Muscle Force Prediction during Knee Flexion/Extension Using EMG-Driven Model

Saran Keeratihattayakorn[1] and Shigeru Tadano[2]

[1] Division of Human Mechanical Systems and Design, Graduate School of Engineering, Hokkaido University, Sapporo, 060-8628, Japan
[2] Division of Human Mechanical Systems and Design, Faculty of Engineering, Hokkaido University, Sapporo, 060-8628, Japan

Abstract— **Predicting muscle force during joint movement is important to gain a better understanding of musculoskeletal system. In this study, an EMG-driven model for predicting the muscle force in lower limb during knee flexion-extension is presented and the rate-effect on muscle model parameters is investigated. The model was based on Hill-type muscle model to describe the contraction mechanism of muscle. Surface electrodes were attached to the subject's leg to detect the EMG signals and the knee joint angle was measured by an electrogoniometer. The subjects performed a series of knee flexion-extension with various movement frequencies. Muscle fiber length, velocity and activation during the movement were used as inputs in the muscle model to predict the muscle force. To study the rate-effect on muscle model parameters, optimization processes were performed to obtain muscle model parameters at various movement frequencies. The external forces calculated from the predicted muscle forces were compared with measured forces from load cell to validate the accuracy of the model. The results showed that the muscle model parameters changed with respect to the movement frequency. In order to improve the accuracy of Hill-type muscle model, various muscle model parameters which change with movement frequency were suggested. Development in muscle model is very useful in studying the musculoskeletal system leads to improvement in diagnostic tool, planning effective exercise training programs and development of rehabilitation procedure.**

Keywords— **Muscle force, Muscle model, EMG, lower limb, Knee joint**

I. INTRODUCTION

The knee is an important mechanical link in the lower limb. The flexion/extension motion of the knee primarily results from the reaction forces generated by the muscles. Knowledge of muscle mechanics is required for designing effective exercise training programs and developing rehabilitation procedures. In order to determine the muscle forces in a noninvasive manner, many methods based on mathematical models were developed [1]. The electromyography (EMG) signal was well known to be related to muscle force generation and thus, EMG was introduced into the model to predict the muscle force. Interest in the EMG-driven model has grown recently after it was proven to be a powerful tool to predict the muscle force in various movements. However, the limitation of EMG-driven model is that the accuracy of the predicted force from EMG-driven model depends on how well we estimated the muscle model parameters. As the knowledge of the manner in which muscle parameters respond to the change of movement velocity is still limited, additional validation of the rate-effect on the muscle model parameters is required. This study aimed to develop an EMG-driven model to predict the muscle force of the lower-limb during knee flexion/extension, and to determine the influence of the rate-effect on the model parameters of the Hill-type muscle model. We believe that the information derived from this study will be useful in modeling the dynamic performance of muscles and improving the existing model.

II. METHODS

A. Hill muscle model

Hill's muscle model is used to describe the mechanism of muscle during contraction. In conceptual, Hill muscle model is that the contractile properties of muscle tissue can be represented by interrelationship between tension, length and velocity of the muscle fiber controlled by muscle activation [2]. Muscle model consists of passive element (PE) and the contractile element (CE) as shown in Fig. 1. The force produced by CE can be expressed by

$$F_{CE} = F_0 \times F_l(l_m) \times F_v(v_m) \times F_{EMG}(t) \quad (1)$$

where F_0 is the maximum isometric force possible by muscle model, $F_l(l_m)$ is the fraction of the maximum isometric force the muscle can produce at current length, $F_v(v_m)$ is the fraction of the maximum isometric force which the muscle can produce at current velocity and $F_{EMG}(t)$ is the current active state of muscle. Surface electrode can be used to measure muscle activation and muscle length can be estimated via the relationship between knee flexion angle and muscle length using a musculoskeletal model.

