INTRODUCTION
The development and progression of knee osteoarthritis (OA) have been clearly associated with the magnitude of knee joint loading experienced during walking. We are therefore interested in developing therapeutic strategies for offloading the knee joint during walking. One strategy that requires no surgery or medication is to modify the walking motion. A variety of potential modifications have been evaluated in experiments on human subjects, but it is unknown which modification optimally reduces the knee joint load, or if the theoretical load-minimizing gait is practical for use in daily locomotion (e.g. incurs a relatively low metabolic cost). Forward dynamics simulations have been touted for many years as a tool for predicting and optimizing clinical outcomes, but to date have not been widely used for this purpose.

Therefore, the purpose of the study was to use forward dynamics simulations to predict walking gaits that minimize the knee joint contact force. The predictions were compared to experimental data to assess their accuracy and feasibility.

METHODS
Simulations were generated using a 2D forward dynamics model of the human musculoskeletal system [1] and compared to experimental motion capture, ground reaction force (GRF), electromyographic (EMG), and metabolic data from walking humans [2,3]. The muscle excitation controls, initial velocities, and stride duration were optimized to minimize a performance index over the time for one periodic stride.

The first simulation (i) attempted to replicate “normal” walking by minimizing the gross metabolic cost of transport (CoT). The other three simulations attempted to reduce the knee joint contact force by minimizing (ii) the peak knee flexion angle during stance, (iii) the peak axial knee joint contact force, and (iv) the peak axial knee joint contact force while tracking the experimental knee joint angle.

RESULTS
The “normal” simulation walked at 1.34 m/s with a CoT of 3.74 J/m/kg, compared to 1.33±0.20 m/s and 3.52±0.29 J/m/kg in the human subjects (mean±SD). The simulated joint angles and GRF deviated from the human experimental means by 1.86 SD on average, even though none of these data were tracked explicitly. The peak axial knee joint contact force was 3.10 times the model’s weight (BW).

Simulations (ii) and (iii) both featured reduced knee flexion in stance (Fig. 1) and reduced the peak joint contact force to 2.73 and 2.31 BW, respectively. Simulation (iv) reduced the peak contact force to 2.42 BW while tracking the measured knee angle to a deviation of 1.35 SD on average, using a “toe walking” gait with reduced ankle range-of-motion. The CoT for simulations (ii)-(iv) ranged from 4.14-4.26 J/m/kg.

DISCUSSION & CONCLUSIONS
Forward dynamics simulations may be useful for predicting novel gaits for offloading the knee. However, all predictions by a generic model may not generalize to an individual, and extensive experimental evaluation may not always be feasible (e.g. in individuals with severe knee pain). Prediction accuracy can likely be improved by developing patient-specific models, e.g. from MRI and joint strength testing.

REFERENCES