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● *Technical Note*

ULTRASOUND STRAIN IMAGING IN ASSESSMENT OF BICEPS MUSCLE STIFFNESS AND DYNAMIC MOTION IN HEALTHY ADULTS

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Abstract—We prospectively evaluated the feasibility of using ultrasound strain imaging (USI) to assess biceps brachii muscle (BBM) stiffness and dynamic motion in 10 healthy adults. The BBM axial deformation was produced by external compression with a sandbag (1.0 kg) tied onto the transducer. The BBM lateral movement was produced by manual passive elbow flexion and extension. By use of 2-D speckle tracking, captured 5-s real-time ultrasound data of BBM were processed to estimate axial strain, representing muscle stiffness, and lateral strain and tissue velocity, representing muscle dynamic motion. Axial (lateral) strain ratio was defined as BBM strain divided by subcutaneous soft tissue strain. There was no significant difference in lateral strain or tissue velocity between the left and right BBM (lateral strain ratio: 4.69 ± 0.07 vs. 4.51 ± 0.08 for extension, 4.82 ± 0.09 vs. 4.69 ± 0.11 for flexion; tissue velocity: 1.58 ± 0.32 cm/s vs. 1.78 ± 0.85 cm/s for extension, −2.03 ± 0.63 vs. −2.03 ± 0.59 for flexion; all p values $>$ 0.05) or between men and women (lateral strain ratio: 4.52 ± 0.06 vs. 4.67 ± 0.1 for extension, 4.71 ± 0.11 vs. 4.83 ± 0.09 for flexion; tissue velocity, cm/s: 1.76 ± 0.76 vs. 1.66 ± 0.65 for extension, −2.21 ± 0.65 vs. −1.88 ± 0.52 for flexion, all p values $>$ 0.05). The difference in axial stain between men and women was significant (axial strain ratio: 3.09 ± 0.43 vs. 3.52 ± 0.26, p = 0.02). Inter- and intra-observer reliability in performing USI of the BBM was good (all intra-class correlation coefficients [ICCs] >0.75). Our results suggest that USI seems to be feasible for and reproducible in estimating BBM mechanical properties and motion dynamics in healthy adults. (E-mail: jig2001@med.cornell.edu) **© 2017 World Federation for Ultrasound in Medicine & Biology.**

Key Words: **Biceps brachii muscle, Lateral strain, Muscle mechanical property, Muscle movement, Ultrasound strain imaging.**

INTRODUCTION

The mechanical properties (stiffness) and motion dynamics of skeletal muscle directly affect daily activities of human beings. It would be ideal to have a noninvasive imaging technique to quantify the stiffness and motion function of skeletal muscle to gain a better understanding of its complex physiologic and pathophysiologic behavior in clinical settings (Bilston and Tan 2015) and to assist clinicians in the characterization of musculoskeletal activities, diagnosis of muscle disorders, monitoring of disease progression and evaluation of treatment response in rehabilitation and sports medicine.

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In general, assessment of muscle stiffness and dynamic motion is considered challenging because of the complexities of its architecture and dynamic behavior in active and passive movement (Ettema and Huijing 1994; Van Loocke et al. 2008). Conventional ultrasonography and magnetic resonance imaging (MRI) have been used to image the anatomic morphology of skeletal muscle (Segal 2007); however, these imaging modalities are not able to quantify the mechanical properties or function of the muscle. Newly developed magnetic resonance elastography (MRE) and functional MRI (fMRI) can provide information on muscle elastic parameters and changes in muscle tissue properties before and after exercise, but are expensive and time consuming (Bilston and Tan 2015; Jenkyn et al. 2003). Ultrasound shear wave elastography has been used to assess muscle stiffness in healthy individuals over a wide age range, after physical activity (Brandenburg et al. 2014; Eby et al. 2015) and in patients with Parkinson's disease (Du et al. 2016) and Duchenne muscular dystrophy (Lacourpaille et al. 2015). Recently, the use of 2-D speckle tracking ultrasound strain imaging (USI) to examine soft tissue has been expanded from assessment of myocardial deformation and function (Dandel et al. 2009) to estimation of the change in skeletal muscle stiffness in physiologic (*e.g.,* exercise [Chino et al. 2012, 2014]) and pathologic (*e.g.,* Parkinson's disease [Gao et al. 2016]) conditions.

