Validation of Synthesized Squat Motion with Smith Machine through Biomechanical Simulation and EMG Measurement

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1. Introduction

Modeling and simulation of the human body and motion have recently used in the sports field to analyze the effect of physical exercise on the human body[1]. Weight lifting equipment helps to strengthen muscles by applying loads to specific muscles. However, weight lifting equipment can cause injury if it is used incorrectly or if too much weight is lifted. Therefore, the equipment should be designed so that the proper amount of load can be applied to a specific part of the body to maximize the effect of exercise and minimize the risk of injury.

To assess the effects of weight lifting equipment on the human body during exercise, muscle contraction forces must be measured and analyzed. However, measuring them in vivo is difficult, time-consuming, and costly. Furthermore, it is difficult to recruit test subjects whose physical condition covers a sufficiently wide range.

The purpose of this pilot study was to verify the usefulness of the AnyBody v6.0.3 (AnyBody Technology, Denmark)[2] biomechanical analysis system using exercise motions synthesized in the process of sports equipment design. The kinematic relationships between body segments and joint angles during the squat motion were modeled as mathematical functions from the motion capture data. To verify the usefulness of the squat motion model, the results of simulations of synthesized motion were compared with electromyography (EMG) measurement data.

2. Methods

2.1 Capturing 3-D Motions

Squats conducted by six college students in their late twenties using KoreaSports' Smith machine were measured. A total of 38 reflection markers were attached to the bodies of the test subjects, according to Vicon's plug-in-gate marker set[3], and ten infrared cameras (Vicon MX-T40[4], UK) were used to capture the movements of the markers.

2.1.1 Kinematic Relationships between Joints

Models of the human test subjects were created using the AnyBody Managed Model Repository (AMMR) v1.6.3. Angle data for the knee, hip, and ankle joints were obtained from the motion data captured during the squat motions and stored in the C3D data file format commonly used for three-dimensional (3D) motion data capture. Linear regression functions were obtained for the knee, hip, and ankle joint angles as a function of the height of the bar of the Smith machine.

2.1.2 AnyBody Model for Squat Motion

The squat motion data were generated using the motion regression functions described in Section 2.1.1. A human body model was generated using a sample full-body model in the software repository. A Smith machine was modeled using toolbox for solid modeling in AnyBody .

In AnyBody, the interactions between the human body and the equipment were represented by defining the contact conditions between hand and bar, shoulder and bar, and foot and ground using AnyScript.

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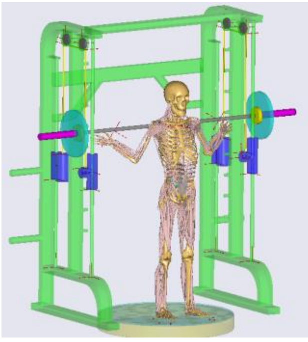


Fig. 1 Squat motion model

2.1.3 Measurement of Body Data

Six major muscles (i.e., the rectus femoris, vastus medialis, vastus lateralis, biceps femoris, and gastrocnemius) were selected to provide EMG data during the squats. Six channels of a wireless EMG measurement device (Delsys Tringo[6], USA) were attached to the selected muscles on the test subjects to obtain the measurements.

3. Muscle Activity Pattern Analysis Results

The measured EMG data were filtered using a moving average (window length: 1/24 s, overlap: 1/48 s). One cycle of a squat motion consists of sitting and standing. The muscle forces simulated in AnyBody were compared with the EMG data. Because the units of the two sets of data differed, they were scaled so that the peak points of the muscle activity values in the two sets of data were coincident, as illustrated in Fig. 2.

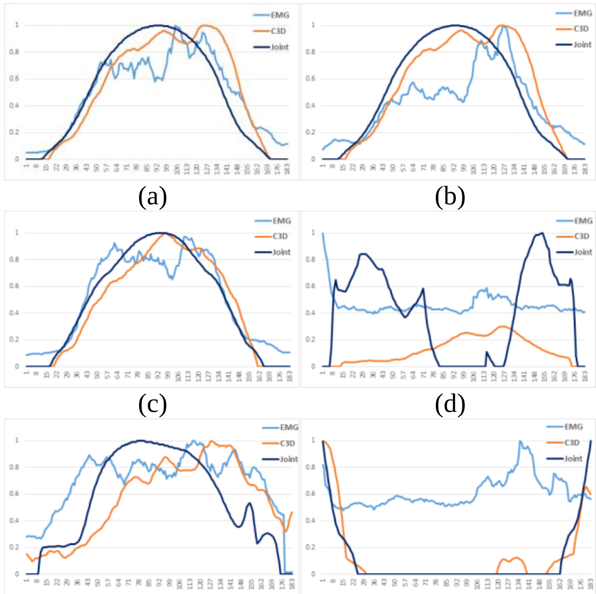
4. Discussion

In this study, muscle activity patterns in measured EMG data and the results of simulations of synthesized motion were compared to confirm the usefulness of the motion synthesis method for the squat motion. We observed similar patterns in the EMG data and simulation results for activity of the vastus medialis, vastus lateralis, and rectus femoris, as shown in Figs. 2(a), (b), and (c).

In contrast, the EMG data and simulation results exhibited very different patterns for the biceps femoris, erector spine, and medial gastrocnemius, as shown in Figs. 2(d), (e), and (f). Activity of biceps fomoris and gastrocnemius is almost same zero through analysis analog data. This means that two muscles did not activate during squat motion. So normalized method isn't applied to biceps femoris and gastrocnemius.

It should be noted that the magnitudes of the external forces at the contact points between the foot and the ground and between the shoulder and the bar were assumed in the simulations of the squat motions.

In future work, we intend to develop a more precise motion model and more plausible assumptions for the external forces at the contact points between the equipment and the human body.



(a) (b)

(c) (d)

(e) (f)

Fig. 2 EMG data and simulation results for muscle activity in a representative case: (a) vastus medialis (VM), (b) vastus lateralis (VL), (c) rectus femoris (RF), (d) biceps femoris (BF), (e) erector spine (ES), (f) medial gastrocnemius (GN)

Acknowledgment

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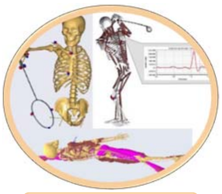
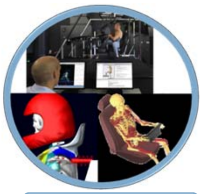


Sports



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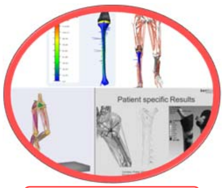
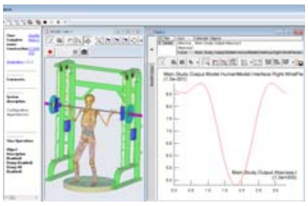
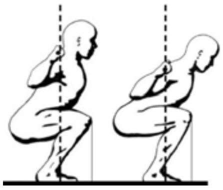


Medical

Introduction





Method

Overview

Measure squat motion
- Experimental setup
- Measure 3-D motion and electromyography(EMG)

Motion capture model
- Implementation of squat model with motion capture data
- Comparison analysis result with EMG

Motion generation model
- Implementation of squat model with regression equation
- Comparison analysis result

