LOWER LIMB KINETICS AND QUADRICEPS ACTIVATION FOLLOWING TOTAL KNEE ARTHROPLASTY WITH THE MEDIAL PIVOT KNEE DURING LEVEL AND INCLINE WALKING

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The purpose of this study was to compare gait patterns and quadriceps muscle activity of patients with a Medial Pivot knee to that of healthy, age-matched individuals. Five total knee arthroplasty patients and five age-matched control participants performed a minimum of three walking trials on both level and inclined surfaces, during which lower limb kinetics, kinematics, and muscle activity were recorded. Patients exhibited increased hip and knee extension moments, as well as increased knee flexion and peak power during stance phase of gait, corresponding with increased activation of the vastus medialis. Findings indicate that patients continue to compensate with the non-operative limb at more than 6-months after surgery, while the vastus medialis plays a key role in stabilizing the knee.

KEY WORDS: osteoarthritis, total knee arthroplasty, EMG, gait.

INTRODUCTION: Total knee arthroplasty (TKA) is a common procedure used to treat severe knee osteoarthritis. While this surgical approach has been successful in reducing chronic pain and improving functional abilities, limitations remain after TKA as prosthetic designs continue to fall short of being able to mimic the natural mechanics of a healthy knee (Moonot, Railton, Field & Banks, 2009; Alnahdi, Zeni & Snyder-Mackler, 2011; Levinger, Menz, Morrow, Perrott, Bartlett, Feller, & Bergman, 2012). With a growing population of younger, more active individuals undergoing this procedure, there is a need for a prosthesis that provides greater stability, better functional outcomes, and a longer survivorship. The Medial Pivot (MP) knee has been designed to meet these demands, replicating the natural knee design of a stable, conforming medial aspect, and a rotating lateral aspect that moves from front to back around the pivot point.

Despite the theoretical advantage of this newer design, there has been little research to investigate how the MP design translates to functional outcomes. In the past, studies have reported decreased quadriceps strength and muscle activation during gait for TKA patients. Yoshida and associates (2008) found that quadriceps strength and knee range of motion at the operated limb remained significantly lower than that of matched controls at 12 months post-op. Such discrepancies are of considerable interest for post-operative success, as the authors (Yoshida, Mizner, Ramsey & Snyder-Mackler, 2008) found significant associations between quadriceps strength and performance measures on functional tasks. Several studies focused on activity levels of TKA patients have noted that some of the most popular post-operative activities include hiking, exercise walking, golfing and Nordic walking (Naal, Fischer, Preuss, Goldhahn, von Knoch, Preiss, Munzinger & Drobny, 2007). Because these require patients to navigate both level and non-level surfaces, it was of interest to analyse the gait of MP patients on both level and incline surfaces. The purpose of this study was to examine the role of quadriceps involvement in gait mechanics among patients with a MP knee, compared to healthy, age-matched individuals during level and incline walking.

METHODS: Five patients (age: 63 ±8 years, BMI: 29.6 ±1.9 kg/m^2) were recruited for post-operative analysis at a minimum 6-months (mean: 9 months) after receiving unilateral total knee arthroplasty with a MP knee. Normative data was obtained from five healthy control participants (age: 50 years, BMI: 27 ± 4 kg/m^2), recruited from the local community. Participants were recruited if they were between 50-75 years of age, had a BMI below 35 kg/m^2, and if they were not suffering from any other lower limb joint disorders. Approval was obtained from the institution's research ethics board, and informed consent was provided by all participants.

Three-dimensional (3D) kinematics and kinetics of the lower limbs were measured during level and incline walking using a ten-camera motion analysis system (Vicon MX, Oxford Metrics, UK). Participants were outfitted with 45 reflective markers, placed according to a modified Helen Hayes model. Two force plates (Kistler, Switzerland) were embedded within a 4m steel ramp, inclined at a 12.5% slope. Two force plates (Bertec, USA) imbedded in the floor were used for assessing level walking. Knee kinetics were obtained with inverse dynamics. Surface electrodes (BTS Bioengineering, Italy) were placed over the vastus medialis, vastus lateralis and rectus femoris on each limb. Maximum voluntary contractions (MVCs) were recorded for each patient performing isometric knee extension, knee flexion, ankle plantar flexion, and dorsiflexion. The EMG signals were full-wave rectified, passed through a fourth-order, zero-lag low-pass Butterworth filter (8 Hz cut-off), peak-normalized to MVC and time-normalized for gait cycle (foot strike to foot strike). The linear envelope EMG curves were individually averaged over the three trials for each of the 16 muscles and the integral of the LE EMG was taken for each curve and averaged for each muscle. An ensemble average was then calculated for the operated limb, non-operated limb, and the control limb.

