PROPOSAL OF A METHOD BASED ON THE JOINT REACTION FORCES TO CHOOSE THE MOST PHYSIOLOGICAL OPTIMISATION CRITERION IN INVERSE DYNAMICS ANALYSIS

[1]Luca Modenese, [2]Nicola Petrone, [1]Andrew Phillips

[1]Division Structural Biomechanics, Dept. Civil and Environmental Engineering, Imperial College, London, UK

[2] Mechanical Engineering Department, University of Padova, Italy

email: l.modenese08@imperial..ac.uk , web: http://www.imperial.ac.uk/structuralbiomechanics

INTRODUCTION

The most frequent use of musculoskeletal models in clinical application is in inverse dynamic analysis, where the kinematics (input of the simulation) is usually supplied by motion capture sessions. The muscle forces necessary to execute the movement (output) are calculated by minimising an objective function that is supposed to have a physiological meaning [1]. This procedure is necessary due to the statically indeterminate nature of the problem. The expression of the cost function is not a negligible parameter of the simulation because it could influence deeply the predictions of the model, so the choice of it becomes a crucial step in setting up an inverse dynamic analysis.

Also accepting the assumption that, in recruiting the muscles the central nervous system (CNS) uses an optimum criterion, the physiological object of the optimisation is not clear: for instance, it could be muscular fatigue [2] or a mechanical performance index [3] in dependence of the task required and the characteristics of it.

This study outlines a possible rationale to choose the most feasible recruitment criterion when using a musculoskeletal model to analyze a task with known kinematics and joint reaction forces (JRFs).

METHODS

In this study the hypothesis of a fixed minimisation function to emulate the CNS strategy was rejected and it was proposed instead to consider the JRFs as indirect indicators of the muscle recruitment criterion adopted. Therefore the objective function was chosen after comparing the JRFs measured *in vivo* with the ones predicted by the model.

As the glenohumeral forces (JRFs between scapular glenoid and humeral head) were measured with an instrumented prosthesis in a patient performing some simple tasks [4], this data was considered the physiological *gold standard* to evaluate the potential of the proposed method. Using a three dimensional shoulder model available in the AnyBody® database (geometric parameters taken by [5]), a 45° pure abduction in the sagittal plane was simulated considering two different load conditions: unloaded arm and holding a 2 kg dumbbell. JRFs for this tasks are available in [4].

Three different recruitment criteria were used to solve the same inverse dynamic analysis generated by the imposed kinematic data (a sinusoidal joint angular function that allows defining complete 45° abduction in 4s): a linear criterion, a polynomial quadratic criterion and a min/max criterion (for a review see [6]). A constant strength muscle model was used (maximum muscle forces independent of fiber length and contraction velocity), as the main interest was not in muscular modelling but mainly in the application and evaluation of the proposed method.

RESULTS AND DISCUSSION

The results of such simulations were consistent with the conclusions of some previous studies. The linear approach, as found in [7] but analysing the muscle forces, is the least physiologically meaningful in both simulations.

For the unloaded case, the min/max criterion is clearly the most suitable, in the loaded simulation the quadratic criterion is preferred. The difference in the preferable criterion is due to the excessive muscular synergism [8] when using the min/max criterion in the loaded simulation.

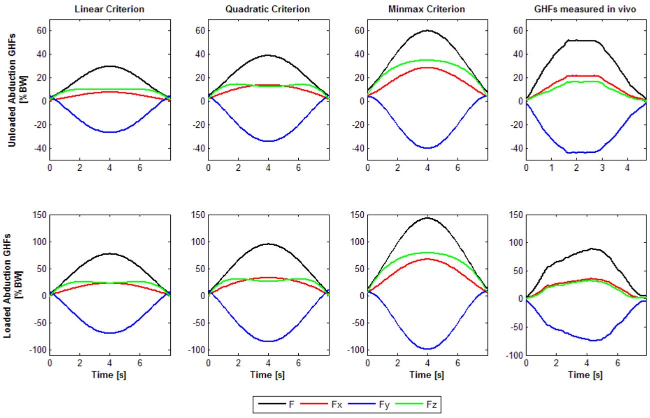

Figure 1: Glenohumeral forces for loaded (2 kg) and unloaded 45° abduction of the shoulder for different muscle recruitment criteria and *in vivo* [4]. Force components are referred to ISB recommended coordinate systems.

CONCLUSIONS

A method based on the measured JRFs was proposed to choose the most physiological muscle recruitment criterion when solving inverse dynamic problems.

The results from a preliminary study were encouraging to further develop this method in order to include an explicit relationship between the numerical and the experimental JRFs directly in the minimised objective function. In such a way a further physiological constraint will be imposed to the optimization problem, improving the predictions of musculoskeletal models containing joints where is possible to measure the JRFs.

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