Measure squat motion

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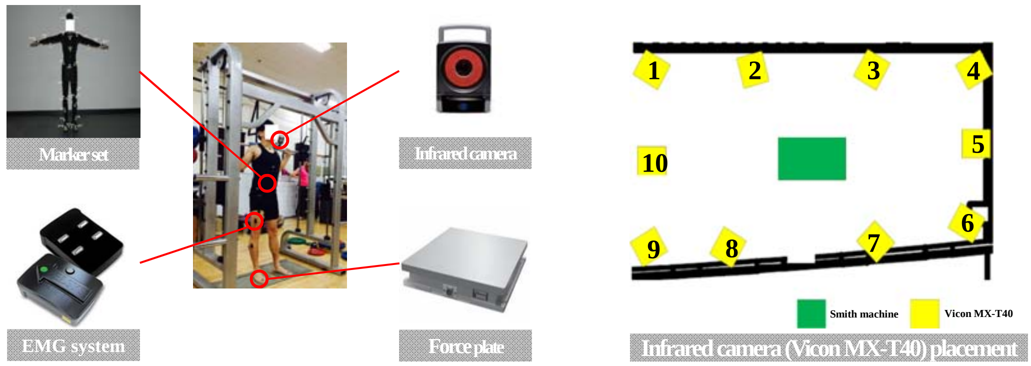
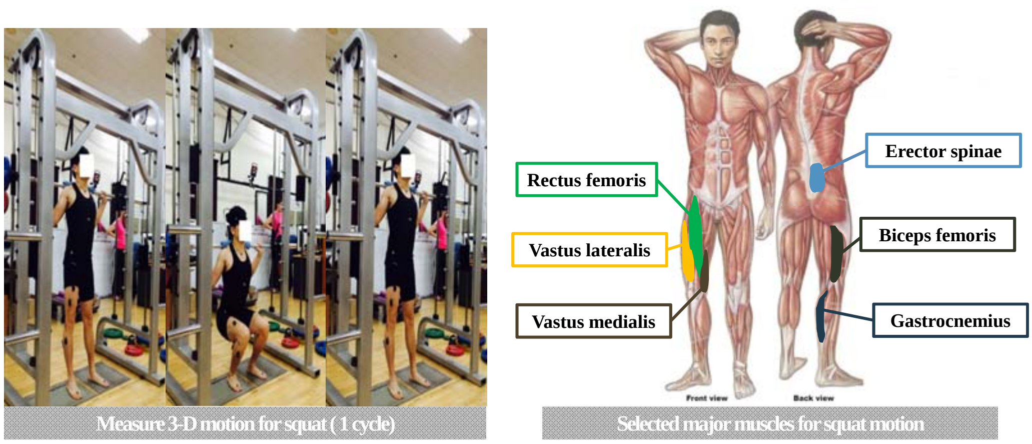
Experimental setup



Measure motion and electromyograhpy



Motion capture model

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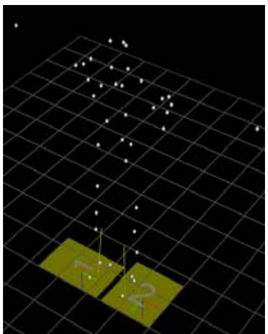
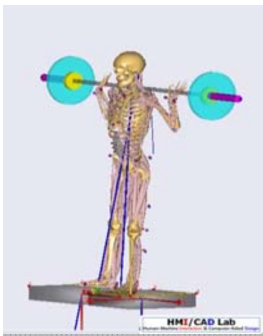
Implement squat model with motion capture

- Squat model with motion capture data(C3D file)
  - ✓ Human model is full body model(AAUHuman) of AnyBody Managed Model Repository(AMMR) v1.6.3
  - ✓ Motion capture data type is C3D, data processing(point labeling and healing) in NEXUS


