AN ALGORITHM FOR ESTIMATION OF SHOULDER MUSCLE FORCES FOR CLINICAL USE

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INTRODUCTION

The complexity of the shoulder joint, with its extensive range of motion and large number of muscles, calls for close examination of possible muscular strategies involved, to understand some of the disorders of this intricate articulation and to treat these more effectively. Because each muscle can possibly give rise to rotation components about three orthogonal axes simultaneously (for instance, it could abduct, flex, and medially rotate the humerus at the same time), it becomes necessary to describe the muscular effect on the shoulder joint for each of these three actions, separately. Most of the previously developed computational methods have unfortunately been tailored to meet special cases of loading (usually to balance an external moment acting in one principal direction) and therefore do not readily lend themselves for application in a clinical environment where one wishes to test, for instance, the effect of a neurological or muscular deficiency on a model in which an arbitrary combination of external loading conditions would apply. We therefore developed an algorithm to predict muscle forces and test joint stability, for any external load and in 12 discrete positions of the humerus with respect of the scapula.

METHODS

Moment arm length and line of action of each muscle segment was measured off a realistic three-dimensional full-size epoxy model of the thorax, scapula and proximal humerus, based on a fresh cadaver adult specimen, using the tendon travel method [1], in the 12 arm positions of interest. The muscles of the shoulder were segmented to allow for differentiated actions. The algorithm for shoulder force estimation (*ASFE*) involves decision-making iteration loops. In the main loop, muscle segments that can exert a significant moment to oppose the greatest of the three external moment components, while totally disregarding the two lesser ones, and muscle segments that can exert moments which oppose all three external components simultaneously, are first chosen. A small arbitrary force is initially attributed to this set of muscles in proportion to their cross-sectional area and introduced in the system of equilibrium equations. In further, similar, iteration steps, new values of muscular forces are attributed that again equilibrate only a small proportion of the remaining unbalanced external force. Only small increments of muscle force are attributed in each loop to ensure that at no stage, the muscular moment overshoots the external one. The issuing imbalance, also referred to as 'error', converges to an acceptable level. Each thus determined muscle force is stored after every loop and finally summed up to give the final estimate. The resulting joint force is calculated by adding all muscle forces to the external force and is controlled to fall within the glenoid boundaries. If joint stability is not reached at the end of the process, a superimposed force exerted by all

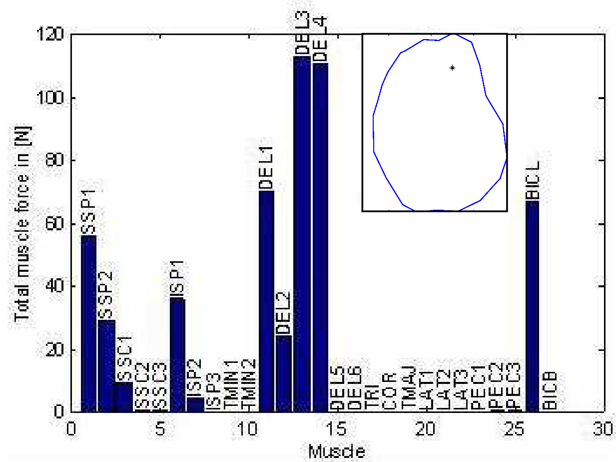

Figure 1: Forces exerted by the 27 muscle segments for abduction with a 9Nm external moment and with the humerus in 30° elevation in the scapula plane and in neutral rotation. The inserted field shows the intersection of the resultant with the glenoid.

the rotator cuff muscles (enforced cavity-compression through co-contraction) is simultaneously raised, and the algorithm restarted until stability is achieved.

RESULTS AND DISCUSSION

The worked-out examples show interesting features of probable muscular activity and give results in good agreement with the literature (simulations, electromyographic studies). Figure 1 is an example. Although stability can be achieved by increasing the overall rotator cuff activity (co-contraction), this is rarely necessary. This also ensures that the magnitude of the resultant is kept as low as possible. Muscle segmentation is of paramount importance for spatial control.

The ASFE offers the advantage of very short calculation time, in generally less than 5 minutes, with a commonly available PC when run with the well-known and widespread Matlab© software.

This algorithm represents a novel force estimation method and a new alternative to the available shoulder simulations.

The strategy of force sharing among muscles opens up the possibility to examine the outcome of muscle deficiencies and to investigate causes of joint instability as encountered in clinical practice.

REFERENCES

1. Fick AE, et al. *Anatomisch-mechanische Studie über die Schultermuskeln, 2. Teil*, Verh Phys-Med Gesell, Würzburg, 1877.