MUSCLE JOINT STRESS CALCULATOR

A report submitted

For the ME696 course evaluation

By

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Abstract

The deltoid muscle is the major muscle with a significant role in shoulder function. It comprises three distinct portions namely anterior or clavicular, middle or acromial, and posterior or spinal. It acts mainly as an abductor of the shoulder and stabilizer of the humeral head. Deltoid tears and not infrequently associated with large or massive rotator cuff tears and may further cause problems to the shoulder function. The contracture of deltoid following repeated intramuscular injections could present with progressive abduction deformity and winging of the scapula. The deltoid muscle and its innervation axillary nerve may be injured during shoulder surgery, which may have disastrous functional consequences. Abnormalities of the deltoid may originate from nearby pathologies of the sub deltoid bursa, acromion, and distal clavicle. After a successful surgery, the muscle stiffens and physiotherapy process is required. The proposed methodology derives the data of the force and stress profile of the deltoid muscle. The profile is based on the height and weight of the individual along with the maximum arm rotation angle (approx.) of the individual. It can also act as a reference in further studies in topological optimization in the parametric design of implants for cost-effective methods.

Introduction

Deltoid Muscle is one of the stress bearing muscles which joints the upper arm and the shoulder at the shoulder joint that originates from outer one third of the clavicle, Acromion process, Spine of Scapula. Each section of the deltoid muscle inserts at the same location, which is the deltoid tuberosity of the humerus or the long bone in the upper arm and is innervated by the axillary nerve. The deltoid is widest at the top of the shoulder and narrows to its apex as it travels down the arm. Contraction of the deltoid muscle results in a wide range of movement of the arm at the shoulder due to its location and the wide separation of its muscle fibers.

It has three distinct functions that correspond to the three bands of muscle fibers. Flexion and medial rotation of the arm moves the arm anteriorly, as in reaching forward or throwing a ball underhand. The lateral fibers abduct the arm by pulling the humerus toward the acromion. Abduction of the arm results in the arm moving away from the body, as in reaching out to the side. Contraction of the posterior fibers extends and laterally rotates the arm by pulling the humerus toward the spine of the scapula. Extension and lateral rotation moves the arm posteriorly, as in reaching backwards or winding up to throw a ball underhand. Contraction of the anterior fibers flexes and medially rotates the arm by pulling the humerus towards the clavicle. Like many other muscles, the deltoid can be sore for a variety of reasons, including overuse, tendon injuries, and pain is caused by overusing deltoid muscle without rest or proper warm-up.

When the arm is raised with the trunk of the body the stress falls on the muscle will stiffens the deltoid muscles. Prescription drugs and Physiotherapy are used to relax and bring tissues to the native state. However, in physiotherapy, the trainer’s only reference is the patient's expression of pain or inability to complete the task provided. Since randomized physical examination is unacceptable in this aspect owing to the pain of the injured person, a computer model is built which is capable of calculating the force exerted in each direction of the deltoid muscle that could be used theoretically to evaluate the Force vs Arm rotation angle, Stress vs Arm rotation angle of the particular joint by the physician.

Literature Review

Blache et al. (2014) implemented a musculoskeletal model to study the effects of lifting height and load on shoulder muscle work. In their study, a musculoskeletal model scaled from 15 male subjects was used to calculate stress and load on the shoulder during six lifting tasks. It was found that overhead shelf destinations lead to an increase in load. A heavier box involved higher stress on the anterior deltoid than a lighter box. It may be said that these outcomes were one of the first estimations of lifting load and height on shoulder fatigue. But the study was applicable for only healthy young male subjects.

Various empirical and experimental methods are illustrated in “A Survey of Measurement Techniques” by Rudolfs et al. (1998). With the help of the immersion method, Harless came up with the absolute and relative lengths of different body segments using five male and three female subjects for his analysis. The immersion method involves determining how much water is displaced by the submerged segment. He created a mass distribution model of the entire human body. In 1884, C. Meeh investigated the body segment volumes of ten living subjects (8 males and 2 females), ranging in age from 12 to 56 years. In order to approximate the mass of the segments, he determined the specific gravity of the whole body.