Full body model

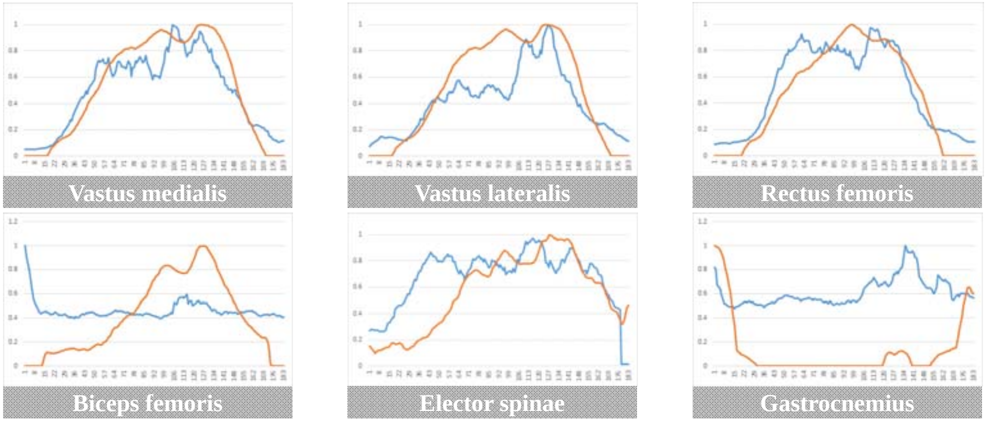

Motion capture data(C3D)



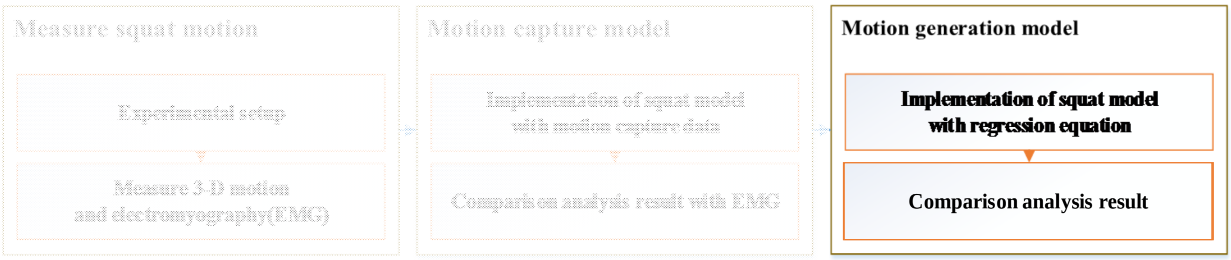
Squat motion model

Comparison of analysis results with EMG

- Comparison of muscle activity pattern of simulation results with normalized EMG (orange line: C3D model, blue line: EMG) for validation of musculoskeletal model for squat with C3D



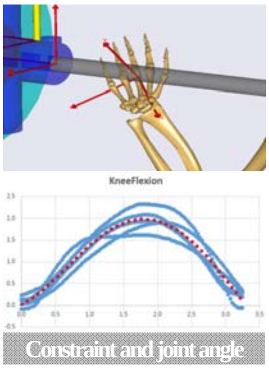
Motion generation model



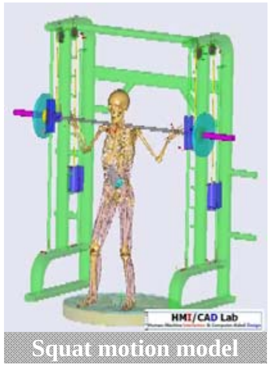
Implement squat model with motion generation

- Squat model with joint angle's relationship
  - ✓ We assume that squat motion is generated by defining constraint condition and joint angle


