LENGTH OF SERIAL ELASTIC ELEMENT AND CONTRACT ELEMENT DURING VERTICAL JUMP: COMPARISON OF STATIC OPTIMIZATION AND DYNAMIC OPTIMIZATION

Yuji Ohshima[1], Norihisa Fujii[2]

Doctoral Program in Physical Education, Health and Sport Sciences, University of Tsukuba, Tsukuba, Japan[1]
Faculty of Health and Sport Sciences, University of Tsukuba, Tsukuba, Japan[2]

The purpose of this study was to: (1) compare the length of serial elastic element, contract element estimated by two different optimizations, and (2) examine that whether those methods are able to evaluate the length of serial elastic element, contract element. One healthy male performed a vertical jump with the maximal effort from a squat position. The coodinate data and the ground reaction force were obtained with a 3D motion analysis system (250Hz) and force platform (1000Hz). For a dynamic optimization, we developed muscle activation driven forward dynamics simulation model. As a result, the pattern of length of element estimated by the dynamic optimization was similar to the pattern reported by Kurokawa et al. (2001). On the other hand, the pattern of length of element estimated by the static optimization differed from the pattern reported by Kurokawa et al. (2001). This finding might be useful to clear the mechanics of human movements.

KEY WORDS: musculoskeletal model, simulation, triceps surae

INTRODUCTION: In order to clear that limiting factor to high performance, it is important to investigate how the elements of the musculoskeletal system interact to produce movement. For example, it has been cleared that the force-velocity relationship is the most important contractile property of muscle regarding limits to maximum sprinting speed (Dorn et al., 2012; Miller et al., 2012). Musculoskeletal model is a useful tool to investigate the interaction of contract element and serial elastic element during movement. There are two different approaches in the use of musculoskeletal model to estimate muscle forces and lengths: static optimization and dynamic optimization. Static optimization 'an inverse dynamics approach' is the method that the joint torque by inverse dynamics distribute the joint moments by muscle forces. On the other hand, it is generally accepted that a dynamic optimization 'forward dynamics approach' provides more feasible estimates of muscle force (Anderson and Pandy, 1999). Thus, it is important to compare the muscle length calculated by two different optimizations.
The purpose of this study was to: (1) compare the length of serial elastic element, contract element estimated by two methods, and (2) examine that whether those methods are able to evaluate the length of serial elastic element, and contract element.

METHODS: One healthy male (Height 1.73m, body mass 70.5kg) volunteered for the present study. The participant performed a vertical jump with the maximal effort from a squat position. Ground reaction forces (GRFs) of the right leg was obtained with a force platform (Kistler, Wintherthur, Swiss), operating at 1000Hz. At the same time, 3D coordinates of 47 reflective markers on a body were recorded with a motion analysis system (Vicon, Oxford UK.) using 20 cameras (MX-T20), operating at 250Hz. Coordinates of the markers were smoothed using a second-order Butterworth low-pass-digital-filter at cut-off frequencies based on the residual method of Wells and Winter (1980). The cut-off frequencies ranged from 5.0Hz to 13.0Hz. Body segment masses, center of mass of body segment and whole body, and moments of inertia of body segments were estimated with the body segment parameters of Japanese athletes (Ae, 1996). Joint torques of the right foot, knee, and hip were calculated using an inverse dynamics. In order to estimate muscle forces and lengths by a static optimization, the musculoskeletal model of support leg comprised 43 Hill-type

muscles was developed (Delp et al., 2007). The distribution problem of the total torque into muscles was resolved by using a static optimization. The objective function (J) was to minimize activation cubed, summed across all joints. The constraint condition was to match the net joint torques of all muscles with those estimated by an inverse dynamics approach.
To develop muscle activation driven forward dynamics simulation model that is a dynamic optimization, we did following procedure. The torso and both lower limbs were modeled by seven segments. Equations of Motion for linked segment models were based on the method reported by Marshall et al. (1985) and, Fujii and Hubbard (2002). The number of degrees of freedom of the hip, knee, and ankle joints were three, one, one, respectively. Interactions of the feet with the ground were modeled using a spring-damper units distributed under the sole of each foot (Anderson and pandy, 1999). The musculoskeletal model composed 40 Hill-type muscles. Each leg has 20 muscles (Delp et al., 2007). The passive torque limiting the joint range of motion was modeled as an exponential curve (Davy and Audu, 1987). The objective function (J) was expressed as follows:

$$j = -\left(\left(H_{takeoff} + \frac{V^2}{2g}\right) - 0.1V_{front\_back}\right) \quad (1)$$

