee muscles and the anterior–posterior migration, the medial–lateral tilt (rotation), and log MTPM of the tibial components at 6 months. Due to the non-parametric distribution of the MTPM data, a log transformation was applied to the MTPM data for statistical modeling. A level of significance of $P = 0.01$ was used. A regression model was also developed for RSA migration. To reduce the number of models developed and number of terms entered in the regression model, only RSA outcomes and EMG variables with significant Pearson correlation coefficients ($P < 0.01$) were modeled. Implant type, speed and body mass index were entered into the model to account for potentially important covariates and were included in the final model if statistically significant. The maximum number of independent variables included in the regression analysis was not allowed to exceed four so as to maintain a ratio of ten measurements per predictor. Multiple regression model diagnostics included residual analyses, multicollinearity and influence analyses.

3. Results

The accuracy of the RSA system was 0.02 mm, 0.02 mm, 0.06 mm and 0.03 mm for the x, y, z translational directions and MTPM respectively. The precision of the RSA system was 0.07 mm, 0.07 mm, 0.11 mm, 0.16°, 0.15°, 0.12° and 0.10 mm for x, y, z translations, x, y, z rotations and maximum total point motion respectively.

Three patients were lost to follow-up at 6 months postoperatively, leaving 37 patients. One patient was lost due to mortality, and 2 due to missed RSA follow-up exams.

3.1. Correlations and model

Pre-operative subject demographics are shown in Table 1. The RSA results are shown in Table 2. The longitudinal RSA results of these patients out to 2 years have been reported previously (Dunbar et al., 2009), and none of the patients included in this analysis were considered to be continuously migrating (12–24 month migration all < 0.2 mm), (Ryd et al., 1995).

Table 1.

Preoperative subject demographics.

	Mean	Range
Age (years)	64.4	42–82
BMI (kg/m^2)	33.0	22.0–42.6
Gait speed (m/s)	0.93	0.38–1.39

Table 2.

RSA results.

	6 months
MTPM (mm) median (range)	0.62 (0.06–2.53)
Tx (mm) mean (range)	0.00 (− 0.22–0.46)

	6 months
Ty (mm) mean (range)	− 0.18 (− 1.00–0.16)
Tz (mm) mean (range)	0.04 (− 0.64–0.85)
Rx (°) mean (range)	− 0.13 (− 1.34–1.19)
Ry (°) mean (range)	− 0.04 (− 1.75–1.36)
Rz (°) mean (range)	0.14 (− 0.58–1.38)

MTPM, maximum total point motion; Tx medial/lateral translation (medial positive); Ty, superior/inferior translation (superior positive); Tz, anterior/lateral migration (anterior positive); Rx, anterior/posterior tilt (anterior tilt positive); Ry, internal/external rotation (internal positive); Rz, medial/lateral tilt (lateral positive).

All 40 patients took part in the initial pre-operative EMG exam. Four PCs explained 90% of the variability for each muscle group. The first PC captured the overall magnitude of muscle activation (as a percentage of maximum voluntary isometric contraction), whereas subsequent PCs captured differences in temporal characteristics throughout the gait cycle, similar to previously reported PCs of EMG data (Hubley-Kozey et al., 2010). A significant, positive correlation was found between PC3 of the lateral gastrocnemius muscle and posterior migration of the tibial component ($r^2 = 0.17$; $P = 0.01$, Fig. 1). PC3 of the lateral gastrocnemius represented prolonged activation of the muscle throughout the stance phase of gait, in particular elevated activity during early to mid stance (Fig. 2). A significant positive correlation was found between the vastus medialis PC3 and posterior migration of the tibial component ($r^2 = 0.34$; $P < 0.001$, Fig. 3). PC3 of the vastus medialis also represented prolonged activation of the muscle throughout stance, in particular during mid to late stance (Fig. 4). More posterior migration of the tibial component was therefore associated with more prolonged activation of the lateral gastrocnemius and the vastus medialis muscles in mid to late stance. No correlations were statistically significant for the hamstring PCs.

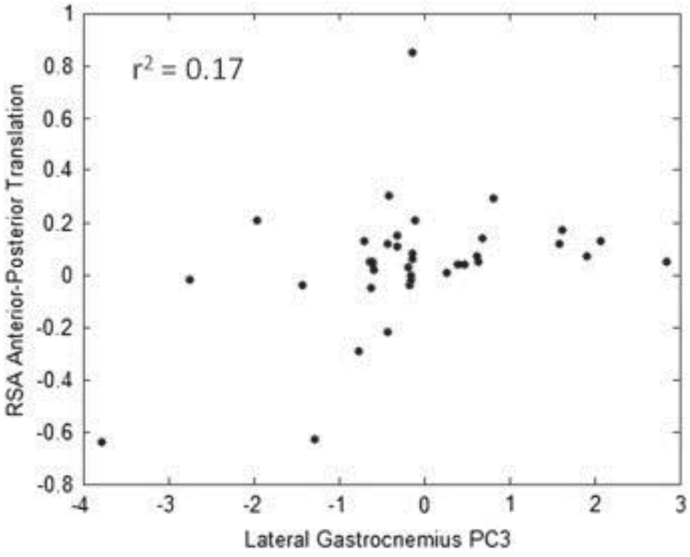

Fig. 1.

