Available online at www.sciencedirect.com
ScienceDirect
Gait & Posture 25 (2007) 380–384
GAIT & POSTURE
www.elsevier.com/locate/gaitpost

Medial gastrocnemius muscle behavior during human running and walking

M. Ishikawa *, J. Pakaslahti, P.V. Komi

Neuromuscular Research Center, Department of Biology of Physical Activity, P.O. Box 35(LL220), FIN-40014, University of Jyväskylä, Finland

Received 20 December 2005; received in revised form 28 April 2006; accepted 2 May 2006

Abstract

Utilization of elastic energy in the tendinous tissues (TT) of the human skeletal muscle may be task dependent. The present study was designed to investigate this problem by comparing the fascicle-TT interaction of the medial gastrocnemius muscle (MG) during ground contact of running and walking. Seven subjects ran and walked with a natural cadence. Ankle and knee joint angular data were recorded by electrogoniometers for estimating the entire MG muscle-tendon unit (MTU) length, together with the ground reaction forces. The MG fascicle length was measured by using the high-speed ultrasound image scanning during movements. The results showed that in running, after the rapid early fascicle stretching (0–10% of the contact period), the fascicles shortened throughout the ground contact while TT was stretched prior to shortening. In walking, the fascicles shortened initially (0–15% of the contact period) due to sudden plantar-flexion. Thereafter, the fascicles and TT lengthened slowly until the end of single support (15–70% of the contact period.). The fascicles then shorted during the push-off phase (70–100% of the contact period). These results demonstrate that the MG fascicles behaved differently between running and walking and did not follow the length change pattern of the MTU during the ground contact period. The estimated working range of active muscle fibers in force–length relationship could shift more to an ascending limb (shorter length) phase in running than in walking. These results suggest that MG fascicles can work within the optimal working range of the sarcomeres in the force–length relation but are responsible for the effective utilization of the TT elasticity during human running.

Keywords: Gait; Locomotion; Ultrasonography; Elastic energy

1. Introduction

Elasticity of the skeletal muscle plays an important role by improving the power output and efficiency in human locomotion, such as hopping and running, where the muscle is actively stretched (the braking phase) prior to the concentric contraction (the push-off phase). This supports the elastic utilization concept [1,2]. This behavior is called a stretch-shortening cycle (SSC) action [3] on the entire muscle-tendon unit (MTU) level. However, muscle fiber displacement, pennation angle of muscle fibers and/or tendon strain can substantially affect the entire MTU length, and has different implications for muscle-tendon function [3–6]. The question arises whether it is possible to store and subsequently utilize the tendinous elastic energy in the same way during the different SSC exercises, for example between hopping, walking and running. Much of what we know about human locomotion and the interaction between fascicles and tendinous tissues (TT), which include the aponeuroses and the free length of tendon, is derived from studies examining a single locomotory task only.

Studies on animal locomotion have revealed that skeletal muscle function may be different for different conditions and tasks [7,8]. It has been proposed that the interaction between fascicles and TT can be changed via alterations in the pattern of muscle activations (timing, duration and intensity) when speed, gait task or environment change [7]. In human movements, it is unknown how the muscle fascicles and TT interact in different locomotion

* Corresponding author. Tel.: +358 14 260 2086; fax: +358 14 260 2071.
E-mail address: masaki.ishikawa@sport.jyu.fi (M. Ishikawa).

0966-6362/$ – see front matter © 2006 Elsevier B.V. All rights reserved.
doi:10.1016/j.gaitpost.2006.05.002

tasks. Consequently, the issue of how skeletal muscles function might change with different tasks has remained relatively unexplored. In human drop jump exercises, the fascicles of the medial gastrocnemius muscle (MG) shortened throughout the ground contact [9]. On the other hand, recent human walking studies showed that MG fascicles contract isometrically [10] or even lengthen [11] during the single support phase (15–70% of the contact period) when MTU and TT are stretching. These different and perhaps contradicting MG fascicle behaviors during SSC exercises may suggest existence of a movement specific fascicle behavior. Consequently, the fascicle-TT interaction during human locomotion needs further clarification. To begin to address issues relating to variability in human skeletal muscle function, the purpose of the present study was to examine how the fascicle-TT interaction together with muscle activation varies in medial gastrocnemius muscle (MG) due to the different tasks of walking and running.