Fischer introduced another approximate method of determining human body parameters by computation known as the "coefficient method." According to this procedure, it is assumed that fixed relations exist between body weight, segment length, and the segment parameters which we intend to find. There are three such relationships or ratios expressed as coefficients. For the upper arm, the ratio is found to be 6.72 for males in comparison to 6.48 estimated by Harless, and for the forearm, the ratio is 4.56 in comparison to 3.62 estimated by Harless. Drillis (1959) determined a method, “Reaction Board Method”, for estimating the mass of body segments of living subjects. Essentially it consists of the determination of reaction forces of a board while the subject lies at rest on it. The board is supported by a fixed base at one end and a very sensitive weighing scale at the other end. He came up with an equation, calculated for different subjects and estimated the relative mass of different body segments.

The common methodology used in the musculoskeletal model to estimate muscle and joint loading is Static Optimization. However, the reliability of this method is criticized and the ability of this method to predict antagonist muscle activity at the shoulder level is poorly understood. Azadeh et al. (2019) aimed to compare muscle and joint force predictions from a subject-specific neuro musculoskeletal model of the shoulder driven entirely by measured muscle electromyography (EMG) data with those from a musculoskeletal model employing static optimization. Data is obtained from six sub maximal upper limb contractions including shoulder abduction, adduction, flexion, extension, internal rotation and external rotation were performed by four healthy adults. EMG driven modelling predicted antagonist muscle function at the shoulder that was not predicted using static optimization. The findings on load and its direction varied substantially between the EMG driven neuro musculoskeletal model and the static optimization. These findings pointed out the limitations in the use of static optimization for predicting the muscle function at the shoulder.

To study the contribution of deltoid muscle on the anterior stability of the shoulder, Tadato et al. (2003) performed a controlled laboratory study. Nine fresh cadaveric shoulders with the arm at 90 degrees of abduction and 90 degrees of external rotation and an electromagnetic device to monitor the position of humeral were used. The deltoid muscle is an anterior stabilizer of the glenohumeral joint with the arm in abduction and external rotation. It was concluded that the deltoid muscle was an anterior stabilizer of the glenohumeral joint with the arm in abduction and external rotation.

Technical Gap

The most commonly described manual muscle test needs the patient to actively flex the shoulder to 90°, if the patient is unable to perform the task it is assessed by lying the patient in the side-position with the humerus fully adducted in neutral rotation, and the elbow maintained in 90° of flexion while resistance is applied to the distal arm toward internal rotation however it can increase the resisted external rotation torque and thereby change the reported resisted strength of the deltoid muscle. Also, optimization-based models may be able to predict forces, but they do not account for differences in an individual’s neuromuscular control system, which may be impaired. The accuracy of these models is greatly influenced by the accuracy of the anatomical data, which must include a full model of the musculoskeletal geometry. Similarly the models of deltoid muscle force from EMG have been shown to be inaccurate.

Hence, to overcome this issue we can model conventional mechanics methods to computational models which then predict the needful parameters accurately by taking height and weight as an input thereby reducing the patient participation.

Objectives of the Proposed Work

- To calculate the force exerted in each direction on the deltoid muscle and to calculate the specific stress values on the deltoid muscle for every particular degree of rotation up to maximum arm rotation angle due to the external load, given height and weight of the individual.
- To generate a graph of Force vs Arm rotation angle.
- To generate Stress vs Arm rotation angle of the particular joint which can be used as a reference by the physician.

Methodology

Studies showed that there is correlation between the total lengths of the human body to the length of the arm. Similar study applies for the weight of the arm. Based on the height and weight of the individual, it was estimated that:

$$\text{Length of forearm} = 0.156 \times (\text{Total length of the Individual}) \tag{1}$$

$$\text{Length of upper arm} = 0.174 \times (\text{Total length of the Individual}) \tag{2}$$

$$\text{Weight of forearm} = 0.016 \times (\text{Total weight of the Individual}) \tag{3}$$

$$\text{Weight of upper arm} = 0.028 \times (\text{Total weight of the Individual}) \tag{4}$$

