Using wrapping surfaces to estimate hip muscle moment arms during activities of daily living

Camille C. Johnson[1], Ethan Ruh[1], Naomi Frankston[1], Shaquille Charles[1], Craig Mauro[1], Michael McClincy[1], William Anderst[1]
[1]Department of Orthopaedic Surgery, University of Pittsburgh, Pittsburgh, PA
Email of Presenting Author: ccj17@pitt.edu

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INTRODUCTION: Hip muscle function is of particular concern when considering post-operative rehabilitation of the joint[1]. However, little is known about the dynamic, *in vivo* function of the hip muscles during activities of daily living. Marker-based motion capture studies have associated dysplastic hip anatomy with shorter abductor moment arm lengths during walking[2], but these measurements are subject to inherent soft tissue artifact[3]. Biplane radiography is a highly accurate technique for measuring *in vivo* bone motion of the hip[4] and has recently been utilized to estimate dynamic muscle moment arms[1], which are important factors influencing the ability to generate force and torque. Accurate estimates of muscle moment arms during positions of deep hip flexion require muscle models that wrap around bone surfaces[5,6]. Normative *in vivo* moment arms of the hip musculature in asymptomatic individuals have yet to be established, particularly during deep flexion activities that challenge hip stability. The goal of this study was to estimate *in vivo* moment arms of select hip extensors, abductors, adductors, and external rotators during walking and squatting in a cohort of asymptomatic adults. We hypothesized that the maximum moment arm length during squatting would be longer than during walking and static standing.

METHODS: Young adults with no history of hip surgery, chronic hip pathology, or severe lower extremity musculoskeletal injury were recruited to participate in this IRB-approved study. Participants performed treadmill walking and bodyweight squatting within a biplane radiography system while ground reaction forces were collected at 1000 Hz from a dual-belt instrumented treadmill (Bertec Corp.). The support phase of gait was defined by vertical ground reaction forces over 50 N. Synchronized biplane radiographs were collected at 50 images per second to image three trials of each hip for each activity. Subject-specific bone models of the pelvis and proximal femur were created from computed tomography (CT) scans (0.37x0.3x0.625mm resolution). Coordinate systems[7] and muscle origin and insertion points for the gluteus maximus (hip extensor), gluteus medius (hip abductor), gluteus minimus (hip abductor), pectineus (hip adductor), and grouped external rotators[1] were identified from bony landmarks on the 3D bone models. Wrapping surfaces were established for the gluteal muscles by using three cylinders fixed to the pelvis[5,6]. *In-vivo* bone motion during each activity was determined by matching digitally reconstructed radiographs, created from the CT-based bone models, to the biplane radiographs using a registration process with a validated accuracy[4] of 0.3mm. The line of action for each muscle was calculated for each frame of synchronized radiographs as the vector from the muscle origin to the insertion. Moment arm length (MAL) was calculated as the perpendicular distance between the hip joint center and the line of action of each muscle[1]; for wrapped muscles, the moment arm was defined as the longest moment arm along the segmental wrapped line of action. MALs were interpolated to gait cycle for walking and every 2° hip flexion for squatting. Differences between the maximum MAL during static standing, walking, and squatting were assessed within each muscle group using ANOVA with post-hoc pairwise comparisons performed as necessary.

RESULTS: Data from 205 trials of 47 hips from 24 individuals were included in the analysis (11M, 13F; mean age 21.9±2.2years; BMI 21.5±4.9kg/m^2). Average walking velocity was 1.1±0.2m/s and the average maximum hip flexion during squatting was 98.0±16.6°. Maximum MAL was significantly different between all activities except the external rotators, where the maximum MAL did not differ between walking and squatting (Table 1). Moment arms of the abductors were shorter during squatting compared to other motions, contrary to our our hypothesis (Figure 1).

DISCUSSION: This study demonstrates the *in vivo* torque generating capabilities of muscles surrounding the hip (reflected by their moment arm) change considerably from the standing position to positions encountered during active functional motions. Specifically, moment arms of the hip extensors and adductors are larger during squatting compared to walking and static standing, while moment arms of the abductors were smaller during squatting compared to walking. Knowledge of these changes in mechanical advantage can be useful in improving function after surgical intervention. These results are limited to treadmill walking and bodyweight squatting in asymptomatic young adults.

CLINICAL SIGNIFICANCE: Muscles involved in hip abduction and stabilization have less mechanical advantage at greater hip flexion, highlighting the importance of strengthening these muscle groups during rehabilitation.

REFERENCES: 1) Hu, et al., *J Ortho Surg and Res.* 2020. 2) Song, et al., *J Biomech.* 2020. 3) Fiorentino, et al., *Gait Posture.* 2017. 4) Martin, et al., *J Arthroplasty*. 2011. 5) Catelli, et al., *35th ISBS Conference Proceeding.* 2017. 6) De Pieri, et al., *PLOS ONE.* 2018. 7) Wu, et al., *J Biomech.* 2002.

Table 1. *Average MAL (mm) during static standing and average maximum MAL during walking and squatting, shown as mean±standard deviation. Values with matching symbols are significantly different between motions).*

Trial Type	Gluteus Maximus	Gluteus Medius	Gluteus Minimus	Pectineus	External Rotators
Static Standing	74.3±3.9*	50.9±5.6*	46.1±5.6*	36.2±2.3*	33.9±9.9*#
Walking	80.5±3.0*	53.6±4.3*	49.4±4.6*	40.8±2.4*	40.2±8.6*
Squatting	86.8±8.4*	47.8±1.7*	44.4±3.7*	42.0±2.7*	39.4±3.2#

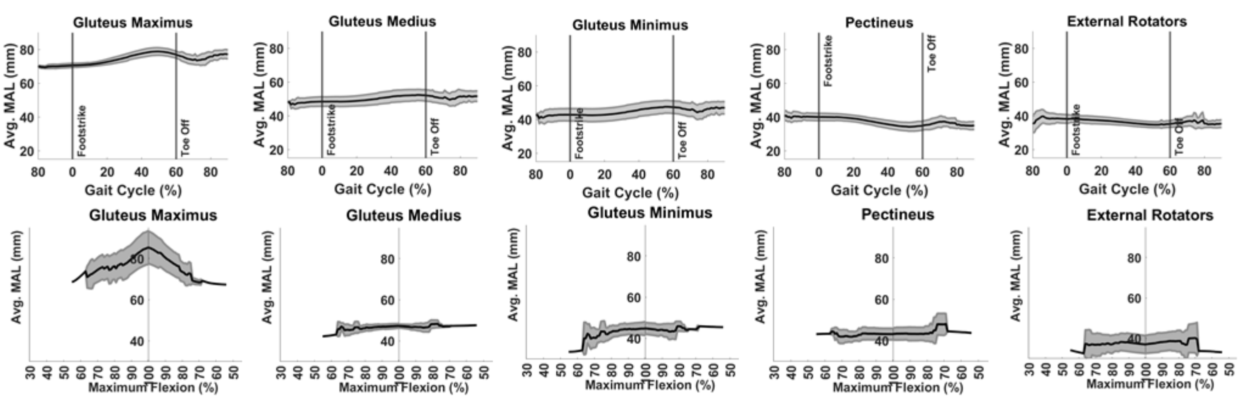

Figure 1: Average moment arm length (mm) across gait cycle (top row) and squatting (bottom row). Solid lines indicate means, and shaded areas indicate standard deviations. For the squatting data, data left of the vertical axis represents the eccentric (lowering) phase and data to the right represents the concentric (rising) phase.