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DESIGN OF STRENGTH EXERCISES FOR THE ABDUCTOR MUSCLES USING MUSCULOSKELETAL MODELING

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Strength training exercises, require a specific joint range of motion and muscle-specific loading to avoid injury and allow adaptation of tissue. The purpose of this study was to design suitable strength training exercises for the hip abductor muscles based on predicted joint loading and motion. Using Opensim modeling, hip abduction/adduction movement was combined with internal/external rotation of the hip and an external force that was applied to the foot. The direction of the force was systematically rotated to mimic a change of the position towards the cable pulley system. *M. gluteus medius* was divided into an anterior and a posterior part. It was not possible to find a single exercise that allowed the training of the anterior and the posterior part simultaneously with a muscle activation >50%. Herein, it has been shown that modeling can be used to design strength-training exercises.

KEYWORDS: strength training, prediction, hip kinetic and kinematic.

INTRODUCTION: During strength training and rehabilitation, the joint range of motion and the internal muscle loading defines the mechanical load of the tissue. Mechanical load can either provoke an acute or overuse injury or a positive adaptation of the tissue. A direct internal measurement of the muscle loading or joint contact force is not possible using noninvasive techniques. For the lower extremities, musculoskeletal modeling can be used to quantify the internal loading conditions during strength training (Schellenberg, Oberhofer, Taylor & Lorenzetti, 2015). Specifically, Schellenberg et al. (2018) validated musculoskeletal modeling with an instrumented artificial knee using the total knee joint force as outcome of the musculoskeletal modelling. Here, the error of the total knee joint force within a flexion angle of 25° to 60° was less than 20%. The average error behaved almost linearly with knee flexion angle, and an overestimation of approximately 60% was observed at deep flexion (ca. 80°) with an absolute maximum error of ca. 1.9 BW.

Using a traditional inverse dynamic approach to calculate the internal loading conditions requires the movement of the segments of the lower limbs as well as the forces acting on these segments. The specific muscle forces can be calculated using the external joint moments and muscle optimization. For the predictive use of musculoskeletal modeling, segment kinematics is required as a modeling input (Plüss, Schellenberg, Taylor & Lorenzetti, 2018). Systematic variation of the external load conditions provides a basis for designing or improving strength exercises for a specific subject and targeted loading of the musculoskeletal structures. In this work, we use the predictive power of such an approach for the example of the abduction muscles of the hip. In particular, the influence of a neutral hip internally as well as externally and the rotation position of the hip were of interest.

Around the hip musculature, strength deficiencies and muscular imbalance are related to injury, such as those in ice hockey players (Tyler, Nicholas, Campbell & McHugh, 2001) or in long-distance runners (Fredericson et al., 2000) and retro patellar pain syndrome (Santos, Oliveira, Ocarino, Holt & Fonseca, 2015).

Therefore, the aim of this work was to model a cable pulley that allows a specific direction of force application and segmental motion on the frontal plain to design strength exercises. The activation in the anterior and posterior part of the abductor muscles were evaluated with respect to the muscle length by means of musculoskeletal modeling.

METHODS: A specific cable machine strength exercise for the movement in the frontal plane representing the hip abduction and adduction was simulated using the open source software Opensim (Delp et al., 2007). Details about the used model, muscle models, and optimization procedure can be found in our previous work (Plüss et al., 2018). The required kinematic inputs of the model were created in MATLAB, including a sine-shaped movement velocity-time curve with a maximum movement speed of 40 degrees per second and a frequency of 100 Hz. The abduction/adduction movement is performed with a starting position at -35 degrees of abducted hip and a movement reversal point at 5 degrees of hip adduction. Additionally, each of the three following hip rotation configurations were simulated: neutral (0°), internal rotated (40°) and external rotated (-40°). An external force with the magnitude of 100 Newtons was applied to the center of a rigidly to the leg attached cylinder, representing the ankle strap. However, the total movement the external force stays parallel to the ground. An initially medial pointing external force was rotated by 15 degrees counterclockwise for every simulation until full rotation was attained. This rotation represents the varying body orientation to the cable machine. The change in muscular activity was evaluated with respect to the hip internal /external position. The muscular activity is here directly defined as the fraction between the actual muscle force divided by P0, the maximal muscle force.

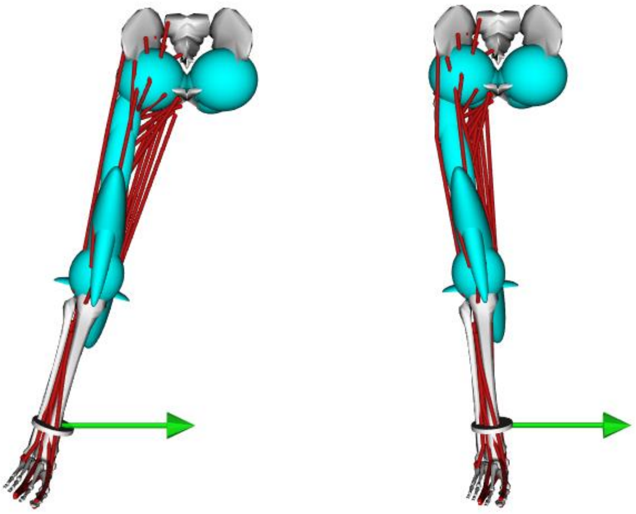

Figure 1: Adduction/abduction movement of the hip in the frontal plane. The external force is applied horizontally. The hip is in a neutral position regarding internal/external rotation.