Full body model



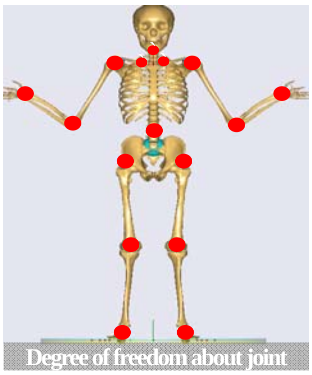
Constraint and joint angle

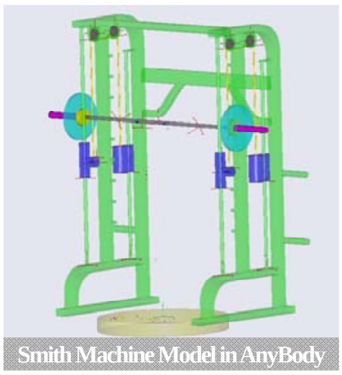


Squat motion model

Human model

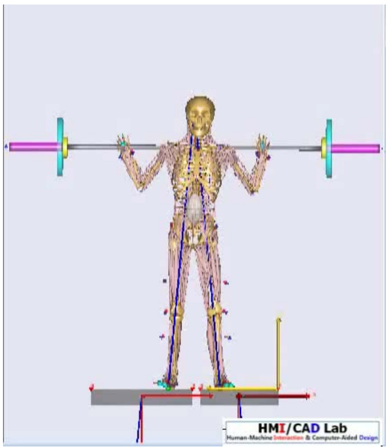
- Full body model has 42 degrees of freedom (42 DoFs)
- Smith machine has the vertical degree of freedom of its horizontal bar (1 DoF)


Degree of freedom about joint

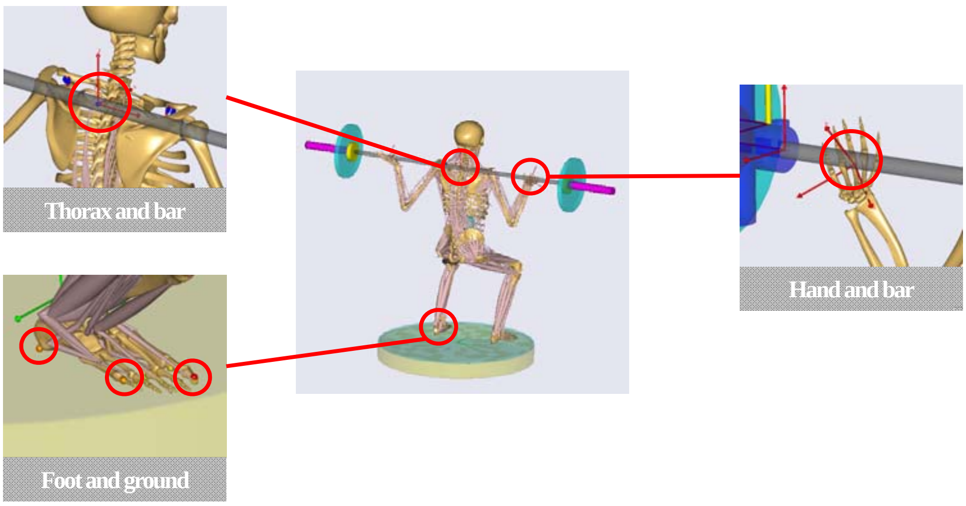

Smith Machine Model in AnyBody

Constraints and degrees of freedom

- Fixed degrees of freedom
  - Neck extension
  - Pelvis rotation(R_x, R_y)
  - Thorax position(Z axis)
  - Thorax lateral bending, rotation
  - Clavicular protraction, elevation, rotation
  - Glenohumeral flexion
  - Human-environment connection
- Moving degrees of freedom
  - Pelvis flexion
  - Hip flexion
  - Knee flexion

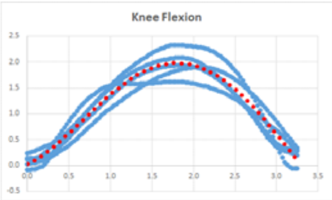


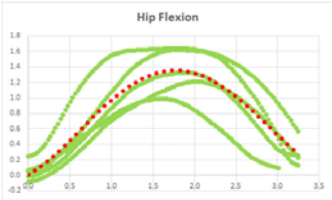
Definitions of human-environment connections

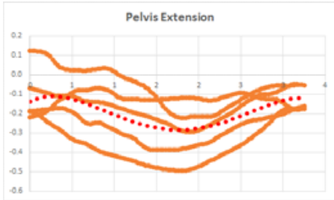


Analysis of joint angles from motion capture

- Capture the motion data for 5 subjects(Age: 27.17 ± 2.14 years, Height: 1.75 ± 0.03 m, Mass: 67.33 ± 3.72 kg) in order to use them for synthesis of motions
- Get the kinematic data of simulation with C3D (pelvis extension, hip flexion, knee flexion)