Scatterplot of lateral gastrocnemius PC3 versus posterior–anterior translation of the tibial component. $r^2 = 0.17$. (Posterior translation is positive).

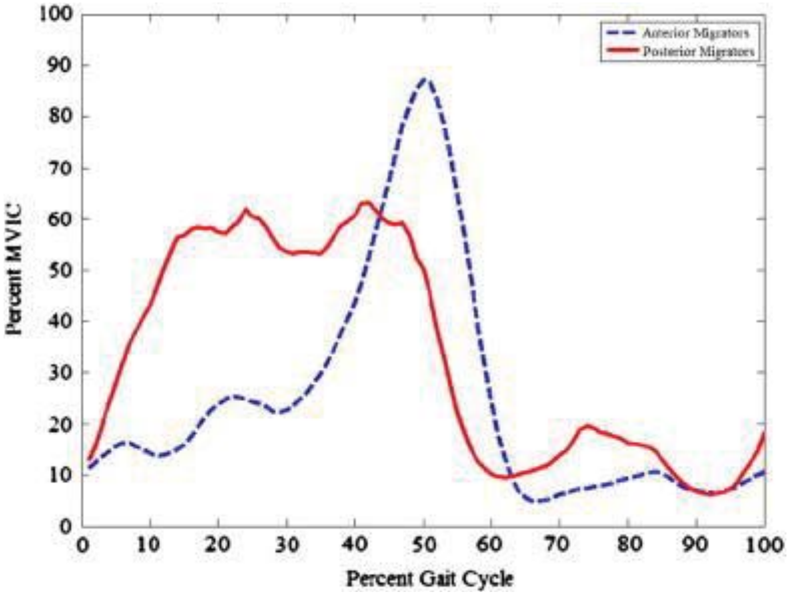

Fig. 2.

Mean lateral gastrocnemius activation profiles as a percent MVIC (maximum voluntary isometric contraction) for the waveforms with the top five PC3 scores (red) associated with posterior migration and the bottom five PC3 scores (blue hashed) associated with anterior migration.

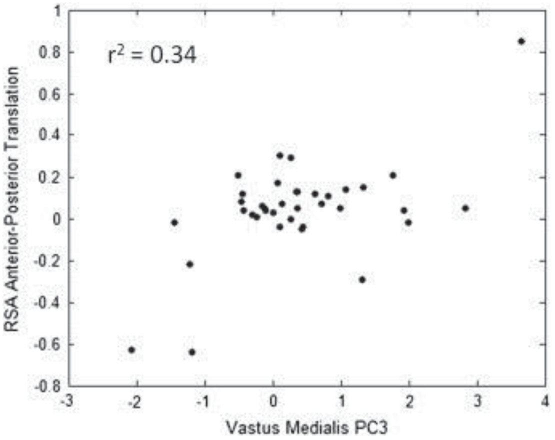

Fig. 3.

Scatterplot of vastus medialis PC3 versus posterior–anterior translation of the tibial component. $r^2 = 0.34$. (Posterior translation is positive).

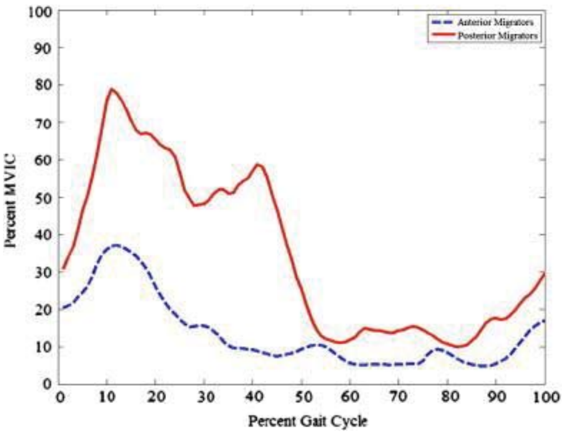

Fig. 4.

Mean vastus medialis activation profiles as a percent MVIC (maximum voluntary isometric contraction) for the waveforms with the top five PC3 scores (red) associated with posterior migration and the bottom five PC3 scores (blue hashed) associated with anterior migration.

