Muscle Forces during Walking in Medial Knee Osteoarthritis

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Statement of Purpose:

People with knee osteoarthritis (OA) walk with decreased knee motion, higher external knee adduction moments (KAM) and higher muscle co-contraction as compared to age matched healthy controls. High adduction moment leads to increased loading on the medial side and the load gets distributed over a smaller area due to truncated knee motion. We have speculated that high co-contraction (measured from EMG) can lead to further increase in joint loading (Schmitt et al., 2007; Lewek et al., 2004). Repetitive high loading from high co-contraction during walking may exacerbate OA progression. However, forces associated with EMG are unknown.

During dynamic activities estimates of muscle force from EMG must take into account characteristics such as electromechanical delay, muscle force-length and force-velocity relationships and the type of contraction (eccentric or concentric) all of which can influence the magnitude of the force produced per unit EMG. Computational modeling can provide estimates of muscle force that would broaden and greatly enhance the interpretation of EMG data during dynamic activities such as walking.

In this study, a forward dynamic model that estimates muscle forces from EMG is used to confirm the speculation that people with knee OA use higher muscle forces during walking that could influence disease progression.

Methods:

To date, 3 subjects with knee OA (mean: age 50.6 yrs; weight 69.6 kg) and 3 controls (C) (mean age: 66.3yr; weight 91.8kg) walked at a self-selected speed while kinematic data were captured with 8 camera VICON motion system @ 120 Hz, kinetic data @ 1080 Hz with 2 six degree of freedom Bertec force plates and EMG @1080 Hz using bipolar, surface electrodes over lower extremity muscles. EMG linear envelopes were created by full wave rectification and filtering the EMG with a 6Hz low pass filter, and normalized to the peak EMG during a maximum voluntary contraction.

The normalized EMGs were transformed to neural activation and as inputs to a Hill-type muscle model. Parameters specific to each muscle included: optimal fiber length, tendon slack length, maximum isometric force, pennation angle and maximum fiber contraction velocity. Simulated annealing optimization was used to determine muscle parameters that minimized the difference between the model-estimated and the net moment computed using inverse dynamics. Muscle parameters were constrained to be within physiologic ranges reported in the literature. The details of this method have been described elsewhere (Buchanan et al., 2004).

The EMG-driven model includes 10 muscles crossing the knee (Vastus Medialis, Vastus Intermedius, Vastus Lateralis, Rectus Femoris, Semimembranosus, Semitendinosus, Biceps Femoris long head, Biceps Femoris short head, Medial Gastrocnemius, Lateral Gastrocnemius) and calculates forces for each muscle. The model is sensitive to subject specific kinematics, anthropometrics as well as muscle specific characteristics. The calculated muscle forces were normalized to the BMI for each subject.

Results:

The OA subjects used substantially higher total muscle force during LR (OA: 68 ± 10.26 N/BMI; C: 59.28± 6.86 N/BMI) and MSt (OA: 68.2 ± 36.2 N/BMI; C: 36.1 ± 1.51 N/BMI) compared to controls.

When comparing individual muscle forces lateral muscles generally produced higher force in all subjects but OA subjects used substantially higher hamstring forces during LR and MSt (Tables 1 and 2).

During weight acceptance when the KAM is high and also as the knee extends in single limb support. The disproportionally higher hamstring forces during LR and gastrocnemius forces suggest that their co-contraction with quadriceps muscles could lead to higher joint contact forces that, combined with the excessive loading due to high KAM, would exacerbate joint destruction.

Further research is required to fully understand the effect of higher muscle forces on OA severity and progression. We are in the process of analyzing muscle forces around the knee during different activities like stair climbing; sidestepping and cutting for people with knee OA and age matched healthy controls. The results from these studies would shed further light on the joint loads in people with knee OA.

Table 1- Average muscle forces, normalized to BMI (MQ- Medial Quadriceps, LQ- Lateral Quadriceps, MH- Medial Hamstrings)

<table>
<thead>
<tr>
<th></th>
<th>MQ (N/BMI)</th>
<th>LQ (N/BMI)</th>
<th>MH (N/BMI)</th>
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<tbody>
<tr>
<td>CONTROL</td>
<td>14.14(5.97)</td>
<td>16.5(5.94)</td>
<td>4.49(8.44)</td>
</tr>
<tr>
<td>OA</td>
<td>11.47(5.25)</td>
<td>13.99(2.13)</td>
<td>9.67(1.18)</td>
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</tbody>
</table>

Table 2- Average muscle forces, normalized to BMI (LH- Lateral Hamstrings, MG- Medial Gastrocnemius, LG- Lateral Gastrocnemius)

<table>
<thead>
<tr>
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<th>LH (N/BMI)</th>
<th>MG (N/BMI)</th>
<th>LG (N/BMI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CONTROL</td>
<td>6.48(3.19)</td>
<td>0.91(0.69)</td>
<td>1.15(0.47)</td>
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<tr>
<td>OA</td>
<td>16.6(6.27)</td>
<td>1.76(2.67)</td>
<td>2.56(8.4)</td>
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Conclusion and Discussion:

Previous speculations that OA subjects use higher muscle forces during walking are confirmed. Higher muscle forces appeared during weight acceptance when the KAM is high and also as the knee extends in single limb support. The disproportionally higher hamstring and gastrocnemius forces suggest that their co-contraction with quadriceps muscles could lead to higher joint contact forces that, combined with the excessive loading due to high KAM, would exacerbate joint destruction.

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References:

