ORIGINAL ARTICLE

Changes in Passive Mechanical Properties of the Gastrocnemius Muscle at the Muscle Fascicle and Joint Levels in Stroke Survivors

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ABSTRACT. Gao F, Grant TH, Roth EJ, Zhang L-Q. Changes in passive mechanical properties of the gastrocnemius muscle at the muscle fascicle and joint levels in stroke survivors. Arch Phys Med Rehabil 2009;90:819-26.

Objectives: To investigate the ankle joint–level and muscle fascicle–level changes and their correlations in stroke survivors with spasticity, contracture, and/or muscle weakness at the ankle.

Design: To investigate the fascicular changes of the medial gastrocnemius muscle using ultrasonography and the biomechanical changes at the ankle joint across 0°, 30°, 60°, and 90° knee flexion in a case-control manner.

Setting: Research laboratory in a rehabilitation hospital.

Participants: Stroke survivors ($n=10$) with ankle spasticity/contracture and healthy control subjects ($n=10$).

Interventions: Not applicable.

Main Outcome Measurements: At the muscle fascicle level, medial gastrocnemius muscle architecture including the fascicular length, pennation angle, and thickness were evaluated *in vivo* with the knee and ankle flexion changed systematically. At the joint level, the ankle range of motion (ROM) and stiffness were determined across the range of 0° to 90° knee flexion.

Results: At comparable joint positions, stroke survivors showed reduced muscle fascicle length, especially in ankle dorsiflexion ($P\leq.048$) and smaller pennation angle, especially for more extended knee positions ($P\leq.049$) than those of healthy control subjects. At comparable passive gastrocnemius force, stroke survivors showed higher fascicular stiffness ($P\leq.044$) and shorter fascicle length ($P\leq.025$) than controls. The fascicle-level changes of decreased muscle fascicle length and pennation angle and increased medial gastrocnemius fascicle stiffness in stroke were correlated with the joint level changes of increased joint stiffness and decreased ROM ($P<.05$).

Conclusions: This study evaluated specific muscle fascicular changes as mechanisms underlying spasticity, contracture, and joint-level impairments, which may help improve stroke rehabilitation and outcome evaluation.

Key Words: Contracture; Muscle spasticity; Rehabilitation; Stroke.

SPASTICITY, CONTRACTURE, and muscle weakness are commonly observed after stroke and are major sources of disabilities poststroke. Clinically, the phenomenon of footdrop is associated with an increase in the tone of the calf muscles. Muscle tone may result from both reflex and nonreflex changes and is usually accompanied with increase of passive joint/muscle stiffness.[1] In the spastic lower limb, it is not clear how hypertonia at the ankle joint is related to changes in the biomechanical properties of the plantar flexor muscles.[2-7] A better understanding of changes in muscle architecture and its association with joint biomechanical properties could help us gain insight into mechanisms underlying spasticity/contracture and provide guidance to the rehabilitation of patients poststroke. The changes in the mechanical properties may be associated with changes in skeletal muscle architecture, such as muscle fascicle length, pennation angle, and muscle thickness. Muscle architecture plays a significant role in normal muscle function and is closely related to the mechanical properties of the joint.[8] Recent studies based on a biomechanical model suggested that an increase in ankle joint stiffness could be attributed to shortened calf muscles.[2] However, there has been little experimental evidence evaluating muscle architecture and joint stiffness in the same patients with ankle spasticity/contracture.

Ultrasonography has been used in studying muscle and tendon function in healthy populations *in vivo* and noninvasively.[9-11] However, only a few ultrasonic studies have been conducted to examine hypertonic muscles in patients with neurologic disorders, with mixed results reported and with a lack of study on lower limb muscle architecture poststroke. Shortland et al[12] reported no difference in muscle fascicle length between children with spastic diplegia and healthy children, suggesting muscle architecture changes do not contribute to contracture in the patients, while Cheatwood et al[13] reported significantly shorter muscle fascicle length in the group of children with spastic cerebral palsy. Li et al[14] found that the fascicle length of spastic brachialis muscle on the affected side was significantly shorter than that on the unimpaired side. The differences in gastrocnemius muscle architecture were also studied in children with cerebral palsy, and fascicle length of spastic muscle was significantly shorter than that in nonparetic muscle of healthy children.[15-17]

List of Abbreviations

ACSA	anatomical cross-sectional area
ROM	range of motion

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The purpose of the this study was to investigate, *in vivo* and noninvasively, the biomechanical changes of the medial gastrocnemius muscle at both the joint level (characterized by the ROM, stiffness, resistance torque at controlled position) and the muscle fascicle level (characterized by the muscle fascicle length, pennation angle, muscle thickness) at ankles in both stroke survivors with spasticity/contracture and healthy control subjects. We hypothesized that there are significant differences in these biomechanical properties at the fascicle and joint levels between the 2 groups, and changes at the joint level are correlated to those at the fascicle level.

METHODS

Participant Selection

A convenience sample of 10 chronic stroke survivors (at least 1 year poststroke; age, 54.7±11y; weight, 84.5±15.5kg; height, 176±5.3cm; shank length, 39.4±1.0cm) with ankle spasticity/contracture were recruited. The Modified Ashworth Score[18] was measured at the ankle (2.57±0.58). In addition, the following criteria were used: the subjects were not involved in any other studies that could potentially affect the test results, and subjects could walk independently without walking aid and sit on a chair for 2 hours. Ten age-matched and sex-matched healthy subjects (age, 56.6±20.7y; weight, 87.1±17.6kg; height, 177.3±3.7cm; shank length, 38.6±1.2cm) without any neurologic or muscular disorders served as controls. All subjects gave informed consent approved by the institutional review board.