A linear regression model was developed for the anterior–posterior migration of the tibial component. The two EMG variables that were most strongly correlated with posterior migration (PC3 of lateral gastrocnemius and PC3 of vastus medialis), implant type, body mass index and speed were entered as possible terms to the model. Body mass index, speed and implant type were not significant terms in the model and were therefore removed from the final model. With the two EMG factors in the model, approximately 50% ($R^2 = 0.49$) of the variability in the posterior migration of the tibial component was explained ($P < 0.0001$). The model showed that higher posterior migration was associated with prolonged muscle activations during stance ($r^2 = 0.34$ for vastus medialis, and $r^2 = 0.17$ for the lateral gastrocnemius). The form of the linear regression equation was:

AP_migration=0.01+0.12×VM_PC3+0.07×LG_PC3.

Discussion

Gait is the most common activity of daily life, and dynamic loading occurs with higher frequency during gait than any other daily activity (Sharma et al., 1998). It is estimated that the average adult takes between 0.5 and 3 million steps per year (Wallbridge and Dowson, 1982). Loading through the knee joint during walking has been estimated at greater than 3 times body weight (Shelburne et al., 2006 and Taylor et al., 2004). The periarticular muscles are responsible for a large portion of the loading (Shelburne et al., 2005).

Successful total knee arthroplasty relies on a strong mechanical interface between the patient's tissues and either a cement mantle or a porous coating around the implant to maintain fixation. All mechanical interfaces are subject to failure under repetitive loading that exceeds the fatigue failure strength of the interface. Heinlein et al. (2009) showed that there were large differences in the magnitude of anterior–posterior shear forces between two subjects with instrumented total knee replacements. In the present study, a large portion of the variability (49%) in anterior–posterior tibial implant migration (which is associated with anterior–posterior shear) can be explained by the pre-operative muscular activity of the gastrocnemius and quadriceps muscle groups. None of these implants were considered to be ‘at risk’ of early loosening by Ryd's criteria, therefore the clinical significance of this work in terms of predicting failure is unclear. However, it has been shown that larger migrations are associated with increased risk of failure (Grewal et al., 1992 and Ryd et al., 1995), therefore, increased posterior migration, although not associated with aseptic loosening in this cohort, may prove to be detrimental to implant fixation in a larger cohort.

The biomechanics literature on the anterior cruciate ligament (ACL) provides some insight on why the activation patterns of the gastrocnemius and vastus muscle groups would affect anterior–posterior shear forces and therefore implant migration. In healthy knees, the ACL resists posterior translation of the femur on the tibia. Therefore the force in the ACL would reflect the posterior shear force on the tibial plateau. Modeling studies of the resultant forces in the ACL (Shelburne et al., 2004a) demonstrated that the gastrocnemius and vastus muscles generated almost all of the force on the ACL during stance with the vasti muscles generating the force in early stance and the gastrocnemius generating it in late stance. The model developed by Shelburne included typical (i.e. asymptomatic) EMG patterns that had the vastus muscle group active in early stance and the gastrocnemius active in late stance. In this study, prolonged activation of the lateral gastrocnemius and vastus medialis throughout stance (patterns associated with those that migrated posteriorly) would increase the duration of shear force applied to the tibial tray by each muscle resulting in increased posterior migration of the components over time. A schematic of the proposed mechanism of posterior shear force generation can be seen in Fig. 5.