Where j is the objective function, V is the vertical velocity of the center of mass of the total body at the instant of take-off, g is acceleration due to gravity, $H_{takeoff}$ is the vertical height of the center of mass of the total body, V_{front_back} is the anterior-posterior velocity of the center of mass of the total body at the instant of take-off

RESULTS AND DISCUSSION: Figure1 shows the length of elements of musculoskeletal model during vertical jump. About dynamic optimization, the muscle-tendon complex (MTC) of gastrocnemius remained at an almost constant the length until -0.05sec and thereafter shortened (Figure1-B-1, C-1). On the other hand, the serial elastic element (SEE) of gastrocnemius elongated until -0.05s and thereafter shortened (Figure1-B-2, C-2). Contract element (CE) shortened from -0.10sec. Kurokawa et al. (2001) verified the behavior of fascicle and tendon of human gastrocnemius during vertical jump in vivo. The study have cleared that at the phase that MTC remained at an almost constant, the fascicle of gastrocnemius already shortened to stretch the tendinous structures, and thereafter at the phase that MTC shorten, the tendinous structure shortened to decrease the shorting velocity of fascicle of gastrocnemius. The pattern of length of element estimated by the dynamic optimization is similar to the pattern reported by Kurokawa et al. (2001). Thus, it is possibility that dynamic optimization is able to investigate the element of musculoskeletal system as behavior of fascicle and tendon during movement.
On the other hand, for static optimization, SEE of gastrocnemius remained at an almost constant the length until take-off (Figure1-B-2, C-2). The pattern of length of SEE estimated by the static optimization differed greatly from the pattern reported by Kurokawa et al. (2001). Additionally, figure2 shows the stretch and shorting velocity of elements of musculoskeletal model during vertical jump. The pattern of those parameters by the static optimization is not smooth. From those result, it is possibility that the static optimization is not able to investigate the element of musculoskeletal system as behavior of fascicle and tendon during movement. As a reason that the pattern of the elements is not smooth and differ from the pattern reported by Kurokawa et al. (2001), We have identified that static optimization might adjustment muscle activation and CE length to fit the joint torque by estimated muscle force for the joint torque by inverse dynamics.