Speckle tracking is a motion tracking method implemented by tracking the position of ultrasound speckle, which is caused by ultrasound interference and reflections from scanned objects. The ultrasound speckle pattern is fairly similar over small motions, which allows for speckle motion tracking within a search region over time (Lubinski et al. 1999; Varghese 2009). With the correlation coefficient method for 2-D speckle tracking, strain is a measure of tissue deformation, the change in tissue length at the compression from its original length. In our study, we measured strain in the region of interest (ROI) over time (Lubinski et al. 1999). Thus, the value of the strain is associated with tissue mechanical properties (stiffness). Strain is high in softer or more elastic tissue, whereas it is low in stiffer or less elastic tissue. We also reported that the change in biceps brachii muscle (BBM) stiffness is correlated with the severity of the rigidity and changes in response to treatment in Parkinson's disease (Gao et al. 2016).

In addition to muscle stiffness, the muscle motion function (*e.g.,* contraction) is also important in skeletal muscle activities (*e.g.,* stretching during an active elbow extension). However, little is known about use of the USI technique in assessment of skeletal muscle dynamics (Segal 2007; Sikder et al. 2014).

The aims of this study were to investigate the feasibility of using USI to assess elbow flexor muscle (BBM) stiffness and motion characteristics and to determine intra-observer and inter-observer variability in performing skeletal muscle USI in healthy adults.

METHODS

The institutional review board at Weill Cornell Medicine of Cornell University approved the study (IRB No. 1601016917), and written informed consent was obtained from all subjects. From August to September 2016, we prospectively performed USI of the BBM in 10 healthy volunteers who had no history of neuromuscular disorders, trauma, orthopedic surgery of the arm or use of medications that may affect muscle tone (contraction or relaxation).

Real-time ultrasound data acquisition

The Acouson S3000 HELX equipped with 9L4 linear array transducer (Siemens Medical Solutions, Mountain View, CA, USA) was used to acquire real-time ultrasound data on BBM deformation and movements.

The subject was placed in the supine position. The arm was relaxed with the forearm supinated. To capture

Fig. 1. Ultrasound strain imaging is performed with the patient comfortable in the supine position and the arm in supinated natural position (180° elbow flexion angle). This graph indicates that a 1.0-kg sandbag (*red arrow*) is tied onto the transducer (9L4 linear array, Siemens Medical Solutions) as the external compression force to produce axial deformation in the biceps brachii muscle (BBM). The transducer is placed on the mid- to lower aspect of the upper arm, where the BBM belly is located. The scanning is along a longitudinal section of the BBM.

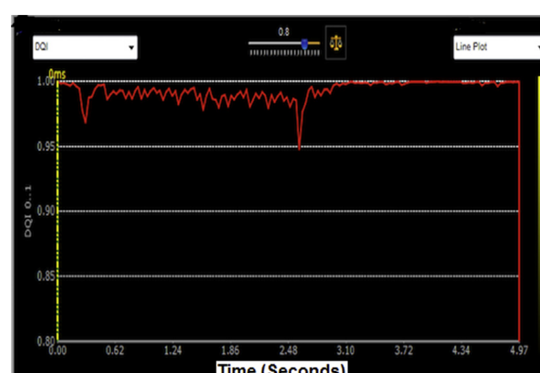

Fig. 2. By use of 2-D speckle tracking, a quality index (DQI) of 0.95 is measured in 5-s real-time axial biceps brachii muscle (BBM) compression. DQI is the measure of the quality of real-time ultrasound data used for tissue strain estimation with the correlation coefficient method. The highest possible value of DQI is 1; however, a DQI >0.90 is considered valid data that speckle kernels correlate well frame by frame in real time-tissue deformation and movement sequences. In the graph, the x-axis is the time in seconds, and the y-axis is the DQI value (0 … 1).