INTRODUCTION
Medial compartment knee osteoarthritis (OA) is the most common type of knee OA. Peak knee adduction angle during gait strongly correlates with internal peak knee abduction moment, a surrogate measure of knee joint loading, in medial compartment knee OA patients [1]. Non-invasive interventions for medial compartment knee OA patients aim to reduce knee loads to help slow down disease progression and improve quality of life. Gait modifications including greater toe-out angle (TOA) and increased step width (SW) during level and stair walking have been found to reduce peak knee abduction moment in healthy and knee OA patients [2,3,4]. In addition, isolated hip abductor strengthening has been shown to reduce peak knee abduction moment in knee OA patients, by reducing pelvic drop and shifting the ground reaction force vector laterally (i.e., shortening the abduction moment lever arm) [5]. Obesity is the most important modifiable factor for knee OA development and progression and, weight loss has been shown to reduce compressive knee forces in knee OA patients during gait [6]. Further, a lateral motion elliptical device (i.e., skating simulation) would be expected to reduce peak knee adduction angle due to the lateral position of the foot relative to the hip joint during the load phase and, increase hip abductor involvement. This study compares exercise on a standard elliptical device using three different foot positions and on a lateral motion elliptical device to provide preliminary findings on knee angular position and muscle activity in healthy men. Greater TOA, wide SW and a lateral motion were expected to reduce the peak knee adduction angle and increase gluteus medius activity compared to straight foot position during elliptical exercise.

METHODS
9 healthy young men (22.6±1.7 yrs) volunteered for the study. A 9-camera motion analysis system (100 Hz, Qualisys, Sweden) and a wireless electromyography (EMG) system (2000 Hz, Delsys, USA) were used to obtain 3D lower extremity joint kinematics and muscle activity, respectively. The EMG surface electrodes were placed over the right vastus medialis (VM), biceps femoris (BF), gluteus maximus (GMax) and gluteus medius (GMed) according to existing guidelines [5]. The skin below each electrode placement site was shaved, lightly abraded and cleaned with an alcohol swab before application. Two maximal voluntary isometric contractions (MVIC) for each muscle were performed using manual muscle testing by the researcher for all subjects. Uni-lateral retro-reflective markers were placed over bony landmarks of the pelvis and right lower extremity, and arrays of markers were attached to the thighs and shanks using elastic wrap. Participants performed a 30 second exercise bout at a stride rate of 50 strides per min on each of four elliptical device conditions: 1) lateral motion elliptical (Crossover, Technogym, USA) and on a standard elliptical trainer (EX-5, Matrix Fitness, USA) with 2) straight foot position, 3) increased TOA and, 4) increased SW. Exercise conditions were randomized and a 2-3 minute “familiarization” period was provided before the 30 second testing of each condition. The average of each variable in the middle six load-phases of the stride (i.e., most anterior to most posterior pedal position) during the 30 second bouts was analyzed. Visual3D (C-Motion, USA) was used to obtain the 3D lower extremity joint kinematic and EMG variables. The EMG signals were band-pass filtered.
with cut-off frequencies of 20 and 400 Hz. The signals were full-wave rectified and smoothed using a root-mean-square (RMS) filter with a moving window of 150 ms. The EMG signals during exercise were normalized to the larger of the two MVIC RMS peak values for each muscle for each participant. The normalized EMG signals were then integrated (iEMG) during all six load-phases for each muscle. One-way repeated measure analyses of variance were used to compare all variables between elliptical conditions (α = 0.05).

RESULTS AND DISCUSSION

The peak frontal knee angle in early load-phase was greater in the TOA condition compared to the lateral (p=0.001), straight (p=0.001) and wide SW conditions (p<0.001) and; smaller during wide SW compared to the lateral condition (p=0.015). The peak frontal knee angle in late load-phase (i.e., abduction) was smaller in the TOA condition compared to the lateral (p=0.007), straight (p<0.001) and wide SW conditions (p<0.001). The smaller abduction angle in TOA may suggest greater late load-phase medial compartment knee loads in TOA compared to other conditions. The frontal plane knee range of motion (ROM) was significantly greater in the lateral condition compared to wide SW (p=0.019). The knee flexion-extension ROM during load-phase was greater in the lateral condition compared to all other conditions (p<0.001). This finding may suggest smaller localized peak knee forces during elliptical exercise in the lateral motion condition. However, the larger VM iEMG value in the lateral condition compared to the straight (p=0.001), TOA (p=0.004) and wide SW (p=0.001) conditions (Fig. 1) may indicate greater knee extensor force production during the lateral motion condition which could lead to larger peak compressive knee forces [6].

CONCLUSIONS

Our findings refute the hypotheses that lateral motion, greater TOA and wide SW would reduce peak knee adduction angle and increase gluteus medius activation compared to straight foot elliptical exercise. The greater frontal and sagittal plane knee ROM may suggest that a lateral motion could help disperse forces within the knee to reduce peak compressive knee forces during elliptical exercise. However, increased VM activity may indicate greater muscle force contributions to yield larger peak compressive knee forces. Knee joint kinetic analyses using the current elliptical exercise methods are warranted to further study knee loads.

REFERENCES


Table 1: Knee kinematic variables between elliptical exercise conditions (mean ± SD) and p-values.

<table>
<thead>
<tr>
<th>Joint Angles (degrees)</th>
<th>Lateral</th>
<th>Straight</th>
<th>Toe-Out</th>
<th>Wide SW</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak add-abduction in early load</td>
<td>0.02±3.85</td>
<td>-1.07±3.32</td>
<td>2.40±3.24</td>
<td>-2.02±3.24</td>
<td>0.0001</td>
</tr>
<tr>
<td>Peak add-abduction in late load</td>
<td>-6.6±6.32</td>
<td>-5.71±3.44</td>
<td>-1.65±2.60</td>
<td>-6.37±4.15</td>
<td>0.003</td>
</tr>
<tr>
<td>Add-abduction ROM</td>
<td>6.88±3.67</td>
<td>4.64±2.04</td>
<td>4.04±1.66</td>
<td>4.34±2.46</td>
<td>0.018</td>
</tr>
<tr>
<td>Flexion-extension ROM</td>
<td>50.13±4.92</td>
<td>23.63±4.64</td>
<td>21.90±7.19</td>
<td>22.92±5.73</td>
<td>0.0001</td>
</tr>
</tbody>
</table>

Note: Frontal peak knee and hip: abduction (-), adduction (+); Load: load-phase on elliptical device *: significantly different than Lateral; &: significantly different than Straight; #: significantly different than Toe-Out; @: significantly different than Wide SW (p < 0.05).