Muscle Force & Activation Patterns During a Sit-To-Stand Transfer in Subjects with Knee Osteoarthritis

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INTRODUCTION: Osteoarthritis (OA) is a degenerative joint disease typically characterized by joint pain and limited range of motion. According to the 2010-12 National Health Institute Surveys, 52.5 million adults in the United States had diagnosed OA [1]. Individuals with knee OA often report difficulty performing daily tasks, such as walking or rising from a chair [2] and seek physical therapy treatment to decrease pain and improve function. However, current physical therapy protocols leave some patients with unimproved functional results [3]. The Sit-to-Stand (STS) transfer is a functional assessment clinicians use to test a patient's ability to rise from a seated position [4]. Previous research has studied STS kinematics, kinetics, muscle activation patterns, and inter-limb differences in healthy young and uninjured elderly subjects [5-9], but it is not understood how individual muscle forces differ between individuals with OA subjects and healthy controls or how muscle activation patterns relate to patient-reported condition. By investigating muscle forces and activation patterns during a STS task, future therapies could potentially target specific muscles needed to accomplish this task in patients with early stage knee OA or after a total knee replacement. Therefore, the purposes of this study were to 1) compare peak muscle forces between the involved and contralateral limbs of subjects with end-stage knee OA, 2) compare the peak lower extremity muscle forces of OA subjects and of young, healthy controls and 3) investigate the associations between peak lower extremity muscle forces and activation patterns and patient-reported functional outcome scores.

METHODS: Using the open-source software package, OpenSim, simulations were generated for seven subjects rising from chair [10]. Subjects (1M/6 F, Age: 59.1± 6.4 y, Mass: 83.4 ± 10.7 kg, Height: 1.63 ± 0.7 m, BMI: 31.2 ± 3.0 kg/m^2) with knee OA (Kellgren-Lawrence Grade III or IV) gave informed consent and were tested according to the protocol approved by Ohio State's Institutional Review Board. Motion capture was used to record subjects rising from an armless, backless chair 55.2 cm from the ground using a 10-camera motion capture (MX-F-40; Vicon; Oxford, UK) system and a modified point cluster technique [11,12]. Wireless electromyography (Telemyo DTS; Noraxon USA, Inc.; Scottsdale, AZ) data were collected bilaterally for 16 muscles in the lower limb. Ground reaction forces were recorded using two force plates (4060-10, Bertec; Columbus, OH) embedded in the floor. Each subject also completed the Knee injury and Osteoarthritis Outcome Score (KOOS), of which 4 relevant subscales were used: Pain, Symptoms, Activities of Daily Living, and Quality of Life (QOL), rated on a scale of 0-100, with 100 indicating no limitations [13]. A custom three-dimensional musculoskeletal model was scaled to each subject's anthropometric measurements, and experimental marker trajectories were used to calculate joint angles for the STS task [10]. Static optimization was used to estimate individual muscle forces by minimizing the sum of the squared muscle activations during the STS task [14]. Using paired t-tests (α=0.05), differences in peak forces in each of the quadriceps, biceps femoris (long head), gluteus maximus, medial gastrocnemius, and soleus between the involved and contralateral limbs in the OA group were determined. Using unpaired t-tests (α=0.05), differences in peak muscle forces in the involved OA limb were compared to peak muscle forces in the dominant limb (highest ground reaction force during STS trial) of 7 young, healthy controls collected in a previous STS study [9]. Muscle cost, a measure of muscle activation and an indirect measure of metabolic cost, and was calculated by summing the squared muscle activation over the duration of the trial [15]. Pearson's correlation coefficients evaluated the associations between peak muscle force and muscle cost and KOOS subscale scores in individuals with knee OA (α=0.05).

RESULTS: Individual muscle forces were not different between the involved and contralateral limb in OA subjects ($p \geq 0.599$) during the STS task. OA subjects produced lower peak muscle force in the rectus femoris and higher peak muscle force in the soleus than young, healthy controls (p=0.019 & p=0.006, respectively). Lower peak vastus lateralis muscle force and greater gluteus maximus muscle cost were significantly associated with higher scores on the QOL portion of the KOOS (r=-0.798, p=0.031; r=0.756, p=0.049, respectively) (Fig. 1a & 1b).