Experimental Setup

A custom knee-ankle joint test device was used to investigate the biomechanic properties of the biarticular medial gastrocnemius muscle. The motor at the knee was fixed rigidly to a frame anchored to the ground, and a leg linkage was mounted to the knee motor through a 6-axis JR3 force sensor.[a] The ankle motor was mounted at the distal end of the leg linkage, and a footplate was mounted to the ankle motor through another 6-axis force sensor. The ankle motor and footplate could be adjusted along the leg linkage so that the ankle and knee motors were aligned with the ankle and knee flexion axes, respectively (fig 1).

Experimental Protocol

A brief medical history including the date of stroke, ambulatory status, use of ankle-foot orthosis, use of antispasticity drugs, and current therapy was documented for each stroke survivor. The leg length (from the lateral femoral epicondyle to the lateral malleolus[19]) and foot height (from the bottom of foot to the lateral malleolus) were measured to align the knee and ankle with the experimental device.

Subjects were seated upright with the thigh and trunk secured using Velcro straps. The leg and foot were attached to the leg linkage and footplate, respectively (see fig 1). Four knee positions, starting from full extension with an increment of 30° of flexion, were tested. At each knee position, the ankle flexion angle was systematically varied between 20° dorsiflexion and 45° plantar flexion, with increments of 10° in dorsiflexion and 15° in plantar flexion relative to 0° of ankle flexion. The knee and ankle motors were locked at each of the target positions. At each knee position, the subject was asked to relax with the ankle at the resting position. The corresponding ankle resting angle and torque were recorded. In addition, the resistance torque at 0° dorsiflexion was measured. At each of the knee and ankle positions, the subject was asked to relax, and the knee and ankle torques and angles were recorded for 2 seconds.

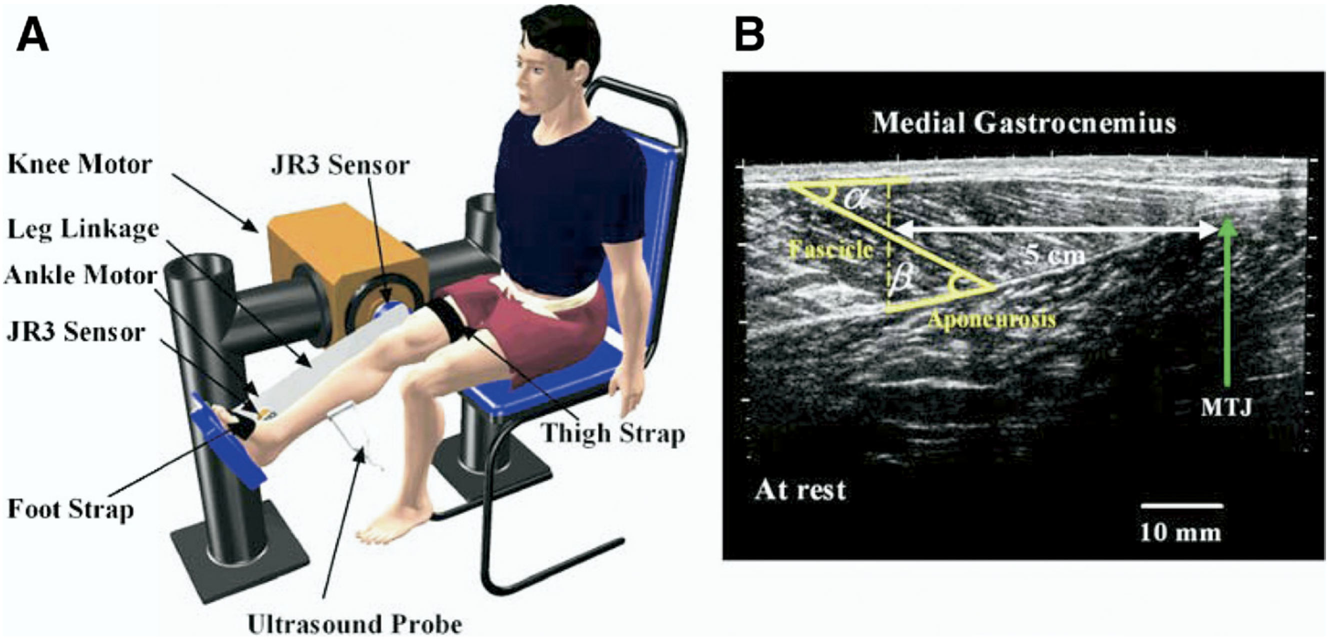

Fig 1. (A) Experimental setup. The knee-ankle evaluation device consists of 2 motors and a linkage between. The JR3 force/torque sensors were mounted on the motor shaft at both joints to measure the joint torques/forces. With the knee flexion axis aligned with the knee motor, the ankle motor can be adjusted along the leg linkage to align it with the ankle flexion axis. (B) Longitudinal ultrasonic images of the medial gastrocnemius muscle at rest. The skin is on the top of the image, and the left side corresponds to proximal. The muscle tendon junction represented the musculo-tendon (muscle aponeurosis) junction. α and β are the posterior and anterior pennation angles, respectively. The medial gastrocnemius muscle tendon junction was taken as the distal reference point.