Computer assisted surgery of the shoulder: validation of a model using a tendon transfer operation

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Introduction

A modelling and visualisation tool for use in computer assisted shoulder surgery is currently under development, based on the finite element musculo-skeletal model described in van der Helm (1994). Kinematics of the upper limb are input to the model, and optimised muscle and joint forces form the output. The model has previously been shown to simulate musculo-skeletal behaviour in the healthy upper limb (van der Helm, 1994). The aim of this study was to validate predictions of the model in the context of a tendon transfer procedure.

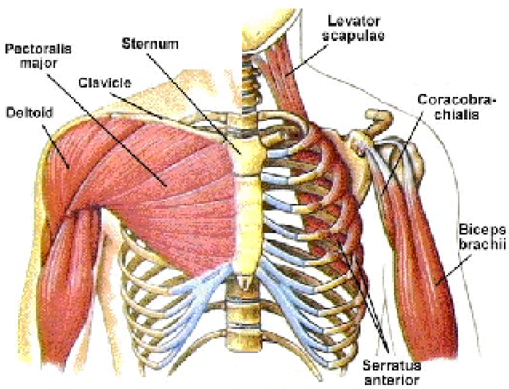

Figure 1 Anatomy of the shoulder (adapted from Martini et al., 2000)

The patient chosen for the case study was a 40-year-old female with a partial paralysis of serratus anterior caused by an injury to the long thoracic nerve. The predominant function of serratus anterior is to maintain the position of the scapula against the thorax during elevation of the arm. This function had been restored in this patient by a transfer of part of the pectoralis major to the angulus inferior of the scapula. The anatomy of the shoulder is shown in Figure 1.

Methods

A three-dimensional motion analysis system (Flock of Birds, Ascension Technology Inc., Burlington, Vermont, U.S.A.) was used to measure the kinematics of the shoulder girdle during anteflexion, abduction and scapular abduction. Receivers were placed on the thorax and upper arm and the movement of the scapula was measured quasi-statically using a scapular locator (Johnson *et al*., 1993). Bilateral recordings were taken before the operation and model simulations using the kinematics of the affected side were used to assist in diagnosis, and simulations of the healthy side were used for control. A tool for the visualisation of the kinematics was developed using VRML (Virtual Reality Mark-up Language), allowing the kinematics to be studied using a standard internet browser. Simulation of the affected side was achieved by reducing the maximum force of the serratus anterior to 5% of its normal maximum value in the model. Simulation of the surgical procedure was achieved by moving part of the pectoralis major insertion to the angulus inferior of the scapula. A SIMM (Musculographics Inc., California, U.S.A.) interface was developed for the manipulation of the model (Figure 2). Behaviour of the model before and after simulation of the transfer was compared with the actual situation of the patient before and after surgery.

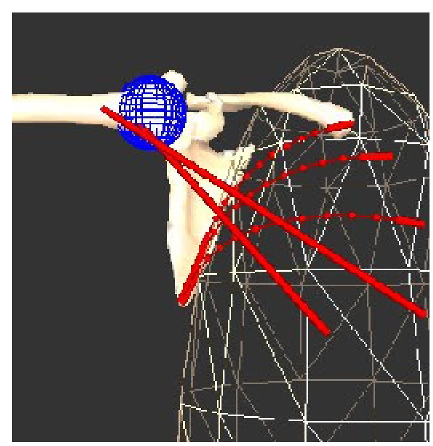

Figure 2 SIMM visualisation of transfer of part of pectoralis major in the model

Results and Discussion

Preoperative measurements of the patient showed that she was able to achieve 120º of humeral elevation, but displayed an abnormal scapular motion. The angulus inferior failed to move laterally in an abduction

