Ultrasound in Med. & Biol., Vol. ■, No. ■, pp. 1–7, 2017

0301-5629/$ - see front matter

http://dx.doi.org/10.1016/j.ultrasmedbio.2016.12.008

● *Original Contribution*

EVALUATION OF POST-STROKE SPASTIC MUSCLE STIFFNESS USING SHEAR WAVE ULTRASOUND ELASTOGRAPHY

Chueh-Hung Wu,* Yu-Chun Ho,† Ming-Yen Hsiao,* Wen-Shiang Chen,*† and Tyng-Guey Wang*

*Department of Physical Medicine and Rehabilitation, National Taiwan University Hospital, College of Medicine, National Taiwan University, Taipei, Taiwan; and †Department of Physical Medicine and Rehabilitation, National Taiwan University Hospital Hsin-Chu Branch, Hsin-Chu, Taiwan

(*Received* 29 *August* 2016; *revised* 12 *December* 2016; *in final form* 14 *December* 2016)

Abstract—Current clinical evaluations of post-stroke upper limb spasticity are subjective and qualitative. We proposed a quantitative measurement of post-stroke spastic muscle stiffness by using shear-wave ultrasound elastography and tested its reliability. Acoustic radiation force impulse with shear wave velocity (SWV) detection was used to evaluate stiffness of the biceps brachii muscles at 90° and 0° elbow flexion. In 21 control subjects, SWV did not significantly differ between dominant and non-dominant sides at either flexion angle (0°: $p = 0.311$, 90°: $p = 0.436$). In 31 patients who had recent stroke, SWV was significantly greater on the paretic side than on the non-paretic side at both 90° (2.23 ± 0.15 m/s vs. 1.88 ± 0.08 m/s, $p = 0.036$) and 0° (3.28 ± 0.11 m/s vs. 2.93 ± 0.06 m/s, $p = 0.002$). The physical appearance of arms and forearms of our patients and controls prevented blinding of the rater to paretic or non-paretic side. At 90°, SWV on the paretic side correlated positively with modified Ashworth scale and modified Tardieu scale (spasticity severity) and negatively with Stroke Rehabilitation Assessment of Movement score (motor function impairment). The intra-class correlation coefficients of intra-rater and inter-rater reliability for SWV measurements were classified as excellent. In conclusion, high SWV was associated with high spasticity and poor function of the post-stroke upper limb, suggesting possible use as a reliable quantitative measure for disease progression and treatment follow-up. (E-mail: Tgw@ntu.edu.tw) **© 2016 World Federation for Ultrasound in Medicine & Biology.**

Key Words: **Stroke, Ultrasound, Elastography, Shear wave, Spasticity, Muscle, Neurophysiologic.**

INTRODUCTION

Post-stroke spasticity can cause significant functional impairment and diminished quality of life (Zorowitz et al. 2013). As a marker of sensorimotor malfunction, post-stroke spasticity requires repeated evaluation for treatment goal setting and follow-up (Brainin 2013). In clinical practice, post-stroke spasticity severity is usually evaluated with the modified Ashworth scale (MAS) (Bohannon and Smith 1987) or modified Tardieu scale (MTS) (Ansari et al. 2008). However, these tools are subjective and do not reflect single muscle stiffness. An imaging tool providing quantitative measurement of muscle stiffness could facilitate treatment decisions and evaluation.

Post-stroke spasticity has a neurophysiologic component (velocity-dependent increase in muscle tone and hyper-reflexia) and a biomechanical component (soft-tissue stiffness) (Haugh et al. 2006). Spastic muscle cells from cerebral palsy patients had shorter resting sarcomeres and increased elastic moduli compared with healthy muscle cells (Friden and Lieber 2003), suggesting that muscle stiffness may reflect disease-related alterations in tissue properties.

Acoustic radiation force impulse combined with shear wave velocity (SWV) detection quantifies tissue stiffness because shear waves travel faster in stiffer tissues. With this technique, it was found that the trapezius muscle was stiffer in chronic neck pain (Kuo et al. 2013) and that the medial gastrocnemius muscle was stiffer in cerebral palsy (Kwon et al. 2012). In patients with

Address correspondence to: Tyng-Guey Wang, Department of Physical Medicine and Rehabilitation, National Taiwan University Hospital, College of Medicine, National Taiwan University, 7 Chung-Shan South Road, 100, Taipei, Taiwan. E-mail: Tgw@ntu.edu.tw

Conflict of interest disclosure: The Siemens Company did not support this study and had no role in the study design and results interpretation.

chronic stroke, greater SWV and echo intensity were reported in the paretic biceps brachii muscle (Lee et al. 2015). However, muscle stiffness in early and post-acute stages of stroke has not been investigated using SWV detection.

