STRAIN CHANGES IN HUMAN TRICEPS SURAE MUSCLES DURING LOW LOAD DYNAMIC CONTRACTIONS

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SUMMARY
We investigated the strain changes in human triceps surae muscles during dynamic contractions using Phase Contrast MR. Subjects performed dynamic dorsi and plantar flexions in MR bore. A total of 15 MR images on soleus and gastrocnemius muscles with two dimensional velocity information were acquired. Tracking of each pixel using the velocity information in MR images revealed the change in displacement and the principal strains. The pattern of strain change during movements tended to be similar at all locations in muscles. However, a significant intramuscular heterogeneity of strain magnitude was observed in both muscles. Larger 1st principal strain over 0.4 concentrated along the superficial aponeurosis in the gastrocnemius, and the distal portion of the muscle belly of the soleus muscles. These results suggest that the strain concentration on a specific part of muscle could be related with the site-specificity of the occurrence of muscle injury and hypertrophy.

INTRODUCTION
In muscle tissues, while sizable strain induces injuries, appropriate strain facilitates their remodeling and hypertrophy (1, 2). Thus, the determination of the time-course of strain distribution is important for understanding muscle behavior during movements and exercise. So far, fascicle behavior has been well investigated using ultrasound; however, this method is limited because it cannot measure local strain information. Recently, Dynamic MR imaging such as Spin tagging MRI and Phase contrast MRI have enabled the measurement of local strain from in vivo contracting muscles and aponeuroses (3, 4). In the present study, we investigated the changes in two dimensional strains and calculated the principal strains of human triceps surae muscles during dynamic contractions.

METHODS
Subjects (7 males) performed 64 dynamic dorsi and plantar flexions without external load in a MR gantry at a rate of 60 cycles/min between the range of 20 to 30 degrees plantar flexion. During dynamic dorsi and plantar flexions, force was recorded with an optical strain gauge attached to the foot plate. It was used as a gating trigger to control MR imaging timing. The image acquisition started at 30 deg of plantar flexion.

To measure velocity of tissue movements, oblique sagittal Phase Contrast (PC) MR images were acquired by a 1.5T machine[16.6 ms repetition time, 5.9 ms echo time, 160 × 320 mm field of view, 128 × 256 matrix size, 5 mm slice thickness, 2 views/segment, velocity encoding 7 cm/s, temporal resolution 63 ms, scan time 1:04] via a head coil (Figure 1). Two dimensional excitations from superior to inferior and from proximal to distal directions were used. The slice location was carefully prescribed to include entire fascicles in the imaging plane. A total of 15 phases were acquired in each cycle.

Using the velocity information in PCMR images, displacement tracking of each pixel was applied. Then, normal and shear strains and the principal strains were calculated by shape function from the displacement change. Experienced principal strains through contractions were evaluated in 18 spatial regions based on muscle anatomical shape as shown in figure 3A.

RESULTS AND DISCUSSION
The pattern of strain changes during movements tended to be similar at all locations in muscles. (Figure 2). Basically, there existed a small peak of 1st principal strain by 63-126 ms. Then strain increased to the maximal value by 441-693 ms after a small reduction.
On the other hand, the magnitude of strains showed a significant intramuscular heterogeneity of lengthening strain magnitude in both the soleus and gastrocnemius muscles. Figure 3B demonstrates the ensemble average of maximal values of 1st principal strain experienced during contractions from all subjects. Larger 1st principal strain over 0.4 was concentrated along the superficial aponeurosis in gastrocnemius muscle (e.g. area 1, 7). In addition, the distal portion of the muscle belly of the soleus muscle experienced larger 1st principal strain than the proximal portion (e.g. area 16, 18).

It is well known that muscle strain in calf often occurs around the muscle-tendon junction of medial gastrocnemius muscle (5). The superficial site of gastrocnemius is near this portion. The distal portion of soleus muscle is close to the aponeurosis where inflammation of Achilles tendon occurs frequently. Also, site-specificity of muscle hypertrophy has been reported (6). Although the force level was weak for stable measurements of clear PCMR images under repeated contractions in this study, the present results suggest that the strain concentration on a specific part of muscle could be related with the site-specificity of the occurrence of muscle injury and hypertrophy.

The heterogeneous strain would reflect regional difference of muscle lengthening behaviors even in synergist muscles. Also, the heterogeneous strain was observed along the fascicle direction in a single muscle. This further implies, according to the length-velocity-force relation of fascicles, differences exist in the force generation profiles both between and within fascicles during contractions.

Recently, PCMRI are helping to increase knowledge of strain of fascicles (3) as well as aponeuroses (4) during joint movements. The combined analysis on fascicles, aponeuroses and the principal strain would determine the interaction between behavior of each tissue and its correlation to tissue injury and hypertrophy.

CONCLUSIONS
Two dimensional tracking using Phase Contrast MR revealed a significant intramuscular heterogeneity of lengthening strain magnitude in both the soleus and gastrocnemius muscles. These methods and accumulated results could contribute to the understanding on cause of injury and fascicle behaviors during human movements and exercises.

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