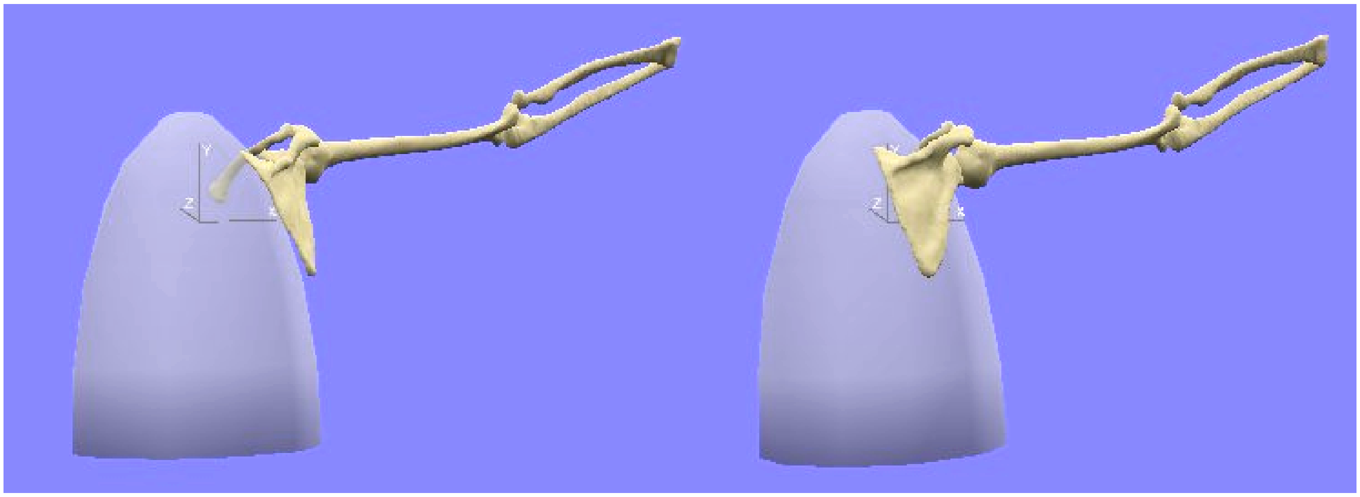

Figure 3 - left: normal scapular motion; right: scapular motion with paralysis of serratus anterior (screenshot of VRML viewer)

of the arm as one would expect, but instead lateral rotation of the scapula was achieved by the superior part of the scapula moving medially (see Figure 3). In a model simulation with the serratus anterior paralysed, the model was unable to find solutions (no feasible set of muscle forces existed to provide equilibrium) for more than 60º of humerus elevation with normal scapular kinematics, but could solve for the situation where the measured abnormal kinematics were used. This reinforces the diagnosis of serratus anterior paralysis as the model reproduces the behaviour that we observe.

In a simulation of the postoperative case, the model was able to simulate normal kinematics of the scapula, with the transferred part of pectoralis major producing almost as much force as the normal serratus anterior. Figure 4 shows the moment balance at the acromio-clavicular (AC) joint, around the z axis (antero-posterior) during an anteflexion movement. The movement was carried out quasi-statically in 17 steps (sample nr. in the figure). The solid lines (model 1) show the control case, where the force of serratus anterior and the contact force between the angulus inferior and the thorax balance the weight of the upper arm and the force of rhomboideus. The dotted lines (model 2) show the post-operative case, where the effect of serratus anterior is clearly reduced (force is limited to 5% of normal maximum) and pectoralis major is used to compensate for this. The model was able to simulate abduction of the arm to 120º with normal scapular kinematics in the post-operative case. No postoperative measurements of the patient are available at the time of writing, but the patient is reported to have excellent shoulder function and a near normal pattern of scapular movement.

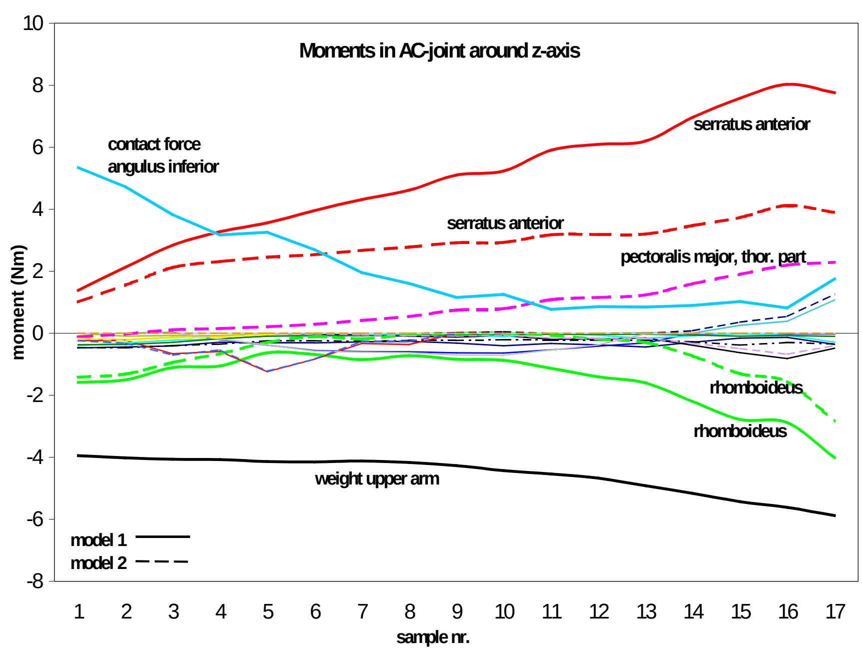

Figure 4 Moment balance at the acromioclavicular joint

Models such as these can be used in computer aided surgery to optimise the treatment of patients by allowing the testing of different surgical solutions. The effects of different procedures , in terms of muscle forces and kinematics, can be seen and analysed prior to surgery, and the best solution chosen for the patient. However, in order for such models to be applied in clinical situations, they must first be validated.

The results of this study show that this model can be used to predict the effects of paralysis of serratus anterior and a tendon transfer operation, and will form a valuable clinical tool.

References

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