INTRODUCTION

Stroke patients usually experience considerable spasticity and/or contracture around the ankle joint and this may be attributed to the changes in mechanical properties of muscles, especially the plantar flexor muscles. A better understanding of the changes of muscle properties in vivo may provide guidance to the rehabilitation and other treatments. Ultrasonography has been used to study muscle function as a powerful in vivo tool (Magagaris et al. 1998; Maganaris 2003; Narici 1996). However, few ultrasonic studies have been done on the hypertonic muscles in stroke survivors. Furthermore, most published studies only examined muscles as a functional group and rarely distinguished individual muscles and their specific contributions.

In the current study, electrical stimulation was used to activate the medial gastrocnemius (MG) selectively to examine the mechanical properties in vivo. To overcome the limited field of view, an extended-view-of-field technique, LOGIQview, implemented in the GE LOGIQ-9 ultrasound machine was used to register the muscle images. The purpose of this study is to quantify in vivo mechanical properties of MG in both stroke patients and normal subjects. In order to do so, muscle architectures including the pennation angle, fiber length and muscle thickness in the MG and joint torques with the changes in both ankle position and knee configurations were evaluated.

METHODS

Ten male subjects (34±6 yr) without neuromuscular injury and ten male stroke patients (55±8 yr) participated in the study, under an approved IRB protocol and with informed consent.

Subjects were seated upright on a custom chair with thigh strapped to the seat using Velcro™ straps and the knee and ankle joints were aligned to the centers of two JR3 force/torque sensors (JR3, Inc., Woodland, CA, USA), which were mounted on a customized leg-foot linkage. Four knee configurations, starting from fully extended position with increment of 30 degrees in flexion, were tested. Ankle angle was also systematically varied with an increment of 10 (dorsi-flexion) /15 (plantar flexion) degrees in the range of motion.

A Compex™ electrical stimulator was used to produce trains of biphasic pulses with pulse width of 300 µs and frequency of 40 Hz. The duration of each electrical train was 600 msec and the interval between two consecutive electrical pulse trains was 3 seconds. Each stimulation trial lasted 50 seconds and there were around 10 contractions induced in each trial.

All ultrasound images were collected by an experienced operator using a B-mode ultrasonography scanner with 12 MHz, high-
resolution linear array probe (GE LOGIQ-9 with an M12L probe, Waukesha, WI). Working in the LogiqView mode, the probe was placed perpendicular to the skin and moved smoothly along the middle line of the MG starting from proximal and moving to distal.

Data analysis was conducted by custom MATLAB programs (The MathWorks Inc., MA, USA). The data were digitally low-pass filtered with a 4th-order Butterworth filter at 5 Hz. Two-way ANOVA was performed and the significant level was set at $P<.05$.

**RESULTS**

Compared to normal subjects, stroke patients exhibited significantly shorter muscle fibers (Figure 1), smaller muscle thickness and lower posterior pennation angles under passive condition ($P<0.05$). The fiber level changes were correlated closely with joint level changes. The ankle resting angle in the stroke patients was significantly more into plantar flexion than that in normal subjects (Table 1) ($P<.05$). Similar shift of ankle resting angle into PF was observed for both stroke and normal groups as the knee was gradually extended. With hypertonia, stroke patients had much reduced range of motion, especially in dorsiflexion. When knee was fully extended the mean ankle angle is $0.6^\circ$ in stroke patients compared to $20^\circ$ in normal subjects. Stroke patients with hypertonia showed higher resistance torques ($6.2\pm5.4 \text{Nm}$) at $0^\circ$ dorsiflexion than healthy subjects ($0.7\pm0.7 \text{Nm}$) with the knee flexed at $30^\circ$ ($P<.05$).

**CONCLUSIONS**

Results on muscle architectures of normal subjects in this study agree with previously published data. One novelty of this study is that an extended-view-of-field technique, implemented in the state-of-the-art GE ultrasound device, was used to record the complete length of muscle fiber length. To the best of our knowledge, this is also the first study to examine muscle architecture changes in both passive and actively contracting muscle in stroke survivors. Further study is being carried out to analyze the relationship between the muscle architectural and biomechanical changes at the joint and fiber levels.

**REFERENCES**

Maganaris CN et al. (1998). *J Physiol* (Lond) **512**: 603-614

**Table 1:** Resting angles of ankle under different knee configurations (mean±Std)

<table>
<thead>
<tr>
<th>Knee configuration</th>
<th>Fully extended</th>
<th>Flexed 30°</th>
<th>Flexed 60°</th>
<th>Flexed 90°</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stroke patient</td>
<td>-22.0±7.1</td>
<td>-16.6±6.24</td>
<td>-17.7±3.56</td>
<td>-15±4.69</td>
</tr>
<tr>
<td>Normal subject</td>
<td>-13.4±2.68</td>
<td>-12.9±2.77</td>
<td>-12.5±2.76</td>
<td>-12.5±2.01</td>
</tr>
</tbody>
</table>