INTRODUCTION

Although knee joint load and torque are the primary biomechanical factors assessed in knee osteoarthritis (OA) studies, patients with OA frequently report muscle weakness and fatigue. Previous studies have shown the effect of muscle dysfunction (e.g. quadriceps) on the development and even pathogenesis of OA. However, the relationship between muscle function and OA is still not clear (Hurley, 2003).

Forward simulation is a powerful tool to understand muscle function, but currently no such tools are used for OA. In the current study, we generated dynamic simulations of patients with knee OA using OpenSim (Thelen and Anderson, 2006; Delp et al, in press). The aims of this study were to evaluate the feasibility of applying OpenSim for pathological gait and compare muscle function between limbs for individuals with bilateral knee OA.

METHODS

Three-dimensional kinematic and kinetic data were collected from 12 patients with knee OA on a split-belt treadmill. Experimental data were then processed in Evart. Recorded raw EMG data were rectified, low-pass filtered and normalized to peak magnitude. Subjects signed an informed consent approved by the human subjects review board.

One subject was selected for this case study. The subject was diagnosed with grade I on the right knee and grade IV on the left knee, which resulted in an asymmetric walking pattern.

A 3D musculoskeletal model was generated by OpenSim. It has 10 segments, 23 degrees-of-freedom and is articulated by 54 Hill-type musculotendon actuators. The model was first scaled to subject dimensions. Inverse dynamics and residual reduction algorithms were then used to find the joint angles that best reproduce the experimental kinematics. Computed muscle control (CMC) was applied to compute the set of muscle excitations that drives the model to track the desired kinematics (Thelen and Anderson, 2006). A fast target optimization was used to minimize the sum of squared actuator forces. Finally, the computed excitations were used to drive a forward dynamics simulation. The output of OpenSim included muscle excitation, muscle force, and joint kinematics.

We generated three simulations for the subject at self-selected speed. Each simulation duration was more than a full gait cycle.

RESULTS AND DISCUSSION

Each simulation was completed within 30 minutes on a personal computer with a 3.0GHz Pentium 4 processor. Simulation joint angles were within ± 2° of the experimental data (Figure 1). Ground reaction forces were within ±1 standard deviation of experimental data.
Vastus is one of the knee extension muscles and demonstrates changes in activity with OA. Our EMG data suggested that right VAS was active at early stance (0 - 20% gait cycle) and slightly active at terminal swing phase (80 - 100% gait cycle) (Figure 2, upper half, thick dashed line). Using OpenSim, we found similar excitation patterns which parallel stance phase EMG timing and magnitude (thick solid line). We believe that VAS was active at early stance to provide support for COM and active at swing phase to extend the leg in preparation for heel strike. On the left leg, the peak value of excitation was much smaller than the right side, especially in stance phase (Figure 2, lower half, thin solid line). Considering the left leg has more severe OA than the right leg, we believe that the patient was using less VAS so that the load on left knee would be reduced which is consistent with quadriceps weakness implicated in previous studies.

We noticed that the simulated excitation patterns were not perfectly matched with recorded EMG signals. However, they were more consistent with literature (Thelen and Anderson 2006, den Otter et al. 2004). One explanation for the difference may be the choice of cost function in CMC which may not be perfect for OA subjects, who potentially minimize joint load on the knee while walking. Future work will explore the effect of altering the cost function on predicted excitation patterns.

**SUMMARY/CONCLUSIONS**

With OpenSim, we are able to generate accurate OA simulations in a few minutes. We believe that these tools will be of great use in prediction of muscle excitation patterns, muscle function analysis and clinical treatment.

**REFERENCES**


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