MUSCLE FORCE CHANGES DURING CYCLING WITH PEDAL MODIFICATIONS

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INTRODUCTION

Osteoarthritis (OA) is a degenerative joint disease significantly destroying the quality of life [1] for roughly 27 million adults (14% of adults >25 yrs) in the United States [2]. A common treatment used in current rehabilitation strategies for knee OA is the prescription of aerobic exercise (i.e. walking and cycling) [3]. Low-intensity cycling is as effective as high-intensity cycling for improving joint function, decreasing pain, and increasing aerobic capacity [4, 5]. Cycling rather than other exercise modalities is generally considered an alternative for people with knee OA, but there is a lack of scientific knowledge characterizing the rehabilitation benefits (i.e., muscle and joint force changes), and maximizing the results of cycling for people with knee OA. However, one previous study [6] examined the effects of toe-in pedal modifications and found the peak knee adduction angles decreased, but the peak knee abduction moment (KAM) did not decrease, for subjects with and without knee OA. Preliminary work indicates a decrease in KAM for lateral pedal wedges rather than toe-in, but the muscles forces contributing to knee OA are unknown.

This study aimed to investigate muscle force changes for subjects with and without knee OA during stationary cycling using two different pedal modifications. We hypothesized that lateral pedal wedges of 5° and 10° would change (increase or decrease) the mean muscle forces in both cohorts during stationary cycling compared to a neutral (0°) pedal condition.

METHODS

In this study, we analyzed two females, one with knee OA (height 1.8 m; mass 99.55 kg) and another without knee OA (height 1.7 m; mass 93.18 kg). The motion capture data was previously collected in Visual 3D (C-Motion, Inc.) [6]. Data was collected in the following three different cycling pedal conditions: 1) neutral without pedal wedges, 2) 5° lateral pedal wedge, and 3) 10° lateral pedal wedge. The testing condition order was randomized. Five trials of each pedal condition were collected after 2 minutes of steady state cycling at a 60 RPM pedal cadence and 80 W work rate.

Subject-specific musculoskeletal simulations were created in OpenSim 3.2 (3.2, SimTK, Stanford, CA, USA) for each participant [7]. The subject-specific models were scaled based on scale factors and marker positions from Visual 3D. Inverse kinematics was used to derive the joint kinematics from the experimental marker data. Static optimization was then carried out to estimate muscle activations and forces to generate the inverse dynamics joint moments during the cycling trials with each pedal condition.

We evaluated our hypothesis regarding the differences in mean muscle forces during cycling in the 3 pedal conditions for each subject by conducting a two-sample *t*-test (Matlab 2015) at the 0.01 significance level. A two-tailed test was used due to having no *a priori* expectation about directionality of mean muscle force change.

RESULTS AND DISCUSSION

There were many changes in the mean muscle forces for both subjects in both 5° lateral pedal wedge vs. neutral and 10° lateral pedal wedge vs. neutral (Table 1). Most mean muscle force changes for the subject with knee OA were not statistically significant with the exception of two muscles, which showed a significant decrease ($p<0.01$), on average, of 53% (Iliacus) and 47% (Psoas) in the 5° lateral pedal wedge condition compared to neutral. On the other hand, the subject without knee OA had

7 out of the 10 muscles showing the most significant differences increased ($p<0.01$), on average, for the 5° and 10° lateral pedal wedge conditions. For example, the mean muscle forces for the Quadratus Femoris increased by roughly 357% and Adductor Magnus by over 784% in the lateral pedal wedge conditions. Conversely, only the Soleus mean muscle force significantly decreased ($p<0.01$), on average, for the 5° and 10° lateral pedal wedge conditions. These results suggest that individuals with and without knee OA may alter their muscle forces to achieve the cycling motions using the 5° and 10° lateral pedal wedges. However, there were not as many significant differences in the subject with knee OA and this observation could be due to unique neuromusculoskeletal adaptations in the particular subject analyzed and/or individuals with knee OA. Future work is needed to investigate changes in KAM, muscle forces, and joint contact loads contributing to knee OA in a larger sample of subjects.

CONCLUSIONS

This study examined changes in mean muscle forces for subjects with and without knee OA during stationary cycling using two different lateral pedal wedge modifications compared to a neutral without pedal wedge condition. When cycling with pedal modifications, the healthy subject exhibited more changes in mean muscle force between the 5° and 10° lateral pedal wedge conditions and neutral one compared with the subject with knee OA. Finally, the results of this study add to an increasing body of knowledge suggesting a need for further research to determine changes in muscle forces and, more importantly, resulting joint contact loads for subjects with knee OA during cycling.

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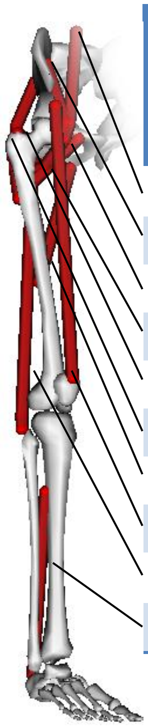
Table 1. Mean forces and standard deviations for the 10 muscles showing the most significant differences between the neutral, 5° lateral pedal wedge and 10° lateral pedal wedge conditions.



Muscle	Mean muscle force (N)					
	Subject with knee OA			Subject without knee OA		
	Neutral	Lateral pedal wedge 5°	Lateral pedal wedge 10°	Neutral	Lateral pedal wedge 5°	Lateral pedal wedge 10°
Psoas	120±132	**64.0±22.6***	103±73.8	35.3±9.80	35.3±26.1	65.0±57.4
Iliacus	122±134	**57.2±27.9***	112±62.3	44.5±7.98	33.5±13.6	54.2±47.7
Pectineus	7.45±9.64	4.25±2.64	5.02±5.28	1.62±0.429	**6.70±0.900***	**8.87±1.32***
Quadratus Femoris	84.2±108	90.0±5.03	174±57.0	28.6±5.32	**83.9±29.9***	**128 ±45.0***
Gemellus	8.99±11.2	8.43±2.25	23.5±20.0	12.0±2.47	**21.5±3.84***	**22.4±7.30***
Gluteus Maximus	43.1±93.2	29.3±18.6	94.3±153	18.9±3.63	**51.6±24.4***	**60.6±11.3***
Adductor Magnus	38.8±57.3	22.9±17.2	34.3±31.1	5.18±1.84	**22.2±10.3***	**45.8±12.1***
Rectus Femoris	314±328	171±95.2	271±107	59.5±9.40	**135±85.5***	**158±56.9***
Biceps Femoris L.H.	53.9±116	28.4±21.6	77.1±200	50.8±14.3	**82.3±22.8***	**80.4±29.2***
Soleus	15.6±3.78	14.9±0.109	14.9±0.215	14.2±0.484	**12.2±0.120***	**12.2±0.290***

* Denotes there was a significant difference in mean muscle forces for the lateral pedal wedge condition compared to neutral for the respective subject ($p<0.01$).