THREE-DIMENSIONAL ARCHITECTURE OF HUMAN GASTROCNEMIUS AND TIBIALIS ANTERIOR MUSCLES DURING ISOMETRIC ACTIONS

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INTRODUCTION

The architecture of a muscle, characterized by the length (fascicle length) and the angle (pennation angle) of fascicles of muscle fibers, is a primary determinant of its function. Recent in vivo approaches employing ultrasonography have shown that architecture of human skeletal muscles change during contractions even in isometric actions [1-4].

Most previous sonographic studies measured muscle architecture only at the midbelly of the muscle, based on the notion that there is a marked uniformity in architecture throughout a muscle [5]. As for the medial gastrocnemius muscle (MG), however, Kawakami et al. [1] found that pennation angle measurements significantly varied among positions, while fascicle length was constant. In their results, the differences in pennation angles still remained when the muscle contracted. Moreover, Nagayoshi et al. [4], who examined the architecture of the tibialis anterior muscle (TA), reported significant differences in fascicle length measurements between proximal 30% and 50% positions in a relaxed condition, without differences in pennation angles. On the other hand, some researchers claimed that homogeneous architecture at the various sites of muscle belly of MG [2] and TA [3] were found both at rest and during contraction. Thus, whether architectural parameters, such as the fascicle length and pennation angle, differ within a muscle at rest and/or during contraction still remains a question.

The present study aimed to ascertain the uniformity of the architecture of human medial gastrocnemius and tibialis anterior muscles both in the relaxed and contracted conditions.

METHODS

Four healthy men (27.8 ± 2.2 yrs) volunteered for the measurements. The subject's right foot was firmly attached to an electric dynamometer. The ankle joint was fixed at 0 deg (for MG) or at 30deg dorsiflexion (for TA), and the knee joint was fully extended while the subject was in a prone position and seated position for MG and TA measurements, respectively. During the ultrasound data acquisition, the subject was asked to relax, then to maintain isometric plantar flexion or dorsiflexion at five force levels (20, 40, 60, 80, 100%MVC).

By moving a 7.5MHz, linear, B-mode, ultrasonographic probe (SSD-5500, Aloka, Japan) on the skin along the center of the muscle belly, serial cross-sectional images of muscles were obtained. An electromagnetic position sensor was attached to the ultrasonic transducer to provide position and orientation information for each image acquired. All the serial ultrasonic images (recorded at 30 frames/s) were stored in a computer simultaneously with the positional information, by which, three-dimensional ultrasound (3D-US) images were reconstructed.

The 3D-US images could be cut at any planes with respect to the muscle orientation. Several planes were taken from different regions over the longitudinal axis of the muscle belly so that fascicles of interest were visualized throughout their lengths. In each image, the fascicle length was measured along the fascicle as the distance between its aponeurotic attachments, and the pennation angle was measured as the angle between the deep aponeurosis and fascicles.

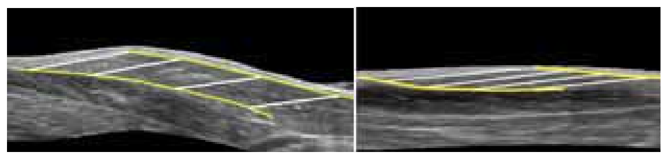

Figure 1: Typical examples of reconstructed ultrasound images of the MG (left) and TA (right) at rest condition.

RESULTS AND DISCUSSION

A preliminary study for 2 subjects showed that the fascicle length of MG was constant throughout the muscle in the relaxed and contracted conditions. On the other hand, fascicle length of TA showed an increasing trend along the center line of the muscle belly towards the distal direction in rest conditions, which remained when the contraction levels increased. The uniformity of fascicle length for MG and the nonuniformity for TA support previous reports [1,2,4].

The pennation angles of MG and TA both differed among various sites. In the relaxed condition, pennation angles were maximal at the middle position and minimal at the extreme ends in both muscles. The site of the maximal values moved proximally with increasing contraction levels. The position-related differences within muscle are similar to a previous finding [1] for MG, while no reports have been made for the nonuniform pattern of TA pennation angles at rest and/or during contraction.

The present results indicate that MG and TA have heterogeneous architecture within muscle that change by contraction, and that they should not be treated by planimetric models.

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