A healthy arm can be rotated to a maximum of about 135° (approx.). The deltoid muscle can be rotated to a maximum of about 10° (approx.). It is considered that the rotation of deltoid muscle against the arm rotation is linear distribution. A static load is held at the forearm. The load falls on the deltoid muscle when the arm is abducted at an angle of 90° with the trunk of the individual. For every position of the arm, the center of mass (COM) of the arm, the moment of the shoulder, the stress in the deltoid muscle, the force in x-component, and the force in y-component are calculated. The muscle stress is calculated by muscle scaling, using a physiological cross-sectional area (PCSA) value for the deltoid muscle group. The dynamics of the COM of the whole arm changes during the lifting of the external loads and for each particular position.

The principal behind the calculations is a simple cantilever problem. The individual`s hand is considered as a cantilever beam in which one of the ends are fixed i.e.., the shoulder joint in this case. On the other end of the cantilever which is a free end ie.., the palm of the individual, an external load is held steadily. The force calculated here is the reaction force on the fixed end of the due to the load. Similarly, the moment at the fixed end ie.., shoulder joint is also calculated.

Results and Discussion

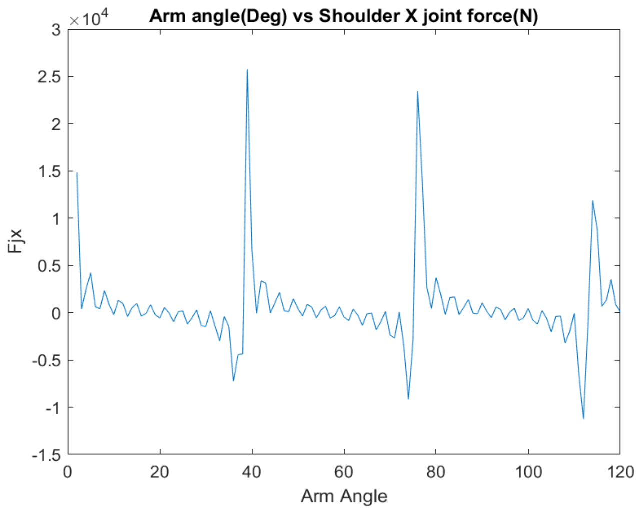
The methodology discussed is derived into a mathematical model. For a given individual with

