



Short communication

Triceps surae muscle–tendon unit length changes as a function of ankle joint angles and contraction levels: The effect of foot arch deformation

Soichiro Iwanuma^{a,b}, Ryota Akagi^d, Satoru Hashizume^b, Hiroaki Kanehisa^e, Toshimasa Yanai^c, Yasuo Kawakami^{c,*}^a Japan Society for the Promotion of Science, 6 Ichibancho, Chiyoda 102-8471, Tokyo, Japan^b Graduate School of Sport Sciences, Waseda University, 2-579-15 Mikajima, Tokorozawa, Saitama 359-1192, Japan^c Faculty of Sport Sciences, Waseda University, 2-579-15 Mikajima, Tokorozawa, Saitama 359-1192, Japan^d Department of Sports Sciences, Japan Institute of Sports Sciences, 3-15-1 Nishigaoka, Kita, Tokyo 115-0056, Japan^e National Institute of Fitness and Sports in Kanoya, 1 Shiramizu, Kanoya, Kagoshima 891-2393, Japan

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ABSTRACT

The purpose of this study was to clarify how foot deformation affects the relationship between triceps surae muscle–tendon unit (MTU) length and ankle joint angle. For six women and six men a series of sagittal magnetic resonance (MR) images of the right foot were taken, and changes in MTU length (the displacement of the calcaneal tuberosity), foot arch angle, and ankle joint angle were measured. In the passive session, each subject's ankle joint was secured at 10° dorsiflexed position, neutral position (NP), and 10° and 20° plantar flexed positions while MR images were acquired. In the active session, each subject was requested to perform submaximal isometric plantar flexions (30%, 60%, and 80% of voluntary maximum) at NP. The changes in MTU length in each trial were estimated by two different formulae reported previously. The changes of the measured MTU length as a function of ankle joint angles observed in all trials of the active session were significantly ($p < 0.05$) larger than corresponding values in the passive session and by the estimation formulae. In the passive session, MTU length changes were significantly smaller than the estimated values when the ankle was plantar flexed. The foot arch angle increased as the contraction level increased from rest ($117 \pm 4^\circ$) to 80% ($125 \pm 3^\circ$), and decreased as the ankle was positioned further into plantar flexion in the passive session ($115 \pm 3^\circ$). These results indicate that foot deformation profoundly affects the triceps surae MTU length–ankle joint angle relationship during plantar flexion.

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1. Introduction

Evaluation of length changes of the triceps surae muscle–tendon unit (MTU) during ankle joint movements is important to understand its mechanical function (i.e., force–length relationships of muscle and tendinous structures). The change in triceps surae MTU length for a given ankle joint rotation has been predicted by formulae developed on the basis of cadaveric data (Grieve et al., 1978; Hawkins and Hull, 1990). These formulae are based on the relationship between changes in ankle joint angle and MTU length (i.e., the displacement of the calcaneal tuberosity). However, proximal displacement of the calcaneal tuberosity occurs during isometric plantar flexion (Maganaris, 2005). This implies that the above formulae are not suitable for evaluating changes in triceps surae MTU length.

Other cadaveric studies have shown that the foot segment is deformed by the forces applied to it (Carlson et al., 2000; Ker et al., 1987). It is likely that the corresponding deformation also occurs *in vivo*, by the Achilles tendon force produced by the triceps surae muscles and other external forces that constrained the foot to move along a certain path or to rotate about a fixed axis. It can, therefore, be hypothesized that contraction-induced foot deformations give rise to a difference in the triceps surae MTU length–ankle joint angle relationships between conditions with and without contraction of the triceps surae muscles. The present study is aimed to test this hypothesis by measuring foot deformation *in vivo* under these conditions.

2. Methods

2.1. Subjects

Six women and six men voluntarily participated in this study. The mean values $\pm$ SDs for their age, height, mass, and lower leg length were 24 ± 2 yr,

* Corresponding author. Tel./fax: +81-4-2947-6784.
E-mail address: ykawa@waseda.jp (Y. Kawakami).