RESULTS: The MP knee exhibited similar mechanics to control participants during both level and incline walking. In contrast, the non-operated knee of TKA patients displayed greater hip extension moment, knee flexion, knee extension moment, and peak power during the stance phase of incline walking, when compared to both the operated limb and control participants. Changes in knee power during the gait cycle are shown in Figure 1, with negative values indicating power absorption, and positive values representing power generation. The gray area represents mean power (± one standard deviation) of control participants.

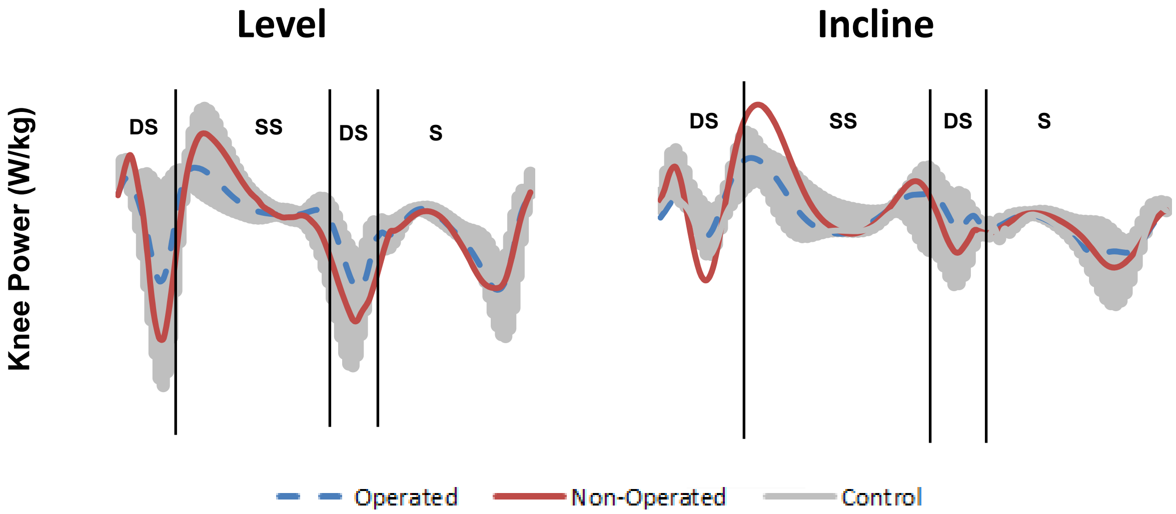

Figure 1. Knee power during level and incline gait, normalized to gait cycle. DS = double support, SS = single stance, S = swing.

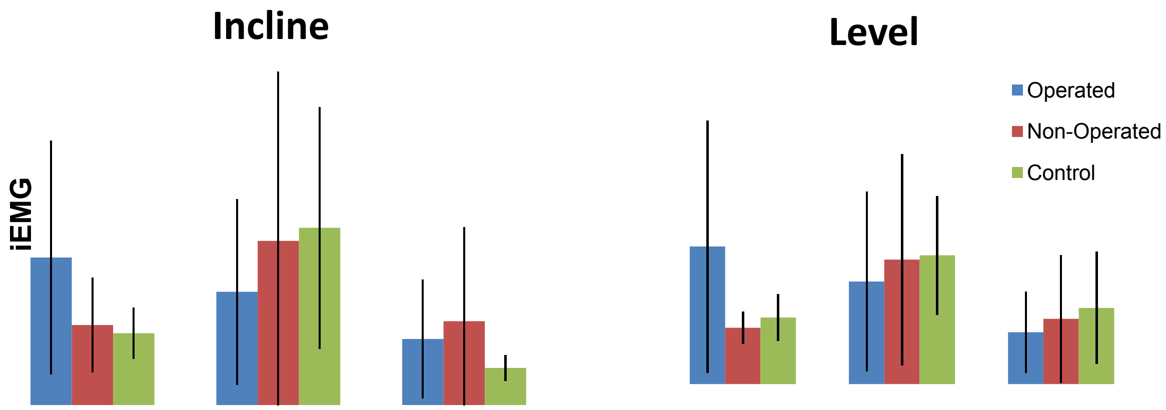

Figure 2. iEMG profiles for activation of the quadriceps muscles during level and incline walking.