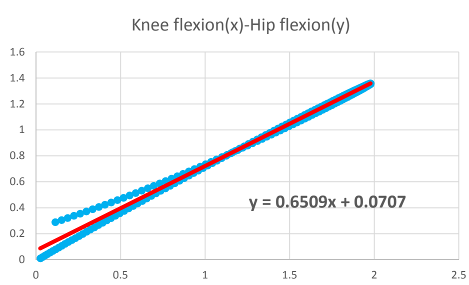


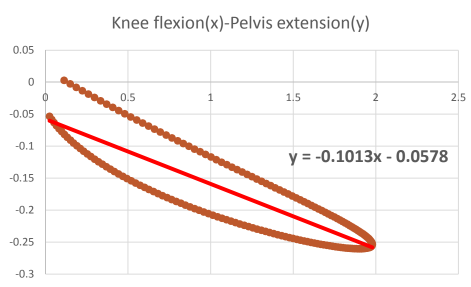




Correlation analysis

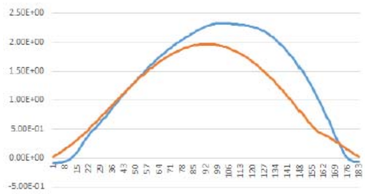
- Calculate a linear regression equation about the relationship between hip flexion and knee flexion
- Get the linear equation using Microsoft Excel 2013



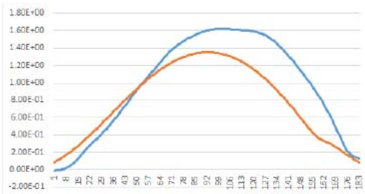


Implementation of motion generation

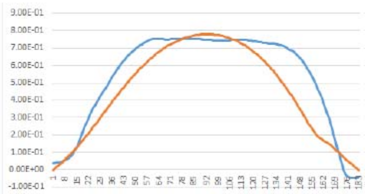
- Knee flexion
  - ✓ Knee flexion is the main independent variable which will determine the other moving joint angles
- Pelvis-thorax extension, hip flexion for Knee flexion
  - ✓ Will be determined by the linear relationships with respect to the knee flexion