In the study described here, we proposed a quantitative measurement of post-stroke spastic muscle stiffness using shear-wave ultrasound elastography and tested its reliability. We hypothesized that SWV is greater in paretic biceps brachii muscle during early and post-acute stages of stroke, varies with duration from stroke onset and correlates with clinical evaluations of upper limb function.

METHODS

Study groups

The study protocol was approved by the Research Ethics Committee of our university hospital. Both a control group and a stroke group were recruited, and all patients provided written informed consent. The study was conducted between April 24, 2013 and April 7, 2014. All study protocols conformed to national and international guidelines on the treatment of human patients in experiments.

Inclusion criteria for the control group were (i) age >20 y, (ii) absence of cervical radiculopathy symptoms or other central or peripheral neurologic deficits in the upper limbs, (iii) a normal bilateral elbow range of motion (ROM, flexion 0°–145°) and (iv) ability to cooperate and relax during the examination. Exclusion criteria were (i) history of diabetes mellitus, hyperthyroidism or hypothyroidism; and (ii) history of upper limb trauma or surgery.

Inclusion criteria for the stroke group were (i) age >20 y; (ii) diagnosis of stroke by board-certified neurologists and evidence of ischemic stroke or hemorrhagic stroke on brain computed tomography or magnetic resonance imaging, which was interpreted by board-certified diagnostic radiologists; (iii) first onset of stroke with unilateral involvement; (iv) duration from stroke onset <6 mo; and (v) normal bilateral elbow ROM. Exclusion criteria were (i) a history of or scheduled upper limb surgery, (ii) significant upper limb trauma within the previous 2 y, (iii) presence of cervical radiculopathy or other peripheral neurologic deficits of the upper limb according to the past history in the patient record, (iv) history of diabetes mellitus, hyperthyroidism, or hypothyroidism, (v) significantly greater echo intensity of the paretic biceps brachii muscle (fibrotic changes) compared with the non-paretic side on ultrasound visualization (Lee et al. 2015) and (vi) use anti-spastic medication, including nerve blockers or botulinum toxin injection within 3 mo.

Before SWV measurements, all patients underwent routine conventional B-mode ultrasound examination to confirm there was no muscle tear, no hematoma and no fibrotic changes in the biceps brachii muscle.

Shear wave velocity of biceps brachii muscles

All ultrasound examinations were performed by a physiatrist with 2 y of experience in musculoskeletal ultrasound examination on more than 1000 cases. The examiner was familiarized with the study protocol for optimization of SWV measurements by examining 15 non-stroke subjects not included in the study (preliminary test group), who were recruited by convenience sampling.

An Acuson S2000 ultrasound system (Siemens, Munich, Germany) equipped with a 7- to 9-MHz linear transducer (9 L4, Siemens) was used to obtain B-mode scanning images and SWV values from both upper limbs. Each participant was instructed to lie supine on the examination bed with bilateral shoulders and elbows in a relaxed neutral position. The SWV was obtained with the elbow at 0° flexion (complete extension) and then at 90° flexion. In the stroke group, the elbow was extended slowly and gently to 0° flexion to avoid pain and unwanted muscle contraction. To avoid motion artifacts in both groups, a self-made elbow stabilizer was used to maintain the elbow at 90° flexion.

Surface electromyography (Automove AM80, Danmeter A/S, Odense, Denmark) was used to detect muscle contraction. Three surface electrodes were applied, one above the area of the biceps brachii motor point, one at the musculotendinous junction and one ground electrode above the area of the triceps muscle. The same electrodes were used to monitor electromyographic activity and to deliver electrical stimulation. Each participant was instructed to relax his or her elbow during ultrasound examination. When the level of biceps brachii activity reached a threshold of 20 μV, a low-amplitude electric stimulation of the biceps brachii was automatically triggered to remind the participant to relax. Thus, we could ensure there were no bursts of activity while acquiring ultrasound images (Fig. 1).

To standardize the location of measurements, the transducer was placed over the lower one-third of the line connecting the coracoid process to a point equidistant between the medial and lateral epicondyles. The region of interest (ROI, 0.5 × 0.5 cm) was the middle of the muscle belly (Fig. 2). The probe was oriented parallel to the muscle fibers to obtain SWV measurements in the longitudinal axis and rotated 90° for SWV measurements in the transverse axis. Transducer pressure would affect measurements of muscle stiffness (Syversveen et al. 2012), so a thin layer of acoustic gel was kept on the skin and the transducer was held stationary during SWV acquisition. Acoustic radiation force impulse was applied to