RESULTS: By varying the position towards the cable and changing the hip rotation configuration, the loading of the *M. gluteus medius* could be influenced. Using an external hip rotation position, the activity for the posterior part could be increase by a factor of 2. The change of the muscle length was lower compared with the normal position. Similarly, for the anterior part, an internal hip rotation position was required to increase the muscle activity by a factor of 2. Here, not only the activity but also the change of the muscle length was enhanced. No setting was found that allowed simultaneous training for the anterior and posterior parts with an activity level >0.5.

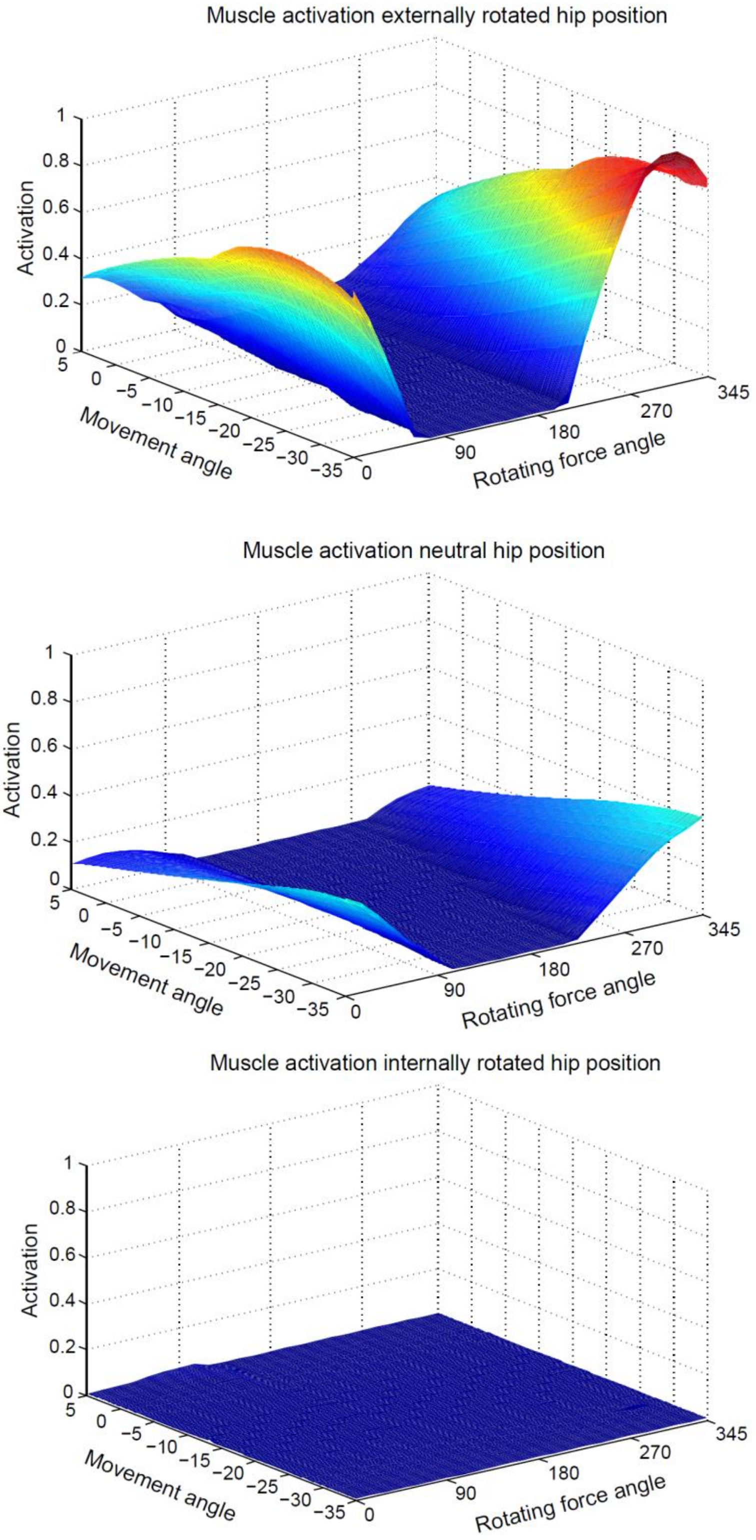

Figure 2: Activation pattern of the posterior part of *M. gluteus medius* with respect to the hip adduction/abduction angle and the direction of the external force. Top: externally rotated hip position. Middle: neutral hip position. Bottom: internally rotated hip position.

DISCUSSION: Knowledge about internal muscle movement and internal loading conditions on the tissues are crucial for targeted training. Herein, a classic hip abduction strength exercise with an external load using a pulley system was simulated with the aim to quantify the muscle loading and movement. Based on the existing literature, it is well known that the direction of the external force highly influences the muscle activation pattern. The main finding of the study provides evidence to select suitable exercises as well the set-up of the cable system to the athlete. This study demonstrates that the hip rotation position is also of great importance. Khayambashi, Mohammadkhani, Ghaznavi, Lyle and Powers (2012) used an internal rotation of the hip during strength training exercises for abductor muscles to show an improvement of pain and health status in women with patella femoral pain syndrome compared with a control group without exercise.

CONCLUSION: The hip rotation position has a strong influence on the activation of the *M. gluteus medius.* No setting was found that allowed the simultaneous training of the anterior and the posterior parts. Thus, two different exercises need to be performed. An internally rotated hip is recommended to train the anterior part, while an externally rotated hip should be used to train the posterior part.

Herein, it was possible to show the predictive power of musculoskeletal modeling. In the future, such approaches can be used to design strengthening exercises based on the individual anatomy in a subject-specific manner.

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