Knee flexion

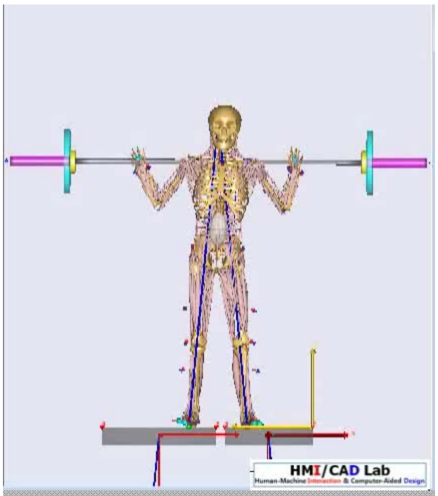


Hip flexion

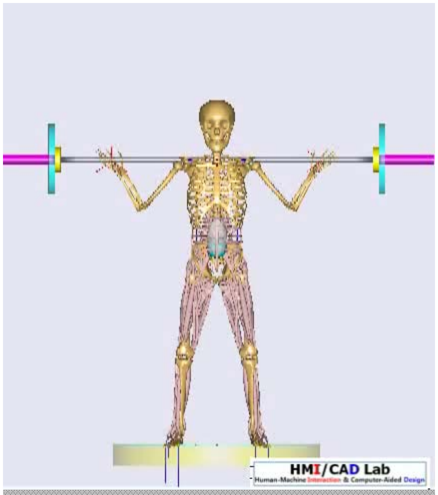


Ankle flexion

Squat Model



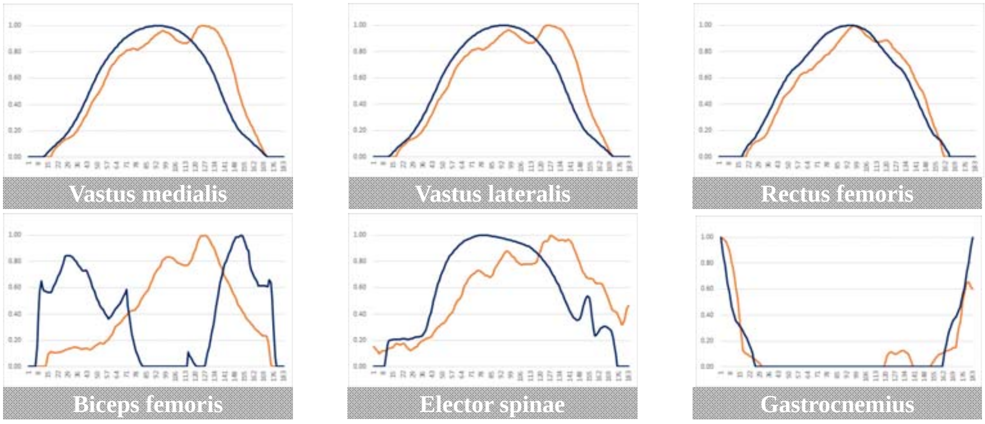
C3D model



Synthesized motion model

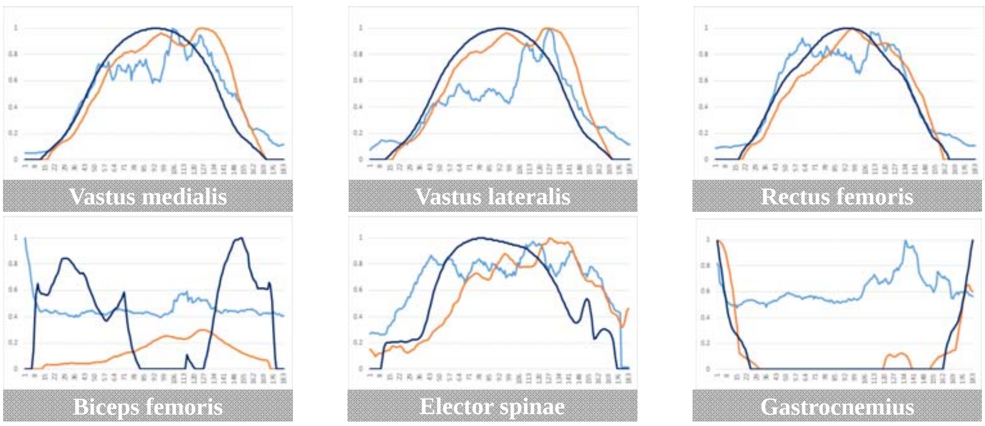
Comparison of results from different simulations

- Comparison of simulated muscle activity patterns between C3D and synthesized models (orange line: C3D model, dark line: synthesized model) for validation of synthesized model for squat



Comparison of simulation results with EMG

- Comparison of simulated muscle activity patterns with EMG (orange line: C3D model, blue: synthesized model, blue: EMG) for validation of synthesized model for squat



Discussion

Discussion

- Comparison of simulation result using C3D with electromyography (EMG) data for squat. Four muscles' (vastus medialis, vastus laterlis, rectus femoris, erector spine) activity patterns are very similar.
- Muscle activity pattern is similar in terms of activation time and activity value except biceps femoris, gastrocnemius. Because biceps femoris and gastrocnemius were not activated during squat motion.
- In case of synthesized motion model, four muscles' (vastus medialis, vastus laterlis, rectus femoris,, gastrocnemius) activity patterns are similar to those of C3D motion model.
- We assumed the relationships between joint angles for creating squat motion. But the generated motion is not exactly as same as the motion capture data(C3D).

Thank you for your attention

Q&A

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