DISCUSSION: While our study found no differences in peak muscle forces between the involved and contralateral limbs of OA subjects during a STS task, previous research demonstrated inter-limb differences in peak muscle forces during a STS task in young, healthy subjects [8], suggesting that subjects with OA may have less muscle force asymmetry than young healthy individuals during a STS task. Previous research also reported a difference in quadriceps force in subjects with end-stage OA during maximum isometric contractions [16]; this contrast may be related to different sample sizes (n=7 versus n=28) or different exclusion criteria, as the previous study excluded subjects with a history of contralateral knee problems while our study did not. The lower peak rectus femoris muscle force in the OA subjects was expected, as quadriceps weakness is a known symptom of OA [16]; however, the negative association between peak vastus lateralis muscle force and QOL warrants further investigation. A novel finding was that the peak soleus muscle force was greater in subjects with OA, which supports a previous study where the soleus and gluteus maximus compensated for simulated quadriceps weakness in young, healthy subjects during gait [17]. The positive association between gluteus maximus muscle cost and QOL suggests that increasing the muscle activation (and thereby increasing the muscle cost) would have a positive effect on patient-perceived QOL. Additionally, this study is the first to relate patient-reported outcomes with individual muscle forces or muscle cost, providing clinicians with correlations between muscle forces and activations and self-reported QOL.

SIGNIFICANCE: The correlations between QOL, peak vastus lateralis muscle force, and gluteus maximus muscle activation patterns emphasize the importance of these muscles in rehabilitation for patients with knee OA, suggesting that making modifications to physical therapy protocols with respect to these muscles may positively affect patient QOL.

REFERENCES: 1. Hootman, J.M. & Helmick, C.G., *Arth Rheum*, 2006. 54(1): p. 226-9. **2.** Noble, et al., *Cl Orth & Rel Res*, 2005. 431: p. 157-65. **3.** Bennell, K.L., et al., Arthritis Rheumatol, 2014. 66(4): p. 950-9. **4.** Lord, S.R., et al., *J Gerontol A Biol Sci Med Sci*, 2002. 57(8): p. M539-43. **5.** Roebroeck, M.E., et al., *Clin Biomech* (Bristol, Avon), 1994. 9(4): p. 235-44. **6.** Schenkman, M., et al., *Phys Ther*, 1990. 70(10): p. 638-48; discussion p. 648-51. **7.** Doorenbosch, C.A., et al., *J Biomech*, 1994. 27(11): p. 1299-307. **8.** Caruthers, E., et al. *Amer Soc of Biomech*: Abstract No. 269, 2013 **9.** Patsika, G., et al., J Electromyogr Kinesiol, 2011. 21(5): p. 689-94. **10.** Delp S.L., et al. *IEEE Trans Biomed Eng*. 2007. 54(11): p. 1940-50. **11.** Andriacchi, et al., *J Biomech Eng*, 1998, 120(6): p. 743-9. **12.** Jamison, S.T., et al. *J Biomech*, 2012, 45(11): p. 1881-5. **13.** Roos, E.M. *Qual Life Outcomes*, 2003. 1: p. 64. **14.** Crowninshield RD and Brand RA. J Biomech 14, 7p.93-801, 1981. **15**. Van der Krogt, M.M., et al. *Gait & Post*, 2012. 36, 113-9. **16.** Stevens, J.E., et al., *J Orth Res*, 2003. 21, p. 775-9. **17.** Thompson, J., et al., *J Biomech*, 2013. 46(13), p. 2165-2172.

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IMAGES AND TABLES:

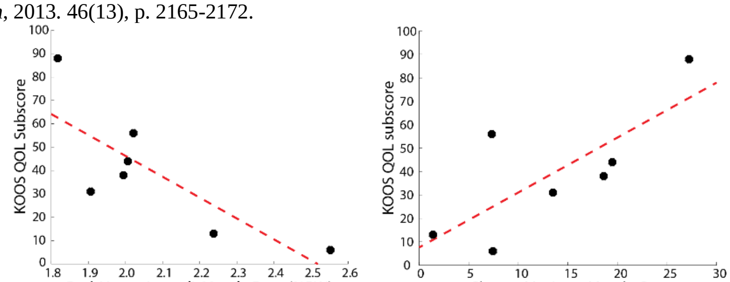

Figure 1. Scatterplots for a) peak vastus lateralis muscle force (normalized by %BW) (left) and b) gluteus maximus muscle cost (unitless) (right)