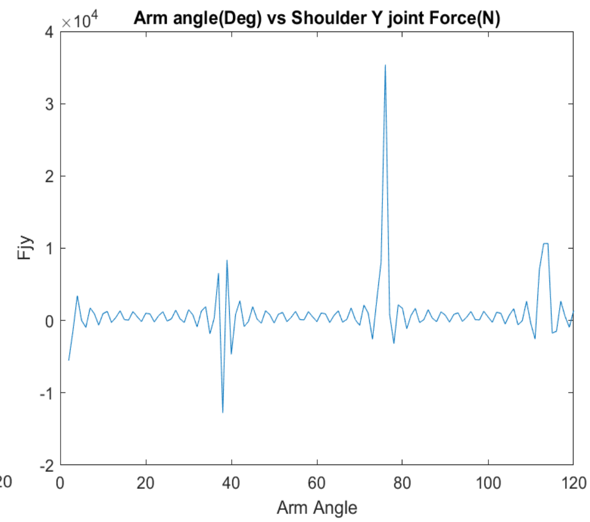
Height = 1.75m

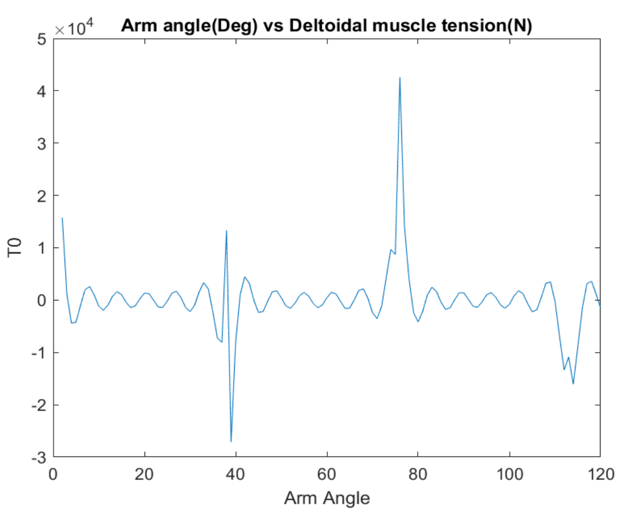
Weight = 70kg

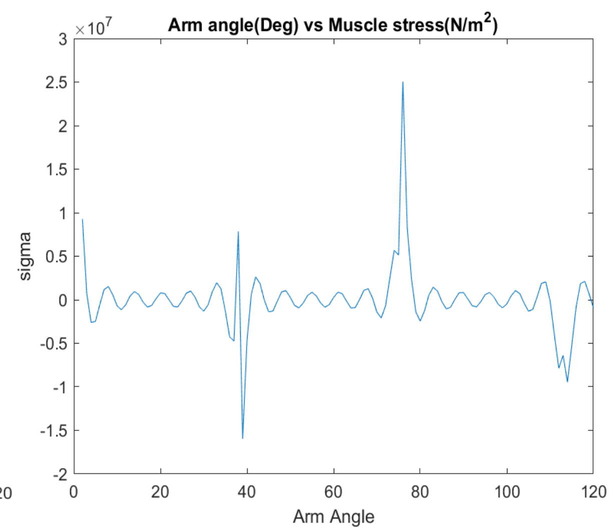
Maximum arm rotation = 120°

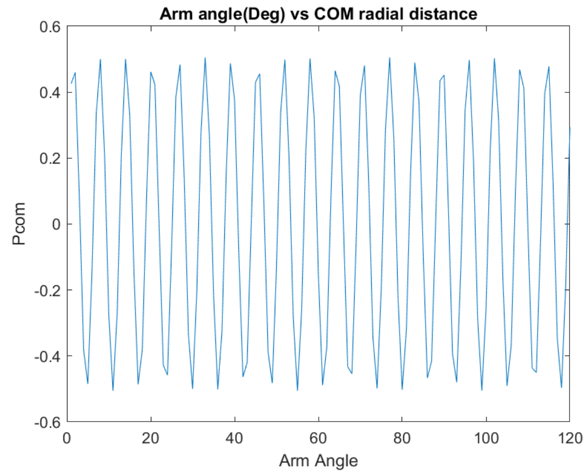
External loading = 15 kg











The extremities in the above plots indicate that the forces and moment on the deltoid joint occur at similar arm angles. The negative quantity indicated the change in direction of the reaction forces and moments. These plots give a basic understanding of deltoid muscle`s flexion and extension for every arm angle which is the ultimate reason for the shoulder joint movement.

Summary

The deltoid muscle is a rounded, triangular muscle located on the uppermost part of the arm and the top of the shoulder. When carrying heavy objects while the arm is fully adducted, the muscle will produce a line of force (static contraction) that prevents the inferior displacement of the glenohumeral joint. The deltoid also undergoes eccentric contraction when the arm is being lowered, or adducted. That allows adducting the arm in a controlled manner. While lifting objects, deltoid muscle is acted upon by different loads and stresses at different angles of lifting. The aim of this study is to estimate these loads and stresses on deltoid muscle. To find that, we estimated the length and weight of the forearm and upper arm, given total height and weight of the subject using relative ratios developed by various scholars. A typical young adult (Height = 1.75m & Weight = 70kg), an external load of 15 kg with maximum arm rotation of 120° are considered for the observations and then plots of arm shoulder joint force, deltoid muscle tension, deltoid muscle stress and COM radial distance all with respect to arm angle were obtained. It can be seen that all the plots show upward spikes at approx. arm angles of 40°, 80° and 120° which indicates that these are the critical angles for any stress tests for limbs.

Future Work

- With the help and results of the current work, a 3D model testing mechanism (stress tests) can be developed to verify the strength/workability of prosthetic limbs.
- It is very important to verify the strength of shoulder implants before bringing it into work. With the help of present work, a 3D model can be developed for performing stress tests on shoulder implants.

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