Determination of Muscle Force and Joint Loading in a Simulated Jump Landing Task Using AnyBody

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Disclosures: R. Summers (N), V. Vaddamani (N), T.E. Hewett (NIH), V. Goel (Spinal Balance Inc., OsteoNovus Inc., Turning Point LLC, Endosphere Spine, Depuy, SI Bone Inc., Apex Spine/Medyssey, Spine Soft Fusion, Spinal Elements Inc., AO Foundation/FORE, K2M, NIH, NSF, Third Frontier Program, and ODSA)

Introduction: Understanding the role of muscle forces on knee reaction forces can help identify potential risk for soft tissue injury such as anterior cruciate ligament (ACL) injury and meniscal tears. Chappel et al. showed that women exhibited greater anterior tibial shear force than men in several jump tasks, in addition to larger valgus and knee extension moments [1]. Myer et al. have previously shown decreased medial quadriceps electromyographic (EMG) activity in females when compared to males in an exercise that simulated a high ACL injury risk activity, which indicated decreased control of frontal plane valgus collapse [2]. However, muscle EMG activity is not linearly related to muscle force [3]. Computation of knee muscle forces and joint reaction forces and moments can aid in finite element (FE) investigation of whole knee joint mechanics and investigation of ACL injury risk. The hypothesis tested was that investigation of the muscles utilized during a jump task would aid in further elucidation of sex-based differences in ACL injury risk when included in the FE models.

Methods: Motion capture data was obtained for three male (24.5 ± 0.5 years, 80.74 ± 7.65 kg, 184 ± 3.3 cm) and one female (30 years, 48 kg., 161 cm) using 10 Raptor-E cameras (Motion Analysis Corp., Santa Rosa, CA) and one AMTI force plate (AMTI, Watertown, MA). Cortex software (Motion Analysis Corp.) was used to collect the motion and force plate data. The subjects were fitted with 18 reflective markers located on the left and right sides of the lower body at the anterior iliac spine, posterior iliac spine, greater trochanter, lateral femoral condyle, shank, lateral malleolus, heel, first metatarsal, and fifth metatarsal (Figure 1). The subjects were asked to perform a maximum effort jump task from ground level onto a force plate in front of them. The AnyBody Musculoskeletal Modelling System v6.0.2 (AMS) (AnyBody Technology, Aalaborg, Denmark) lower body gait model from the AnyBody Managed Model Repository v 1.6.3 (AMMR) was used to perform the motion analysis and inverse dynamics calculations [4]. The lower body model included the hip, knee, and ankle joints along with 159 muscles and six joint degrees of freedom [5]. It allowed for scaling of the model to match subject specific anthropometrics and then read the C3D files to guide motion. It used a built-in solver to compute joint reactions and muscle forces that resulted from the motion utilizing an inverse dynamics approach.

Results: Table 1 contains peak force and moment values for all four subjects analyzed in this study. Peak force values are reported for each subject in addition to the body weight (BW) normalized values for comparison. Peak moment values are reported in addition to the BW and height (BW*H) normalized values. The female subject (F1) had a peak anterior shear force (ASF) of 1945 N (4.13*BW). The male subjects averaged a peak ASF of 3294 N (4.1*BW) with a range of 2256 – 4020 N. Peak valgus moment in F1 was 21.1 Nm (0.03*BW*H) and the males averaged 39.40 Nm (0.03*BW*H) with a range of 31.61 – 54.99 Nm. At peak valgus F1 had a vastus lateralis to vastus medialis ratio (VL:VM) of 2.26 while the males averaged 2.19. Subject M2 had minimal VL:VM forces predicted during peak valgus. During landing the model predicted minimal hamstrings forces in the male subjects, but peak anterior shear force did occur at peak quadriceps load. In the female subject the model predicted peak quadriceps load at peak ASF with a ratio of 3.60 with the hamstrings. The males averaged a normalized quadriceps load of 4.17*BW, while the female showed 4.07*BW.

Discussion: The male subjects were considerably larger than the female subject; however, normalized quadriceps loading at peak ASF and VL:VM at peak valgus were close in magnitude. Notwithstanding a limitation in sample size, the results match differences highlighted in the literature between males and females in jump landing tasks, such as lower VM strength in females compared to males, while adding a prediction of muscle forces during these activities [1,2]. Previous studies have shown improved predictions in FE models with inclusion of muscle forces [6,7]. The next steps for this study include the addition of the predicted muscle forces to representative male and female FE models to study the effects of muscle loading on whole knee joint biomechanics during dynamic activities typically seen in sporting activities.

Significance: FE analyses have been used to investigate effects of surgery and injurious loads previously. Addition of physiologically relevant muscle and joint loadings can further increase efficacy and predictive capacity of these models, while simultaneously reducing study costs typically associated with *in vivo* and *in vitro* testing.

References:

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Acknowledgements:

This study was supported in part by the National Institutes of Health (R01 AR056259-06-TEH) and the NSF Industry/University Cooperative Research Center at The University of California at San Francisco, CA and The University of Toledo, Toledo, OH (www.nsfcdmi.org). A special thanks goes to Dr. M. Samir Hefzy for use of his gait lab in conducting this experiment.

Images and Tables:

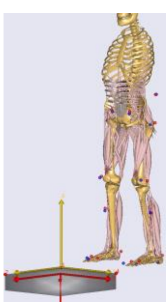

Figure 1. Representative AnyBody model showing virtual (red) and C3D (blue) marker relative locations on the skeleton prior to optimizing virtual marker positions to C3D data.

Table 1. Normalized force (quadriceps and anterior shear force (ASF), body weight only) and moment values (body weight and height) during a simulated jump task for the female (F1) and three male (M1, M2, and M3) subjects. The ratio of vastus lateralis to medialis (VL:VM) forces at peak valgus moment are also presented

Subject	VL:VM	Normalized ASF	Normalized Valgus Moment	Normalized Quadriceps Load
F1	2.26	4.13	0.0279	4.07
M1	2.17	4.4	0.0363	4.65
M2	-*	3.27	0.0255	2.98
M3	2.20	4.63	0.0253	4.81

*M2 predicted VL and VM forces near 0 N in magnitude during landing