INTRODUCTION:
Postoperative implant migration measured with radiostereometric analysis (RSA) has been shown to be predictive of early implant failure due to aseptic loosening. This makes RSA an important screening tool for new implant designs and surgical techniques. However, frequently overlooked contributors to implant migration are patient characteristics. It has been shown that high preoperative flexion moments during gait can predispose patients with total knee replacement to exhibit continuous migration leading to early aseptic loosening. Previous work from our center showed that preoperative BMI and adduction moments also are contributing factors to postoperative migration. These results indicate that the outputs of the patient’s musculoskeletal system can predispose the patients implant to migrate.

Work has focused on the mechanical outputs of patient’s gait. The goal of this study was to investigate the muscular inputs that drive the patient’s gait. Muscle forces are major contributors to joint loading. Muscle activation patterns measured with surface electromyography (EMG) in individual patients who had total knee arthroplasty were investigated to determine if specific muscle activation patterns predispose total knee replacements to migrate.

METHODS:
Thirty seven total knee replacement patients who were part of a larger randomized controlled RSA trial were recruited to this study. Study participants had been randomized to receive the Nexgen LPS Trabecular Metal tibial monoblock component (n = 19) (Zimmer, Warsaw IN) or the cemented NexGen Option stemmed tibial component (n = 18) (Zimmer, Warsaw IN). Ethics approval was received from the institutional review board.

In the week prior to their surgery, patients went to the dynamics of human motion laboratory and underwent EMG data collection. Subjects were prepared utilizing standardized protocols for motion capture and EMG analysis of seven lower extremity muscles (Hubley-Kozey et al., 2006). Two surface electrodes were placed in line with the muscle fibers on the prepared skin over vastus lateralis, vastus medialis, rectus femoris, lateral and medial hamstrings, and lateral and medial gastrocnemius using standardized placements (Hubley-Kozey et al., 2006). EMG data were full wave rectified, low pass filtered (6 Hz), time normalized to 100% gait cycle and amplitude-normalized to maximum voluntary contractions obtained at the same visit.

The variability in subject EMG patterns was captured with a set of discrete scores that represented weightings on objectively-extracted features of the gait waveform data using principal component analysis (PCA).

Surgery was performed by four experienced surgeons following a standardized surgical technique (PCL resection, patella resurfacing, RSA bead placement in polyethylene and tibia) and postoperative protocol (continuous passive motion as tolerated, no drains, weight bearing as tolerated). Within 4 days of surgery and at 6 months post-operatively, patients had bi-planar knee x-rays taken. RSA analysis was performed with MB-RSA (MEDIS, Leiden). RSA results were reported as maximum total point motion (MTPM), and 6 degrees of freedom translations and rotations at 6 months.

STATISTICAL ANALYSIS:
To deal with the non-parametric nature of MTPM data, a logarithmic transform was applied to the MTPM data and the result was used for further analysis. As the six degrees of flexion motion data was normally distributed it was not transformed.

The first three principal component scores from each muscle were correlated with MTPM, and the six degrees of freedom measurements. The results of the correlations were used to limit the variables entered into a stepwise linear regression model.

To deal with the multiple comparisons performed in the correlation calculations, statistical significance was set at 0.001 giving a 4.78% chance of finding a significant correlation by random chance in the 49 correlation calculations performed approximating a 0.05 significance level for a single comparison.

RESULTS:
A positive correlation was found between the third principal component of the lateral gastrocnemius muscle (representing low activation of gastrocnemius activation early stance) and the anterior migration of the component ($R^2=0.247$, $P=0.002$), although this correlation was not significant after correction for multiple comparisons. A significant correlation was found between the vastus medialis principal component three (representing high vastus medialis activation in early stance) and the anterior migration of the component ($R^2=0.338$, $P=0.000$). The second principal component of the medial hamstrings (representing the high muscle activation in early stance) was correlated with medial migration of the component ($R^2=0.196$, $P=0.006$), as was BMI with log MTPM ($R^2=0.140$, $P=0.022$). However, after correction for multiple comparisons neither was deemed significant.

A stepwise regression model was developed for anterior migration of the tibial component. To reduce the number of terms in the model only the two EMG variables that were most strongly correlated with anterior migration (third principal components of lateral gastrocnemius and vastus medialis), the third principal component scores for the other muscles of those groups (medial gastrocnemius, vastus lateralis), implant type and BMI were entered as possible terms. The stepwise regression eliminated all variables but the lateral gastrocnemius and the vastus medialis. The regression equation was:

$$\text{Anterior-Posterior Migration} = 0.01 + 0.12 \times \text{Vastus Medialis PC3} + 0.074 \times \text{Lateral Gastrocnemius PC3}$$

$$R^2=0.487, R^2\text{ Adj}=0.457, P=0.0001$$

DISCUSSION:
In previous work, Taylor et al. 2004 found that the anterior posterior shear on an implant was highly temporally localized to the late stance phase of gait. It is not surprising that we found that principal components that described the temporal characteristics of muscle activation were associated with anterior-posterior migration of implants.

Subjects who had a low third principal component score for the lateral gastrocnemius tends to have continuously high activation of the gastrocnemius muscle group throughout stance, and also demonstrated posterior migration of the component. As the gastrocnemius activates it pulls the femur posteriorly, this applies a posterior shear to the tibial component and leads to posterior migration over time. Lack of this muscular force would lead to increased anterior shear and increased anterior migration.

Low activation of the vastus muscle group in late stance lead to higher anterior migration, and high activation lead to posterior migration. Again this is logical from the mechanics of the situation, as vastus muscle activation in late stance would apply a high posterior force to the femur causing posterior shear and migration of the component. A lack of vastus activation leads to less posterior shear and anterior migration.

Although the results are from preoperative EMG, we assumed that they are representative of the postoperative patterns. Muscle activation patterns are learned over time and while we expect that the patterns will be altered post operatively we assumed that the patterns developed over a lifetime would persist long enough postoperatively to affect the migration of the total knee replacement components. There is limited data in the literature to either support or refute this assumption, but the strength of the relationship found suggests that there is some validity in it. It is recognized that other variables may have contributed to the migration of the components, such as surgical variables, bone quality and other patient specific characteristics.

CONCLUSIONS:
Postoperative anterior-posterior migration of the tibial component of total knee replacement can be partially explained by the preoperative activation patterns of the muscles around the knee.