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Development of an ergonomic musculoskeletal model to estimate muscle forces during vertical jumping

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Abstract

This study investigated a musculoskeletal model that includes the function of the antagonistic muscles and biarticular muscles and models muscles acting across the hip, knee and ankle joints, simultaneously. Furthermore, this study can be applied to dynamic motions. One vertical jump trials were conducted to validate the proposed model. Electromyograms (EMGs) of tibials anterior, gastrocnemius, soleus, rectus femoris, vastus lateralis, semimembranosus, biceps femoris, short head and gluteus maximus were used to compare with the estimated muscle forces. The results showed that the muscle forces estimated by the proposed method had a stronger correlation with EMGs than those of an optimization method. The correlations of the proposed method and the optimization method were 0.4 and 0.01 of TA, 0.95 and 0.86 of GAS, 0.95 and 0.93 of SOL, 0.94 and 0.01 of RF, 0.93 and 0.97 of VAS, 0.83 and 0.91 of SM, 0.75 and 0.01 of BFSH and 0.95 and 0.92 of GMAX. Thus, the proposed method was considered to successfully estimate the muscle forces during vertical jumping.

Keywords: Musculoskeletal model; vertical jumping; muscle force

1. Introduction

Estimating muscle forces during motion is important to the fields of sport, ergonomics and bioengineering, and may contribute to improvements in sports techniques, rehabilitation procedures, product designs and work environments. Optimization methods [1] that minimize the sum of the muscle

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forces across a joint and equal the net moment of force at the joint are usually used to estimate muscle forces. Unfortunately, these methods usually do not consider the functions of antagonistic muscles and biarticular muscles. Antagonistic muscles are the muscles that act in opposition to the prime movers or agonists of a movement. Biarticular muscles are the muscles that work simultaneously on two joints. If musculoskeletal models do not consider these roles of muscles, they are unlikely to accurately portray the magnitudes of the agonistic muscles. This study investigated a musculoskeletal model that includes antagonistic muscle activity and biarticular muscles acting across the hip, knee and ankle joints. Furthermore, this study can be applied to dynamic motions. One vertical jump trial as dynamic motion was conducted to validate the proposed model. Electromyograms (EMGs) of tibialis anterior, gastrocnemius, soleus, rectus femoris, vastus lateralis, semimembranosus, biceps femoris, short head and gluteus maximus were used to compare with the estimated muscle forces. As validation, the results of EMGs were compared with the muscle forces estimated by the optimization method and those of the proposed method.

Nomenclature

A_i	cross sectional area of muscle i
F_i	force of muscle i
M_j	net moment on joint j
r_i	moment arm of muscle i

2. Methods

2.1. Musculoskeletal model

As there are many muscles in the lower extremity, it is difficult to model all the contributory muscles. So this study used a musculoskeletal model that includes nine representative muscles in sagittal plane as shown in Figure 1. The following muscles are included: 1-tibialis anterior (TA), 2-gastrocnemius (GAS), 3-soleus (SOL), 4-rectus femoris (RF), 5-vastus lateralis (VAS), 6-semimembranosus (SM), 7-biceps femoris and short head (BFSH), 8-iliopsoas (IL) and 9-gluteus maximus (GMAX). GAS, RF and SM are biarticular muscles and others are monoarticular muscles.

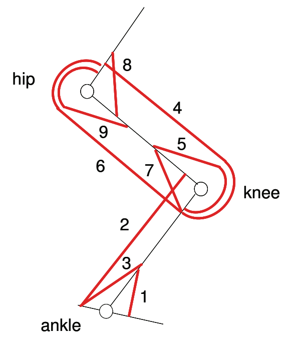

Fig. 1. Muscular arrangements at the lower extremity