GENERATION OF SUBJECT SPECIFIC SHOULDER KINEMATIC MODELS FROM MOTION CAPTURE DATA AND ANYBODY SIMULATION

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SUMMARY

Kinematic data of a single subject was obtained using the facilities at the Motion Capture Laboratory at Cardiff University School of Engineering. The subject was asked to perform a series of Activities of Daily Living (ADLs) as well as defined anatomical motions (e.g. forward flexion), while the motion data was captured. Using the software package, AnyBody Modelling System™ (AnyBody Technology A/S), the motion capture data was input to an upper torso model available within the open repository of the vendor and the joint reaction forces at the glenohumeral joint were evaluated.

Comparison of peak glenohumeral joint loads calculated for abduction of the humerus versus those determined by Bergmann et al. in other published work show very good agreement in the case where no weight is carried, and the situation with 2kg weight also shows very good agreement with only small overestimation. The peak glenohumeral loads calculated for the three different daily activities were all in good agreement with those calculated by the Newcastle shoulder model either being at the maximum value or in between max. and mean values.

INTRODUCTION

In order to guide the design of orthopaedic implants, it is essential to have accurate knowledge regarding the mechanical loading conditions the implant is subjected to. Whilst it is well established that some instances of motion are more aggressive in terms of glenohumeral loading than others (e.g. 90 degrees of humeral elevation/abduction is often referred to as a worst case condition in the arm) [Refs?], it is not well established that these necessarily represent the “worst cases” in terms of fixation or in terms of eccentric loading.

A careful consideration of the realistic spectrum of motion of the shoulder enables identification of other instances of loading which may subject the glenoid fixation to high eccentric loads. This input is needed to develop more detailed knowledge about the envelope of loading which should be used as input for the verification of the designs of shoulder arthroplasty.

To account for the high degree of variability in performing the same activity between different subjects, it is important to use subject specific motion capture data to drive any mechanical analysis of the loading conditions in the glenohumeral joint. It is possible that an activity which generates an instance of high load in one subject may not be as critical an activity as it is in other subjects.

The objective of this study is to make use of motion capture data for the upper limb to enable an analysis of the joint reaction forces in a shoulder, using an inverse dynamic model of the shoulder. Comparison between these results against those available in the broader published literature will be made to evaluate the validity of the methodology. The ultimate goal of this work is to develop advanced testing standards for the upper limb.

METHODS

Acquisition of Motion Capture Data:
Kinematic data for a healthy subject was acquired in the Motion Capture Laboratory at Cardiff University School of Engineering. A Qualisys Pro-Reflex system and skin marker clusters were used to track the relative positions in global space of a series of, where possible, palpated bony landmarks (see Figure 1). The subject was asked to perform a series of Activities of Daily Living (ADLs) as well as defined anatomical motions (e.g. forward flexion), while the motion data was captured [1]. A scapular locator was used to evaluate any artifacts introduced to the motion capture due to relative motion between the skin and scapula bone. This was recorded statically at defined intervals during the anatomical motions. Joint rotations were recorded with respect to the guidelines of the International Society of Biomechanics (ISB) [2].

![Fig 1: Marker locations on the upper limb used for Motion Capture](image)

Analysis of Joint Reaction Forces:
Using the software package, AnyBody Modelling System™ (AnyBody Technology A/S), the motion capture data was input to an upper torso model available within the open repository of the vendor. The three dimensional
musculoskeletal model of the shoulder complex, which is based on the Dutch Shoulder model [3], allows for an estimation of muscle and joint contact forces based upon kinematic input by means of an Inverse Dynamic Analysis and an optimisation algorithm for muscle recruitment. The humeral and scapular anatomies for the AnyBody skeletal model were scaled to the subject specific segment lengths.

Based on the subject specific motion capture data, abduction of the humerus to 45 degrees, with and without a 2kg weight in the hand, was modelled and peak joint reaction forces were compared to in vivo data measured with an instrumented shoulder prosthesis by Bergmann et al. [4]. In addition, three activities (eating, reaching opposite axilla, reaching side and back of head) were also simulated and compared to the results from the Newcastle Shoulder Model [5].

RESULTS
Comparison of peak glenohumeral joint loads calculated for abduction of the humerus versus those determined in vivo [4] shows very good agreement (3%) in the case where no weight is carried, and the situation with 2kg weight also shows very good agreement with only 6% overestimation (Figure 2). The peak glenohumeral loads calculated for the three different daily activities were all in good agreement with those calculated by the Newcastle shoulder model [5] either being at the maximum value or in between max. and mean values (Figure 3).

CONCLUSIONS
Glenohumeral joint reaction forces calculated using the Cardiff Motion Capture data with the model used for this study were able to demonstrate a high degree of equivalence with those calculated by previous studies [4,5] despite larger subject specific variation that could have been expected. Co-contracture of the muscles, which is still a challenge to be captured in a numerical model, most likely account for the underestimation of the joint reaction force during a 45° abduction activity without weight in the arm vs. with weight in the arm (Fig 2). These promising results support continued use of this modelling approach to determine the loading response for additional activities of daily living, with motion capture data recorded from a larger number of subjects to account for subject specific kinematics and loading.

REFERENCES