Preliminary Study on Muscle Force Estimation using Musculoskeletal Model for Upper Limb Rehabilitation with Assistive Device for Home Setting.

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Abstract. Post-stroke rehabilitation using assistive device has the potential to cover the need for improvement of the upper limb functionality. Moreover, using a biomechanical model to estimate the muscle activity during the rehabilitation training could improve the training module as well as help understand the target muscle during the motion of body part while using the assistive device. In this study, the author has focused on using a musculoskeletal model of the right arm to estimate the individual muscle force by simulating the movement of the right arm while using the developed assistive device. A developed upper limb assistive device has been investigated for its potential as a rehabilitation device for persons with physical disability of upper limb motion. The muscle force estimation is based on an inverse dynamic method, improved with additional constraints of the joints in order to obtain the muscle’s activity from motion capture data. The acquired muscle force data could be used to improve the arm assistive device in rehabilitation training for home setting purpose.

1. Introduction

The number of stroke survivors in this world is quite large, and most of these survivors experience impairment impact on the upper limb function [1]. Patients who suffer from the upper limb impairment usually have difficulty performing daily activities that require using the upper limb, such as feeding, washing, etc. Some patients may recover some functionality of the upper limb function following the rehabilitation. However, most of the high technology assistive device are placed at the rehabilitation centre and must be operated with the help and observation of the therapists. Recently, wearable assistive devices have also started to play an important role as a rehabilitation device [2–4]. The needs of the assistive device and its cost effective and user friendly nature could help patients with rehabilitation training at home. The lack of the need for a therapist number is an added advantage, thus demanding the assistive device to be robust and easy to handle. The development and improvement of the assistive device need to come together with an understanding of the muscle force and muscle activation of the target muscle during the rehabilitation training.

Presently, three main approaches i.e., assessment scales, movement evaluation, and surface electromyography (sEMG) analysis are widely applied to evaluate the upper extremities. As these assessments are mainly viewed and scored by the therapist, the evaluation results are often subjective and general. The movement evaluation method using the motion capture systems can provide data on the physical movement of the upper limb, which can then be used for monitoring the progress of the
rehabilitation. However, this method cannot account for muscle characteristics in patients, and the neurological mechanism used to overcome the problems associated with their pathology is also still unknown. Although all these methods are useful in the assessment of upper limb function, they are still inadequate for quantitative evaluation due to the lack of deep muscle’s activation information and noise contamination from the movement artefact. Moreover, a direct interaction with the subject is needed in order to gain the information, and this could be a limitation based on the patient’s condition, time consumed to setup the system and the cost for the actual test involving many equipment and subjects.

Given this, this study presents a method using a musculoskeletal model focusing on the upper limb to predict muscle force during the elbow flexion with the assistive device. Individual muscle force was investigated during the movement of the elbow flexion with the healthy subject using the assistive device and the results were compared with those of the one not using any assistive device. Through this approach, the specific functional muscle involved during the movement can be known, making it possible to conduct improvement in the assistive device for rehabilitation training purpose. A brief flowchart of the proposed muscle force estimation is shown in figure 1.

![Figure 1: Flowchart of proposed muscle force prediction using musculoskeletal model.](image)

2. Method
In order to study the muscle force based on the given motion data, a musculoskeletal model from the musculoskeletal software, OpenSim [7] was utilized. A suitable pre-existing musculoskeletal model has been used and scaled to match the marker data. Then the model is validated dynamically by comparing the muscle force estimated from simulation and EMG data from the experiment. Finally, an experiment is performed on a healthy subject with assistive device and the result is compared with the simulation data for the same motion.

2.1. Data Acquisition and Experimental Setup for Musculoskeletal Model Validation

2.1.1. Electromyogram (EMG) & Motion Capture Data Recording.

A healthy subject volunteered for this investigation and gave their informed, written consent. The project was approved by the Human Research Ethics committee at the Shibaura Institute of Technology (SIT), Japan. The subject was quietly seated in the chair with their torso kept upright and their right hand keeping at close to a 90-degree elbow flexion. The reach forward motion is designed to obtain motion of the right upper limb. The motion simulated the elbow flexion from 90 degree to forward reaching and return to initial position. The same motion was repeated three times to get three sets of data. The configuration of the EMG recording and marker placement for motion capture system is shown in figure 2. Motion data was acquired using the Mac3D system available in our laboratory. This equipment consists of 10 infrared cameras that are able to capture the 3D position of the different markers over
During the motion recording, 10 markers were used at specific positions together with marker clusters according to the recommendation on definitions of joint coordinate systems [6]. Six predominant muscles at upper arm activating elbow DoFs were selected to be the muscle of test, as shown in figure 2 (a) and (b). Six channels of bipolar differential amplifier were carefully placed on these muscles based on both the anatomy and hand touch experience. The active EMG electrodes of each channel were positioned at the muscle belly. The skin underneath the electrodes was cleaned with alcohol patch to reduce the resistance between the skin and the electrodes. The motion recording was sampled at 200 Hz and synchronized with the EMG recording through the motion capture system.

