AN ALGORITHM TO ESTIMATE MUSCLE FORCE FROM JOINT ANGLE USING SIMULINK

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The purpose of this study was to compare the muscle length and muscle force from developed model and commercial software. Basically a Hill-type muscle model consists of springs and damper, and thus muscle force was changed by muscle length. Because of this reason, the researchers needed to know the changes in muscle length and developed algorithm to estimate muscle length from joint angle (angle-to-length). Also, we implemented muscle model (length-to-force) based on the model that F. E. Zajac modified the Hill-type muscle model. Muscle lengths and muscle forces show significantly good correlation in ankle muscles in results from two methods. This indicates that angle-to-force can be adapted to developed a tool determining muscle forces in real-time.

KEY WORDS: muscle force, Simulink, musculoskeletal modelling

INTRODUCTION:

In the musculoskeletal model, muscles generate forces independently, but they generate the motion with joint angles by the interaction between the agonist and the antagonist. However the answer to the roles of the muscle is still unknown. To find the roles of the muscle, first, the researchers should know how much muscle force is generated during movement, such as in walking. The force in a single muscle during movement is not directly measureable without invasive methods. Tendon force transducers are not so much accurate and can not be used under the dynamic condition. Therefore, non-invasive methods to measure muscle forces are required and some techniques have been proposed.

One proposed method involves the optimization criteria. This method usually requires the musculoskeletal model, the kinematic data and some assumptions associated with objective functions. Optimization techniques are not very useful in patients due to the complex characteristics of muscle properties.

The modified Hill-type muscle model can be used to estimate muscle forces. This method requires the muscle model and the information of the muscles. In order to obtain the information of the muscles, especially changes in muscle length, the researchers usually use commercial software which includes the musculoskeletal model. However it is too expensive.

In this study, we developed the ankle model to estimate the muscle forces from ankle joint angle using SIMULINK and compared the results from the developed model and from the commercial software.

METHOD:

Subject and Experiment: A healthy man (age: 23years, height: 171cm, weight: 74kg) who never experienced musculoskeletal diseases was participated. The subject was asked to rise and lower their feet. Kinematics were determined for the subject using the 3D motion analysis system (VICON, Motion Systems Ltd., UK) with six infrared cameras, coupled with two force plates (Kistler, Switzerland) and three surface electrodes (Motion Labs System, USA). EMG recordings were performed on three major ankle muscles (gastrocnemius medialis, gastrocnemius lateralis and tibialis anterior).

Musculoskeletal Modelling Software: To obtain muscle lengths and muscle forces, motion analysis data was imported into a musculoskeletal modelling software SIMM (MusculoGraphics, Inc, a division of Motion Analysis Corporation, USA) (Figure 1). We used the muscle model modified by F. E. Zajac (Zajac's Muscle Model, ZMM) of the seven muscle models which is included in SIMM. The length and the force of the ankle muscles were calculated through the inverse dynamics.

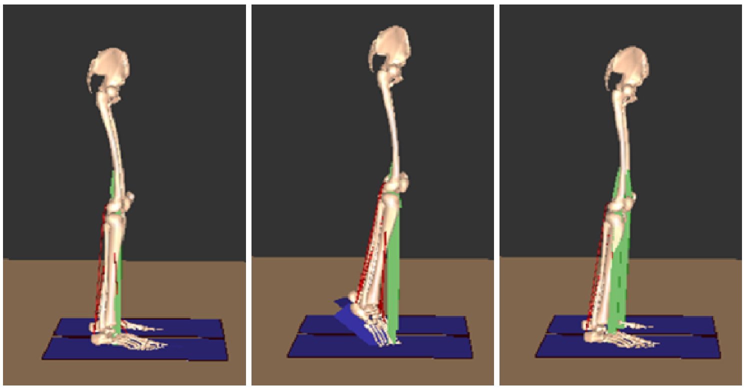

Figure 1: Musculoskeletal model during heel-rise

Developed Model using SIMULINK: In this study, we implemented the muscle model based on ZMM using MATLAB (Mathworks Inc., USA) and SIMULINK (Mathworks Inc., USA) (Length-to-Force). Because the Hill-type muscle model basically consists of springs and damper, muscle force was changed by muscle length. To calculate the muscle length, we developed an algorithm which estimates muscle length from the ankle joint angle (Angle-to-Length).