B. Experiment procedure

The subjects sit comfortably in an upright position and performed a series of knee joint flexion and extension with predetermined movement frequencies range from 0.2 Hz to

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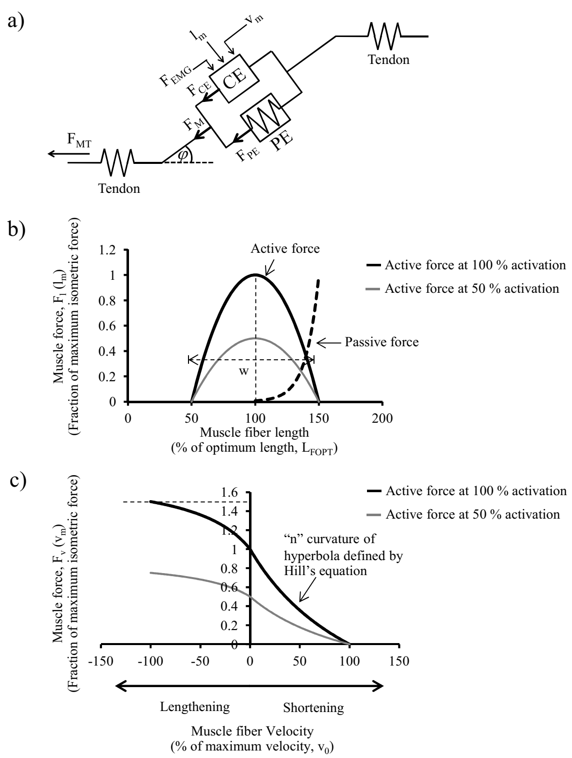

Fig. 1 a) muscle model consists of contractile element (CE), elastic element (SEE) and passive element (PE) b) Force-length relationship and c) Force-velocity relationship of CE.

1.2 Hz. Knee flexion angles were measured by using an electrogoniometer (SG75, Biometric, USA) which was attached on the subject's leg. The external load was measured by the load cell (DTG-20, DigiTech Co.,LTD, Japan) that was fixed to the ground (Fig. 2). The electrogoniometer data and force data were sampled at 1000 Hz. EMG signal was recorded from the rectus femoris (RF), vastus lateralis (VL), hamstrings (Ham) and gastrocnemius (Gam). Signal from electrodes and electrogoniometer were processed offline by using Matlab (Mathworks, USA). The raw EMG signals was converts to linear envelope profile (LE) that represents the muscle tension during dynamic movement. Firstly, the raw EMG were high-pass filtered using Butterworth filter (20 Hz) to remove movement artifact, then full wave rectified and filtered using Butterworth low-pass filter (3 Hz) then normalized by MVC to obtain the filtered, rectified and normalized EMG. Angular velocity profile was obtained by numerical differentiation of the position joint angle obtained from electrogoniometer.

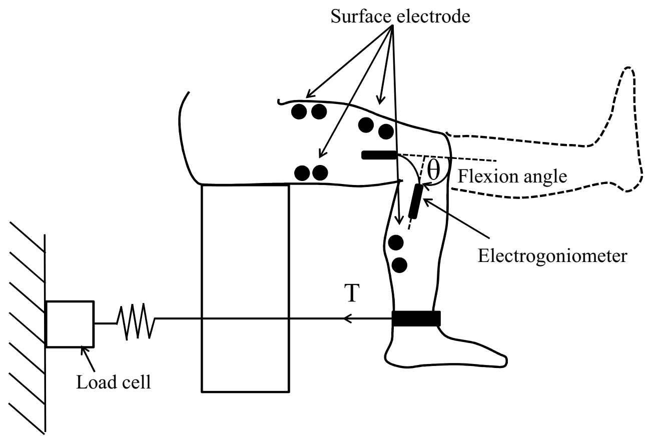

Fig. 2 Schematic drawing of the experimental setup

C. Optimization process

From the muscle model (Fig. 1), the muscle model parameters to be optimized included maximum isometric force F_0, maximum shortening velocity v_0, optimum muscle length L_{FOPT}, operating range on force-length curve w and shape parameter n. The specific set of muscle parameters for each movement frequency was determined using an optimization method (Fig. 3). We have assumed that the external force applied to the subject's leg estimated by the model should match those measured from the load cell. A simulated annealing algorithm was used to tune the model parameters by minimizing the objective function, (J) given by:

$$J = \sum_{1}^{n} \left(T_m - T_c\right)^2 \tag{2}$$

where n is the number of samples during the entire movement in each trial, T_m is the measured external force from the load cell and T_c is the predicted external force calculated from the model.