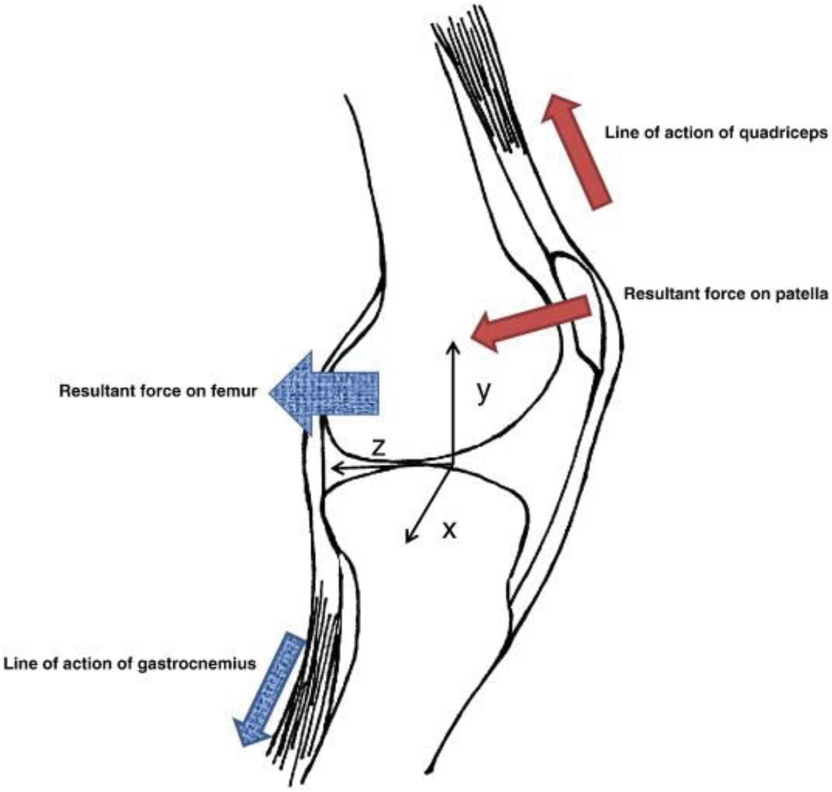

Fig. 5.

A simple schematic of the proposed mechanism of posterior shear force generation. Red arrows indicate the direction of force of the vastus and the resultant force on the patella. Blue hatched arrows indicate the direction of force of the gastrocnemius and the resultant force on the distal femur. The coordinate system corresponds to the directions of migrations measured with RSA. x corresponds with medial/lateral migration, y with superior/inferior and z with anterior/posterior migration.

Migration of total knee arthroplasty components is a multifactorial process that involves the interactions between combinations of mechanical and biological factors. While a significant portion of the variability in post-TKA tibial implant migration was found in this multivariate model (49%), half of the variability in migration was not explained. It is likely that additional mechanical, subject and surgery-specific factors are involved. In a previous study (Astephen

Wilson et al., 2010), post-TKA total migration (MTPM) was related to body mass index and the knee adduction moment during gait. Implant type was not a significant variable in the regression analysis. This may be due to the identical femoral and polyethylene components used in all implants, resulting in similar transmission of forces across the implant. While method of fixation (cemented vs. uncemented) may affect the magnitude of migration, the forces would be more related to the direction of migration. However, a larger sample size would allow for the definition of a more multivariate model of the association between dynamic loading and implant migration, as well as the inclusion of factors that relate to the biological environment.

While post-operative rehabilitation was standard immediately following surgery, there was no prescribed long-term therapy. Therefore we do not know what effects that rehabilitation or physical activity would have on the results. Also, we did not monitor the neuromuscular patterns early post-operatively while the implant was stabilizing. One assumption of this study is that after recovery from the acute trauma of surgery, the early post-operative patterns would be similar to pre-operative patterns. This assumption is supported by data previously published on a larger cohort (Hubley-Kozey et al., 2010) that showed that both the lateral gastrocnemius and the vastus medialis continued to have atypical patterns 1 year following TKA surgery. Other groups have studied the time course of recovery of quadriceps strength following TKA (Mizner et al., 2005) showing that there is a significant drop in quadriceps strength 1 month postoperatively. Despite the early decrease in quadriceps strength in that study, recovery happened faster than expected with the majority of strength returning by 3 months, no difference being detected between preoperative strength and strength at 6 months (Mizner et al., 2005) and other findings of increased quadriceps strength at 1 year postoperative (Hubley-Kozey et al., 2010).

Furthermore, the focus of this paper was not on the magnitude of muscle activation, rather the pattern of activation during gait. However, there is not good data in the literature that explores the change in muscle activation patterns during gait early postoperatively from TKA, therefore, we cannot conclusively comment on the muscle activation patterns prior to the 1 year follow-up. The results of this study are novel in that they do highlight the importance of understanding patient-specific patterns of muscle activation and how they relate to objective TKA outcome. The implications are that pre-operative and early post-operative muscle activation patterns during walking should be monitored and perhaps gait retraining programs designed to alter these patterns should be considered in post-operative care. However, future work will need to focus on understanding the interaction between muscle activation, other dynamic factors and biological variables to create accurate models of the loading environment on the implant and the affect this loading environment will have on migration.

Conclusions

Significant variability in the post-operative anterior–posterior migration of the tibial component of total knee arthroplasty was explained by the pre-operative activation patterns of the muscles surrounding the knee joint during gait. A pattern of prolonged muscle activation throughout the stance phase for both the lateral gastrocnemius and the vastus medialis muscles was associated with increased posterior migration of the tibial component. This was the first study to determine an association between neuromuscular control and TKA implant stability.

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Conflict of Interest Statement

Among the authors of this manuscript, only MJ Dunbar has any potential conflicts of interest. These are as follows: royalties from Stryker Inc, paid consultant for Stryker Inc, research support from Stryker Inc and Zimmer Inc and serves on the editorial board of JBJS Br.

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