2. Methods

Seven healthy male volunteers (age 26.6 ± 2.7 years, height 183.4 ± 6.0 cm, body mass 80.9 ± 15.2 kg; means $\pm$ S.D.) participated after being informed all the risks associated with this study, which was approved by the Ethic Committee of the University of Jyväskylä. The subjects walked with a natural cadence (1.48 ± 0.12 m s^{-1}) and ran (2.74 ± 0.21 m s^{-1}) twice on a 10 m long force platform system (Raute Inc, Finland) (Fig. 1a). The ground reaction forces on the right and left sides were recorded separately to define the ground contact phases. Real-time ultrasound devices (SSD-5500, Aloka, Japan) were used to measure the fascicle length of MG during running and walking [9–11]. A 7.5 MHz linear-array ultrasound probe of 6 cm long was put over the MG muscle and fixed securely. The longitudinal ultrasonographic images in MG were scanned (96 images s^{-1}) during the movements (Fig. 1b). The MG fascicles were identified in each image along their length from the superficial and deep aponeuroses. One end of the fascicle, which was extended off the acquired ultrasound image, was sometimes estimated. Surface bipolar Ag–AgCL electromyographic (EMG) electrodes (5 mm diameter with interelectrode distance 20 mm) were used to record the EMG activities in MG (Glonner electronic, Munich, Germany; input impedance >25 MΩ, common mode rejection ratio >90 dB). Ankle and knee joint rotations were recorded by electrogoniometers attached over the right lateral melleoli and popliteal crease, respectively. These signals were stored simultaneously by a 12-bit A/D converter with a sampling frequency of 1 kHz.

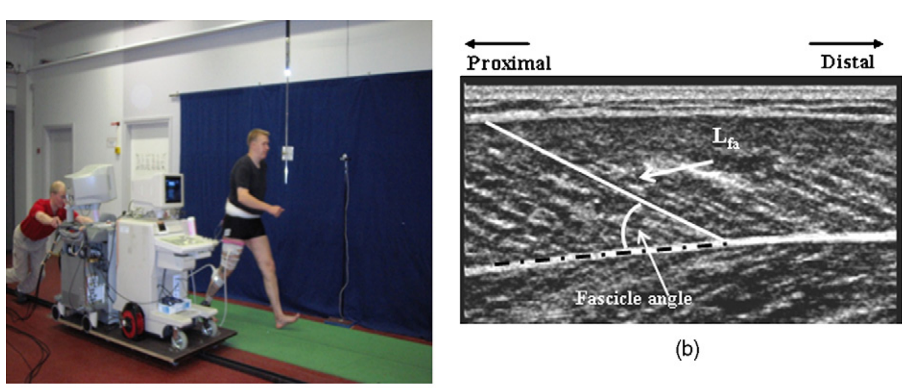
2.1. Analyses

To combine the analysis of the various parameters, the MTU length of MG data was re-sampled at 100 Hz and the fascicle length data at 96 Hz was interpolated at 100 Hz so that the time scales matched. The regression equations of Hawkins & Hull [12] were used to estimate MTU length in MG from measurements of ankle and knee joint flexion angles. The TT length was calculated by subtracting the fascicle length multiplied by the cosine of the fascicle angle from the MTU length [9–11]:

$$L_{TT} = L_{MTU} - L_{fa} \times \cos\alpha$$

where L_{TT} is the TT length, L_{MTU} is the muscle-tendon unit length, L_{fa} is the fascicle length and α is the angle created by the fascicle line and its insertion into the aponeurosis lines (Fig. 1b). The length changes were calculated from the time of initial foot contact to the peak length and from the peak length to the time of toe-off, respectively.

After the EMG signals were rectified, 10 step cycles of the signal data (EMG, ground reaction forces and joint angle data) were averaged for each subject. In the ultrasonographic data the averaging was done for three consecutive step



(a) (b)

Fig. 1. (a) Set-up for the walking and running experiments: the ultrasound images of fascicles and EMG of the medial gastrocnemius muscle (MG) were recorded simultaneously on a unique 10 m long force plate system, composed of two rows of individual force plates. The ultrasound apparatus was pushed at the speed of the subject outside the force plate area. The ankle and knee joint angles were also measured simultaneously by using goniometers. (b) The calculation of the fascicle length (L_{fa}) and the angle from medial gastrocnemius (MG) muscle (the width and depth scanning areas are 58.5 and 60.0 mm, respectively).