INTRODUCTION:
Little is known about the forces in the muscles spanning the hip, and in particular, the forces in the deep muscles that contribute to both mobility and stability of the joint. Understanding the force in the muscles spanning the hip is motivated by the high incidence of injury and degenerative disease at the hip, and the frequency of its surgical treatment. Moreover, recent advances in hip arthroscopy have renewed interest in understanding how the muscles contribute to hip stability and joint load. The stability of the hip during activity is achieved through a balance of bone, muscle, and external forces. Unfortunately, direct measurement of hip muscle forces in vivo is unworkable. Furthermore, studies utilizing instrumented hip prostheses to measure hip joint loads cannot be used to infer muscle force, or applied to the normal or injured joint. Alternatively, musculoskeletal modeling allows muscle and joint loads to be obtained non-invasively.

A three dimensional musculoskeletal model of the human body was used to predict forces in the muscles spanning the hip. The model was developed and verified using OpenSim [1]. A small number of researchers have modeled the interactions between the bones and muscles of the hip. However, few studies have examined the behavior of the joint under loading conditions that occur during daily activity, rehabilitation, and sport. Perhaps most significantly, the mathematical model presented here gives detailed consideration to the geometrical and mechanical properties of the musculotendinous units spanning the joint.

The purpose of this study was to calculate the force in the hip muscles during squatting exercise. Squatting exercise is a common strengthening and rehabilitation activity that also mimics motion found in many sports. The calculations were verified by comparison with measurements of muscle activation made using surface and indwelling EMG.

METHODS:
Hip muscle forces were calculated using a musculoskeletal model of the body that contained a detailed representation of the muscles spanning the hip. The model was built in OpenSim [1] and based on the anthropometry and muscle parameters reported by Delp [2], Anderson and Pandy [3], and Shelburne et al. [4]. The body was represented as a 10-segment, 23 degree-of-freedom articulated joint [3]. Twenty muscles span each hip in the model.

The lower-limb model required as input the joint angles and ground reaction forces for the squatting task. These inputs were obtained from ten healthy individuals (1.72 ± 0.04 m; 674.17 ± 143.3 N; 28.70 ± 2.00 y). All participants provided written consent prior to participation, in accordance with the Vail Valley Medical Center’s Institutional Review Board. The maximum sagittal motions of a partial squat are limited to ~60º of hip and knee flexion. Indwelling electrodes were used to record (1200 Hz) muscle activation from the pectineus, iliopsoas, gluteus medius and piriformis muscles. The electrodes were ultrasound guided to assure correct placement into the muscle and for patient safety. Surface electrodes were used to capture the activation of the gluteus maximus, semimembranosus, adductor longus, and rectus femoris. The EMG data were scaled to maximum EMG reference values measured during the MVC trials. A ten-camera motion analysis system (Motion Analysis, Santa Rosa, CA, USA) was used to capture three-dimensional hip motions at a frequency of 120 Hz. Ground forces were recorded by two forceplates (Bertec), one located under each foot.

RESULTS:
Muscle forces during squatting were calculated using computed muscle control optimization OpenSim [1]. Computed muscle control tracks the kinematic and ground force data of each subject while minimizing the square of muscle stress. Prior to muscle force calculation, the baseline musculoskeletal model was scaled to the height and weight of each subject.

Figure 1: Musculoskeletal model of the body with detail focused on the hip musculature.

Figure 2: Predicted force in the Piriformis and Gluteus Medius muscles.

DISCUSSION:
A 3D model of the body including a detailed model of the hip musculature was used to calculate muscle forces during squatting exercise. Forces in the deep muscles of the hip, (i.e. piriformis, pectineus, iliopsoas, and gluteus medius and minimus) all remained well below their maximum capacity throughout the exercise. This is in agreement with EMG measurements that show these muscles operating generally well below 25% MVC.

REFERENCES:

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