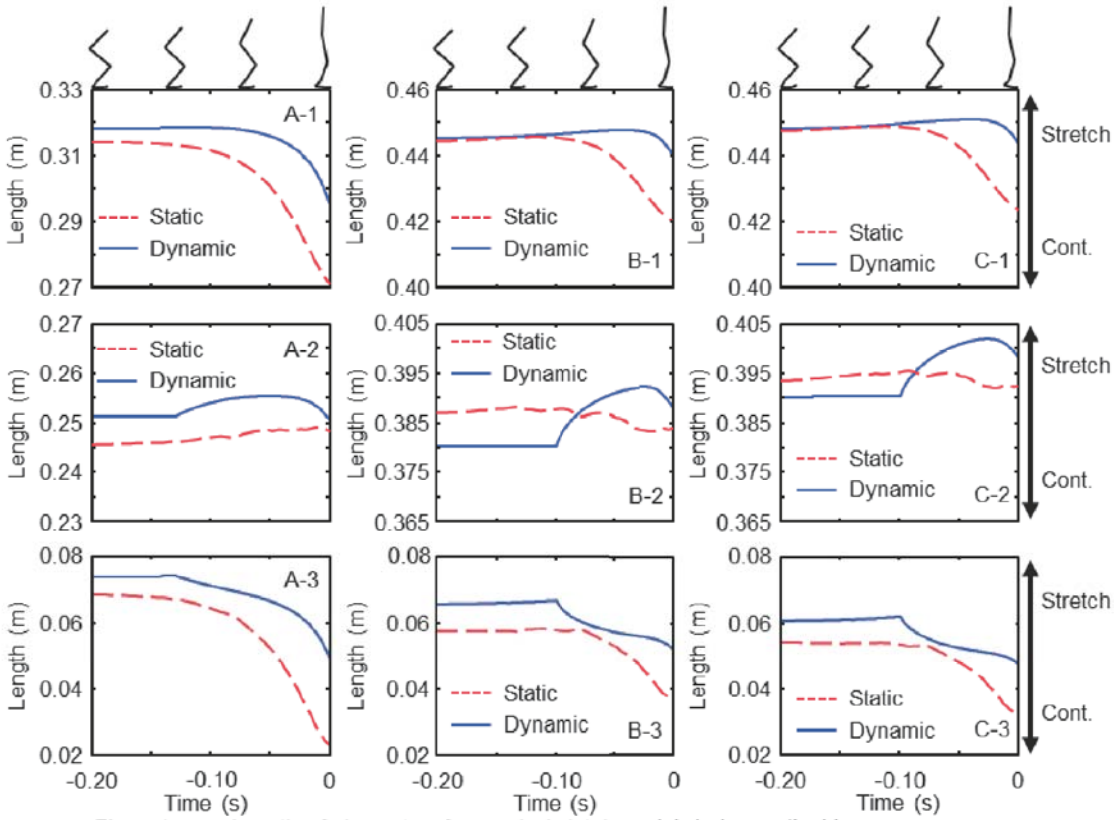

Figure1 Length of elements of musculoskeletal model during vertical jump.
(A: Soleus, B: gastrocnemius lateral side. C:gastrocnemius medial side,
1: muscle-tendon complex, 2: series elastic element, 3: contractile element)

CONCLUSIONS: The important results of this study are as follows: it is possibility that the dynamic optimization is able to investigate the element of musculoskeletal system as behavior of fascicle and tendon during movement. This finding might be useful to clear the mechanics of human movements.

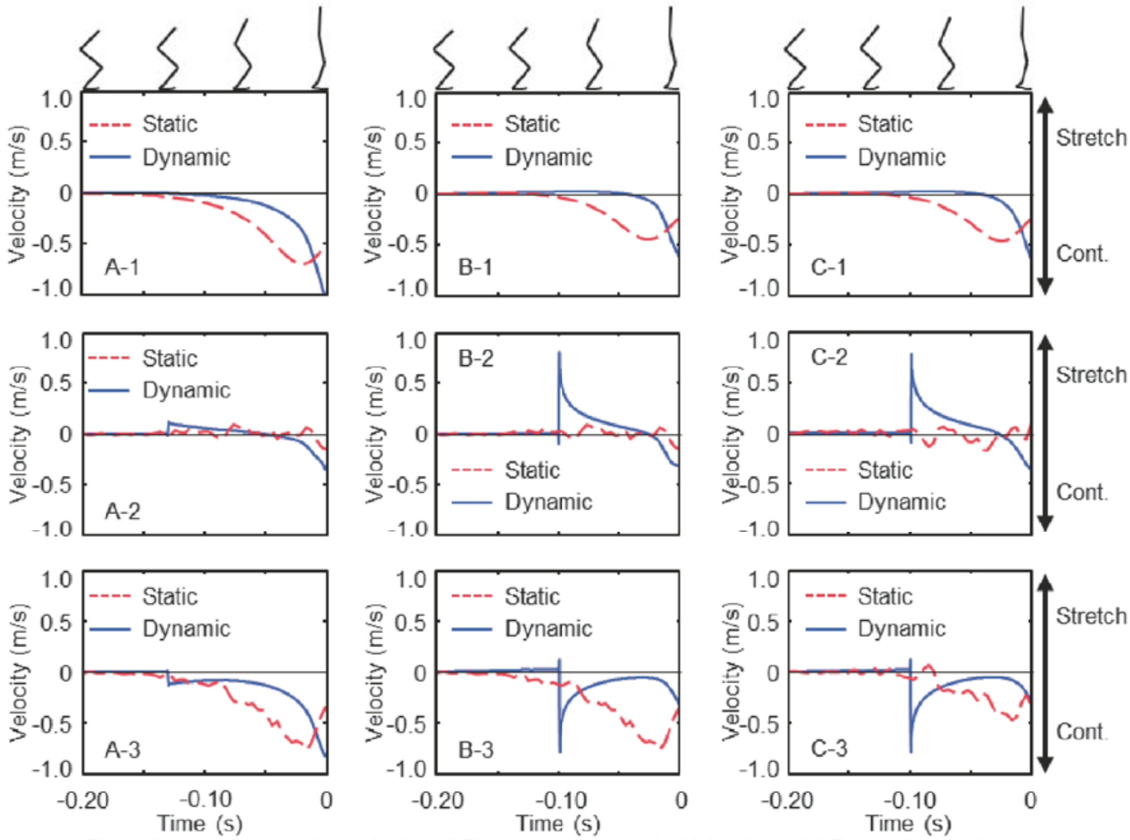

Figure2 Contraction velocity of Elements of musculoskleletal model During Vertical jump. (A: Soleus, B: gastrocnemius lateral side. C:gastrocnemius medial side, 1: muscle-tendon complex, 2: series elastic element, 3: contractile element)

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