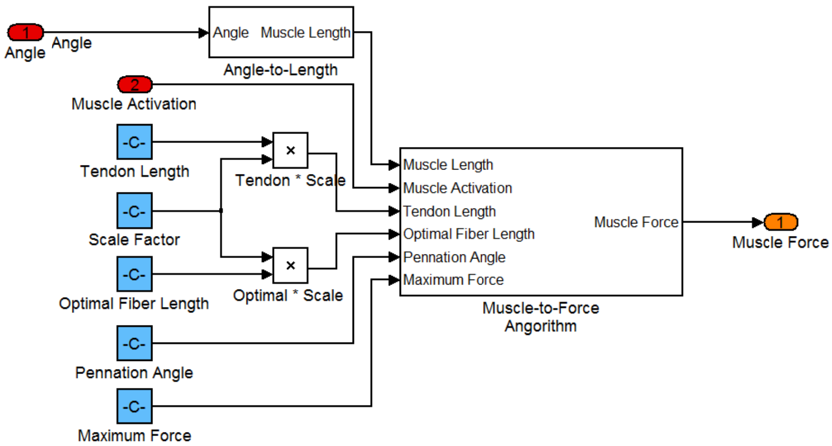

Figure 2: Developed Angle-to-Force algorithm

Statistical Analysis: The results from the two methods were compared for the three different muscles. Correlation coefficients and their significance were calculated using the statistical software SPSS (SPSS Inc., USA).

RESULTS:

In the gastrocnemius medialis, the muscle length values from the developed model and SIMM were significantly similar ($r=0.997$, $p<0.01$) and the muscle forces were significantly similar also ($r=0.989$, $p<0.01$). The results in the gastrocnemius lateralis were observed in good correlation for both the muscle lengths ($r=0.989$, $p<0.01$) and the muscle forces ($r=0.968$, $p<0.01$). In addition, both the muscle forces($r=0.989$, $p<0.01$ and the muscle length ($r=1$, $p<0.01$) from the present study were in very good agreement with those from SIMM in the tibialis anterior.

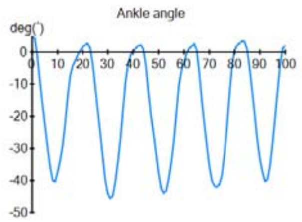

Figure 3: Ankle joint angle during heel-rise movement

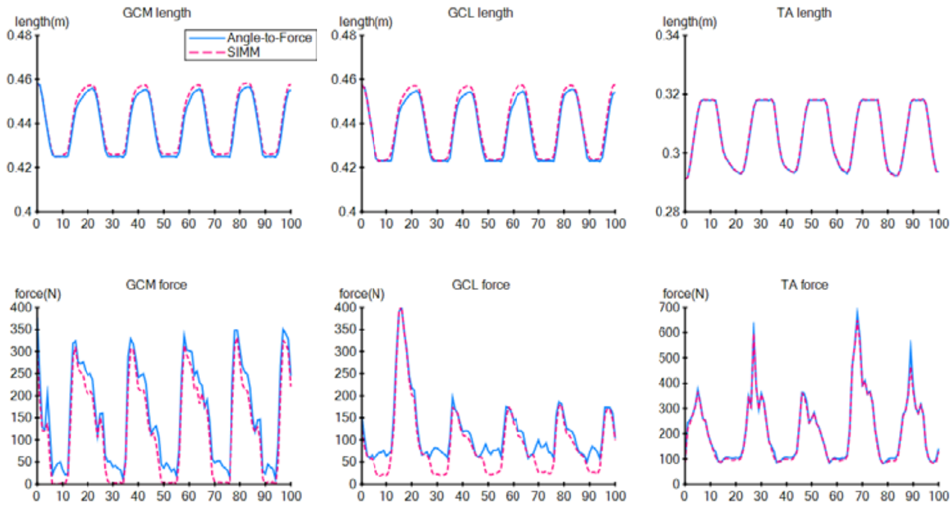

Figure 4: The results from SIMM (dashed) and Angle-to-Force (solid)

CONCLUSION:

In this paper, we estimated the muscle forces of ankle major muscles from ankle joint angle. The muscle model which was modified by F. E. Zajac was very useful in calculating muscle forces and muscle length during movement fast and easily. However it is not appropriate for muscles with very long tendons or high forces which stretch the tendon more due to the assumption of an infinitely stiff tendon. Further studies would be required to apply the present model for the determination of muscle forces in real-time during movements.

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