III. RESULTS AND DISCUSSION

In this study, we used a simple measurement system that consists of surface electrodes and an eletrogoniometer to predict the muscle force. Fig.4 shows sEMG signal from the lower limb muscles and measured knee joint angle during the knee flexion/extension. Muscle kinematics and activation were used as model's inputs to predict the muscle force. The main finding is that muscle model parameters do

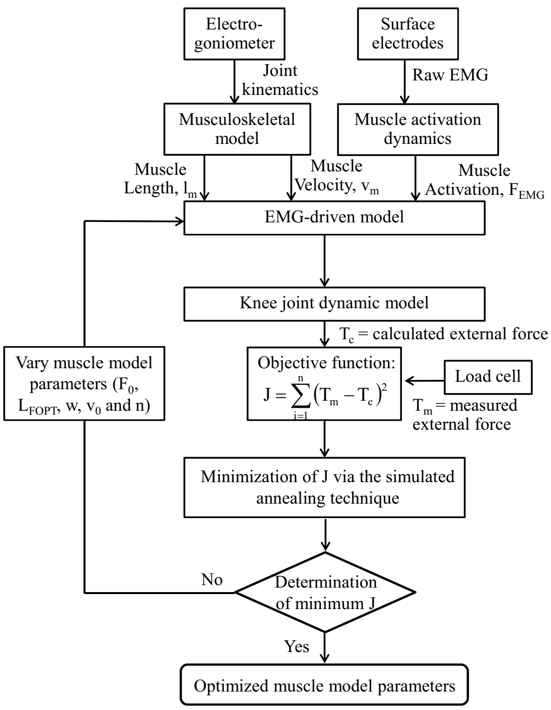

Fig. 3 Optimization process to obtain muscle model parameters

depend on the movement frequency. The change in shortening velocity directly affects the operating point in the force-velocity relationship. The results indicate that there might be a mechanism to optimize mechanical power output and efficiency at different movement velocities by selective recruitment of the suitable fiber type. It is suggested that for accurately predicting muscle force using the EMG-driven model, the change in the muscle model parameters according to movement frequency should be considered. In addition, to further improve the muscle model, the relationship between acceleration and muscle force should be investigated and this should be included into the muscle model.

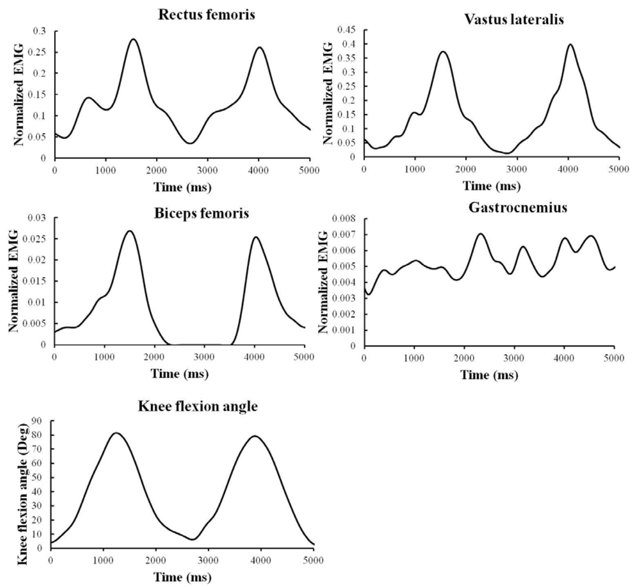

Fig. 4 Example of sEMG signal for four lower limb muscles and knee joint flexion angle

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Author: Saran KEERATIHATTYAKORN
Institute: Hokkaido University
Street: N13 W8, Kita-Ku
City: Sapporo
Country: Japan
Email: saran@ec.hokudai.ac.jp