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INVERSE DYNAMICS OPTIMIZATION INCLUDING MUSCLE DYNAMICS – INFLUENCE ON THE MUSCLE FORCE SHARING PROBLEM OF THE SHOULDER

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Abstract: The muscle dynamics, i.e., activation dynamics and muscle-tendon contraction dynamics, are rarely considered in inverse dynamic simulations due to the limitations of the optimization methods commonly applied. The static optimization cannot handle time-dependent objective functions or constraints because it solves each instant of time independently, whereas the global optimization and extended inverse dynamics methods are limited by the number of muscles and instants of time that can be considered as the size of the optimization problem rapidly becomes too large to be solved. A novel method, named window moving inverse dynamics optimization (WMIDO), was recently proposed to overcome these limitations and allow the analysis of time-dependent objective functions and constraints. Considering that the influence of the muscle dynamics on inverse dynamic simulations is still an open issue, the aim of this study was to compare, using WMIDO, the biological performance of four musculotendon models differing in the simulation of the muscle activation and contraction dynamics. The muscle force sharing problem was solved for abduction and flexion motions of the shoulder using a musculoskeletal model of the upper limb. The musculoskeletal model applied is composed of 7 rigid bodies, constrained by 6 anatomical joints, and acted upon by 22 muscles, represented by 74 muscle bundles. A three-element Hill-type muscle model is used to describe the muscle behavior. Four musculotendon models were considered: (1) rigid tendon model without activation dynamics,[(2)]rigid tendon model with activation dynamics,[(3)]elastic tendon model without activation dynamics, and (4) elastic tendon model with activation dynamics. Considering the Lagrange multipliers associated with the kinematic constraints and the muscle forces as design variables, the muscle force sharing problem was formulated as the minimization of the muscle energy consumption subjected to the fulfillment of the equations of motion, the boundary constraints of the muscle activations, and the stability constraints of the shoulder and scapulothoracic joints. The simulations including activation dynamics had also to ensure the boundary constraints of the muscle excitations. The inverse dynamics optimization was solved in Matlab using WMIDO with a window size of 10 instants of time and a marching step of 4 instants of time. The muscle and joint reaction forces were similar for all musculotendon models considered, which suggests that for slow-speed, standard movements of the upper limb, the activation and muscle-tendon contraction dynamics can be neglected without compromising the solution of the muscle force sharing problem.