![Figure 2](image)

**Figure 2**: The configuration of 6 channels EMG electrodes for upper arm (a) and (b), and a healthy subject performing the reach forward movement is shown in (c) and (d).

2.1.2. Joint angle estimation, Joint torque, and Muscle Force Estimation using OpenSim

Delp et al. [5] have developed an open source platform called OpenSim. This platform allows the dynamic simulation on the musculoskeletal system using provided motion capture data. These simulations use inverse kinematics method to obtain kinematics data such as joint angle of each joint during the movement, which is later used in inverse dynamic simulations to obtain the joint moments. Then, an original algorithm, called Computed Muscle Control (CMC), based on inverse dynamics method is used to compute the muscle forces allowed to obtain the muscle excitation. An upper limb model for the right hand is available in this platform. It has realistic movements and precise muscular topology for the joints. This study utilizes the CMC to validate the OpenSim Model. Then the same approach is used to study the active muscle in the human musculoskeletal model during the motion of the upper arm.

![Figure 3](image)

**Figure 3**: OpenSim upper limb musculoskeletal model. This model was developed by Saul KR [7]. It consists of 7 body segments and 32 muscles across the shoulder, elbow, forearm, and wrist.
2.1.3. Validation Result

![Validation Result Diagram](image)

(a) Experimental processed EMG data (b) Estimated muscles force using upper limb model

*Figure 4:* Experimental muscle excitation and estimated muscle forces for the same reach forward motion.

As mentioned in section 2.1.1, we selected deltoid anterior part (Delt 1), deltoid posterior part (Delt 3), short head of biceps (BicShort), long head of biceps (BicLong), long head of triceps (TriLong), and lateral head of triceps (TriLat) as 6 muscles of interests. Figure 4 (a) shows the processed EMG data for the muscles taken during the experiment and estimated muscle forces shown in figure 4 (b) from the simulation of the musculoskeletal model. By adopting a neural mapping method [10], we assumed that BicShort has the same activation as BicLong and other two heads of triceps have the same activation. We can see in both experimental EMG data and estimated muscle forces from simulation shows that the Biceps muscles are working during the motion and presents the main activity. On the other hand, the triceps muscle does not show big activity due to its minor role in joint motion. We also can see that the pattern of the most muscle forces (Biceps and Triceps) shows similarity with the recorded EMG pattern. The similarity agreement between the recorded EMG data and the estimated muscle forces for the same motion shows that this model is acceptable to predict muscle activity for upper limb right hand motion.

2.2. Experiment with Assistive Device and Simulation with Musculoskeletal Model

2.2.1. Assistive Device, Experiment & Simulation Protocol

A lightweight assistive device [8], which is wire-driven by 2 servo motors was developed. The device can generate the motions of elbow flexion/extension movement and internal/external rotation movement, performed by pulling the wire hung on a pulley connected to the wrist part. During the experiment, the subjects were standing with their torso kept upright and their right hand kept relaxed. One motion designed had the elbow flexion from the natural position to close to a 100 degree. Two separate motions have been designed where the subject performed the motions with and without the assistive device. Then the same motion was simulated using the musculoskeletal model in OpenSim. The marker data taken is produced using the Motion Capture 3D system available in our laboratory. A torque of 4Nm is applied to the musculoskeletal model, simulating the model with assistive device to achieve the same flexion motion close to 90 degree. A target muscle, which is the bicep (short), is investigated for muscle activity.
3. Results and Discussion

The purpose of the current work is to study the muscle activation estimation method via musculoskeletal model when using upper limb assistive device. The muscle estimation was evaluated by simulating the musculoskeletal model using the motion data provided through the experiment of the subject wearing and without wearing the developed assistive device. Figure 6 (a) shows the measured EMG data signal processed with 1Hz cut off low pass filter and figure 6 (b) shows the estimation of the muscle force of the target muscle during the elbow flexion of one subject using and without using the assistive device.

As can be seen from figure 6, the pattern of the muscle force estimation using the musculoskeletal model shows good agreement with the experimental muscle excitation (EMG) pattern. The most significant difference can be observed by magnitude of the muscle activation without device, which is slightly higher when compared to the muscle with assistive movement. Even though it is normal for the assistive part to produce less muscle activities, our proposed estimation method proven can be used and it will be possible for us to get a deeper understanding of the human dynamic movement mechanism while using an assistive device for rehabilitation purpose.

Several limitations of our study should be noted. Firstly, the musculoskeletal model used in OpenSim is only scaled based on the marker data from the 3D motion capture system. The best practice in building the musculoskeletal model, the MRI data from the subject should be used to construct the model from...
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