CHANGING THE STRENGTH OF MUSCLES CROSSING SINGLE LOWER LIMB JOINTS ONLY AFFECTS KNEE JOINT REACTION FORCES

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Introduction

Musculoskeletal (MSK) models are used to estimate the muscle and joint reaction forces (JRFs) in clinical patients by personalizing features such as muscle strength [1]. For example, total knee arthroplasty (TKA) can be associated with a 30% reduction of the maximum isometric force (F_{iso}) of the muscles crossing the replaced joint [2]. This study aims to quantify alterations of JRFs in the lower limb when F_{iso} of muscles crossing either the hip, knee, or ankle joints are altered.

Methods

A gait trial of an 86-year old man with a left instrumented TKA [3] was simulated using a generic OpenSim MSK model [4] scaled to the participant's anthropometry. Joint angles and moments were calculated using the inverse kinematics and inverse dynamics tools. Static optimization and joint reaction analysis were used to estimate muscle forces and JRFs at each joint of the lower limb after altering the F_{iso} of the muscles crossing the hip, knee, or ankle joints from their nominal values up to $\pm$40% in increments of 10%. For comparison, analyses where F_{iso} was altered at the same time for all muscles in the model were also carried out. The differences between the peaks of the JRFs estimated by the nominal and modified models were quantified. Also, the second peak of the JRFs at the knee during late stance was compared against the in-vivo measurement.

Results

The JRFs are presented in Figure 1 with respect to varying F_{iso} of different muscle groups. The variation of the peak JRFs from the nominal value ranged from -0.05 to 0.63 BW at the hip, from -1.39 to 1.43 BW at the knee and from -0.15 to 0.6 BW at the ankle. Weakening the strengths of muscles crossing the hip joint increased the knee JRFs by 1.43 BW at maximum, while this had a limited effect (<0.15 BW) on the peaks of the hip and ankle JRFs. Decreasing F_{iso} of the muscles crossing the knee resulted in a maximum knee JRFs reduction of -1.39 BW at its peak load but not significant changes at the hip and ankle (<0.12 BW). F_{iso} of the muscles spanning the ankle joint had influence on the JRFs at the knee (0.76 BW) and the ankle (0.6 BW) but almost none at the hip (0.02 BW). The changes in all muscle strengths resulted in a similar variation of joint loads at each joint (<0.63 BW). In the swing phase of the gait cycle, there were also minor changes in the hip and ankle JRFs (<0.28 BW). The model with the 40% weaker knee-spanning muscles estimated JRFs closer to the in-vivo knee loads (0.28 BW overestimation at the second peak).

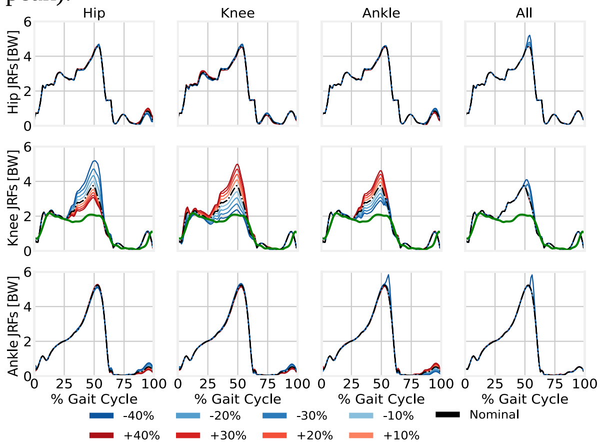

Figure 1: The JRFs at the hip, knee and ankle (rows) for changes in the F_{iso} of the muscle groups of the hip, knee, ankle and all muscles (columns). JRFs from the nominal model are shown in black. Experimental measurement (green) is available for the knee JRFs.

Discussion

As expected, the changes in the strengths of a muscle group altered muscle recruitment and affected other joints via the bi-articular muscles. However, simulation quality was not compromised (muscle forces sustained $\geq$95% of the peak joint moments calculated from inverse dynamics) and joints were differently affected by these alterations. The most and least sensitive JRFs to the changes in strengths of muscles crossing individual joints were the knee and ankle ones respectively, consistently with the findings of [5]. The reduction in the peak JRFs at the knee joint was also comparable to [5] (0.6 BW) although muscle recruitment did not aim to minimize the JRFs and further reduction in F_{iso} of knee-spanning muscles would still be possible. Finally, the best match-up between predicted and recorded JRFs at the knee was found using a 40% decrease in F_{iso} for muscles crossing the knee, consistently with the approach of [1].

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