COMPARISON OF TWO METHODS TO PREDICT FORCES IN DEFICIENT ROTATOR CUFF MUSCLES AFTER TOTAL SHOULDER ARTHROPLASTY

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Introduction

Rotator cuff deficiency after total shoulder arthroplasty (TSA) leads to unsymmetrical prosthesis wear and premature failure. To investigate this issue with a shoulder model, the mechanical indeterminacy of the shoulder must be solved to determine the muscle forces. Two methods are usually applied to solve this indeterminacy: EMG data is used as reference or a physiological hypothesis is minimized. In this work, we implemented both methods into the same musculoskeletal model and simulated normal and deficient rotator cuff muscles.

Methods

This work was done using a model of the glenohumeral joint (GH) after TSA (Aequalis, Tornier) [Terrier, 2007]. The model included deltoid and rotator cuff muscles. Muscles were represented by a passive part, which wrapped around anatomic structures, and an active part to generate the muscle force. Muscle deficiency in the subscapularis was simulated by reducing its physiological cross sectional area to 50%. Bones and humeral head (HH) were modelled rigid. The glenoid implant was linear elastic. An abduction movement from a rest position to 150° was simulated. The translation of the humerus was constrained by the wrapping muscles only to allow its translation on the glenoid. The scapulohumeral rhythm was reproduced [McClure, 2001]. The arm weight was 37.5N (5% BW). The equilibrium of moments was as follows:

$$\sum r_m \times f_m = R_m \times F_m = -\sum r_e \times f_e \qquad (1)$$

with muscle forces f_m and external forces f_e, corresponding moment arms r_m and r_e, the muscle moment arm matrix R_m and the vector of muscle forces F_m. This equation was indeterminate: 10 unknown muscle forces in 3 equations associated to the 3 rotation axes. Two methods were implemented to solve the indeterminacy:

1) EMG method used experimental EMG data as input [Kronberg, 1990]. The algorithm provided muscle forces that satisfied the equilibrium (eq. 1) while staying as close as possible to EMG data [Terrier, 2012].

2) OPT method used the pseudo-inverse of the singular moment arm matrix (eq. 1) to estimate muscle forces through a nullspace optimization process [Ingram, 2012]. The physiological hypothesis was to minimize the sum of square muscle stresses.

Results

In both normal and deficient cases, muscle forces were higher with the EMG than with the OPT method, except for the middle deltoid. Maximal GH load was higher for the EMG than with the OPT method (16% normal, 18% deficient). HH translations were smaller with the EMG than with the OPT method.

In the deficient case, both methods predicted decreased rotator cuff muscle forces and increased MD forces. Both methods predicted decreased GH load and larger inferior-superior HH translations in the deficient case.

Discussion

The comparison of the two methods highlighted their advantages and limits. The EMG method corresponds obviously to real muscle activity but requires EMG data which is difficult to measure. OPT method can be applied to arbitrary movements, but may underestimate rotator cuff muscles. Although both methods predicted the same destabilizing effects for SC deficiency, the choice between these two methods could be critical for analysing prosthesis failure processes.

References

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