Knee power for both limbs of TKA participants fell within the standard deviation curve of control participants during level walking. However, TKA participants exhibited increased power absorption and generation at the non-operative knee during stance phase of incline walking. During both walking tasks, the operated limb of TKA patients exhibited greater activation of the vastus medialis than either their non-operated limb or that of the control participants. In contrast, TKA patients had lower activation of the vastus lateralis muscle at both limbs during walking. Activation of the rectus femoris was lower among TKA patients during level walking, but increases during incline walking, with higher iEMG than control participants. Trends for iEMG values of the quadriceps muscle are shown in Figure 2.

During the stance phase, a peak in activation was seen for each quadriceps muscle. While the operated limb exhibited higher levels of VM activation during this phase for both tasks, the operated limb also experienced lower activation of the vastus lateralis during this period for level walking, while the non-operated limb exhibited similar activation to control participants.

DISCUSSION: Similar kinetics parameters observed between TKA and control participants during level gait suggests that the MP knee successfully mimics natural knee mechanics during this activity. During incline walking, the affected limb appears to once again mimic a healthy knee, however the gait pattern for the non-operated limb is altered during stance phase of gait (approximately 0-30% of the gait cycle). This phase is characterized by an eccentric contraction of the quadriceps to prevent the knee from collapsing during weight acceptance, followed by concentric quadriceps contraction to reach peak flexion during the single support phase (Barr & Backus, 2001). This pattern of quadriceps contraction is reflected in the initial peak in power absorption, followed by a peak in power generation seen on both graphs in Figure 1. McIntosh, Beatty, Dwan & Vickers (2006) reported that as healthy individuals transition from level to incline walking tasks, an observed increase in the power generation phase is associated with a rapid increase in knee flexion during the first half of the gait cycle. This may explain the higher peaks in power generation observed in incline walking, as both TKA and control participants exhibited increased knee flexion during stance for incline versus level walking. This would also be associated with increased concentric quadriceps contraction, which may explain the higher quadriceps iEMG levels among TKA patients during this phase. While the control participants also exhibited increased VM and VL iEMG levels during incline walking, iEMG for the rectus femoris actually decreased.

While the MP knee resembled that of control participants during incline walking, the non-operated limb exhibited increased knee flexion and knee extension moment compared to both the operated and control limbs. During the loading phase (~0-12% of gait cycle), the non-operated limb also demonstrated greater peak power absorption, followed by greater power generation during midstance (~12-30% of gait cycle). Similarities between the MP and control knees do not suggest that these altered mechanics of the non-operative limb are a result of compensation. However, it indicates that some discrepancies remain for TKA patients during incline walking. It is possible that the differences observed with the non-operative limb during single stance phase may reflect an increased need to stabilize and generate power while the operated limb is swinging forward up the incline.

While quadriceps inhibition is a factor that has been previous associated with TKA patients, no previous TKA studies have focused exclusively on muscle activity of patients with a MP knee nor have they examined incline gait for TKA patients. Due to its unique medial-stabilized structure, the vastus medialis may play a unique role in joint stabilization. The higher level of muscle activation, particularly during the stance phase, may reflect an increased need for stabilization as the vastii muscles contract to stabilize the knee during weight acceptance and single support stance. The unique design and mechanics of the MP knee warrants future, prosthesis-specific research, to understand if quadriceps activity is specific to prosthetic design or simply a characteristic of post-TKA gait. Results for level walking are encouraging for patients' participation in activities that involve mostly level surfaces, such as with exercise walking. Further research is warranted to understand any potential effects that may result from alterations to non-operative knee mechanics during activities that involve incline walking, such as golfing and hiking. Increased power absorption about this limb may be associated with accelerated osteoarthritis progression, a topic of concern following unilateral TKA.

CONCLUSION: Following TKA, patients with a MP knee exhibit relatively similar gait patterns to healthy individuals of a similar age and BMI, while some discrepancies are seen with the non-operative limb during incline walking. These discrepancies should be further investigated, in regard to implications it may have to disease progression on the non-operative limb from engaging in activities that are more demanding than simply level walking. The medial-stabilized design of the MP knee may result in increased activation of the vastus medialis muscle to stabilize the limb during functional tasks, which is of interest for selection of rehabilitation protocols and participation in sport following surgery.

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