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Original Article

Ultrasound strain elastography in assessment of resting biceps brachii muscle stiffness in patients with Parkinson's disease: a primary observation

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ABSTRACT

The aim of this study was to evaluate the feasibility of ultrasound strain elastography (SE) for the assessment of resting biceps brachii muscle (BBM) stiffness in patients with Parkinson's diseases (PD). From May 2014 to December 2014, we prospectively performed SE of BBM in 14 patients with PD and 10 healthy controls. Based on the Unified Parkinson's Disease Rating Scale for scoring muscle rigidity (UPDRS, part III), muscle rigidity scores in 14 patients with PD included 3 patients with high rigidity (UPDRS III–IV) and 11 patients with low rigidity (UPDRS I–II). Ultrasound strain was represented by the deformation of the BBM and subcutaneous soft tissues that was produced by external compression with a sand bag (1.5 kg) tied onto an ultrasound transducer. Deformation was estimated with two-dimensional speckle tracking. The difference in strain ratio (SR, defined as mean BBM strain divided by mean subcutaneous soft tissue strain) between PD and healthy controls was tested by unpaired *t* test. The correlation between SR and muscle rigidity score was analyzed by Pearson correlation coefficient. The reliability of SR in assessment of BBM stiffness was tested using intraclass correlation coefficient. In our result, the SR in PD and healthy controls measured 2.65 ± 0.36 and 3.30 ± 0.27, respectively. A significant difference in SR was noted between the healthy controls and PD ($P = .00011$). A negative correlation was found between SR and UPDRS rigidity score ($r = -0.78$). Our study suggests that the SR of BBM to reference tissue can be used as a quantitative biomarker in assessing resting muscle stiffness associated with muscle rigidity in PD.

1. Introduction

Parkinson's disease (PD) is a chronic neurological disorder. About 60,000 Americans are diagnosed with PD each year, and an estimated 7–10 million people are living with PD worldwide. For the diagnosis of PD, the primary symptoms in PD include rest tremor, bradykinesia, postural instability, and passive rigidity. Passive rigidity is a function of the abnormal muscle and occurs at rest resulting from an alteration of mechanical properties in muscle tissue [1]. Currently used clinical examination methods for the assessment of the severity of muscle rigidity include the Unified Parkinson's Disease Rating Scale (UPDRS, part III) [2] and the Hoehn and Yahr Scale [3]. These methods are subjective because the assessments are based on physical examination by the observer [2] and are nonquantitative. Myotonometry, an electronic tissue compliance meter, has been used to assess compliance and resistance of muscles in PD [1,4]. However, this technique is not capable of real-time observations of the muscle anatomy and morphology (e.g., muscle fiber orientation) that strongly affect the accuracy of assessing muscle mechanical properties. Scanning along the long axis of muscle fibers tends to be anisotropic, whereas scanning transverse to muscle fibers appears to be isotropic [5,6].

Magnetic resonance elastography, a noninvasive imaging technique, has been used for the assessment of neuromotor muscular abnormalities [7–9]. However, the high cost and the requirement for patients to remain still during the procedure limit its use as an imaging technique for examining muscle rigidity in the patient with PD.

Ultrasound elasticity imaging (UEI) has been developed for quantitatively estimating tissue mechanical property (stiffness) changes associated with tissue pathological conditions (e.g., muscle rigidity in PD). Most commonly used UEI techniques in assessment of muscle stiffness are shear wave elastography (SWE) [6,10,11] and ultrasound strain elastography (SE) [5,12]. SWE directly measures tissue Young's modulus of the tissue to quantify tissue stiffness based on the speed of shear wave propagation in the tissue [5]. In muscle biomechanics applications, SWE has been used to quantify stiffness in passive muscles [11,13].

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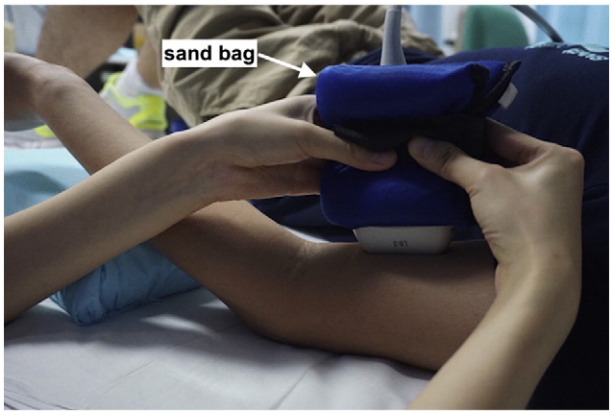

Fig. 1. A 1.5-kg sandbag (white arrow) was tied onto a linear array transducer used as the force for external compression. The transducer was placed on mid to lower arm where biceps brachii belly is located. The observer used both hands to hold transducer to maintain transducer surface normal to the skin. Scanning was along longitudinal section of BBM fiber. The patient was placed in the supine position and the arm muscle was relaxed (forearm is elevated 15°).

However, the reliability of SWE in assessing muscle stiffness is affected by the anisotropic nature of the skeletal muscles [5,6]. SE is an emerging imaging technique for assessing tissue mechanical property (stiffness) based on the fraction of tissue deformation under an external compression (e.g., a compression using the ultrasound transducer). Tissue strain is a surrogate for tissue stiffness. Low strain corresponds to high tissue stiffness, whereas high strain corresponds to low tissue stiffness [12,14,15]. A quantitative parameter in SE is strain ratio that is calculated by dividing the average strain in the region of interest such as diseased tissue by the average strain in the reference represented by normal tissue when the force used in SE is not known. SE has been used in distinguishing malignant from benign thyroid nodules [16] and determining high-grade tissue fibrosis in the renal cortex [17].

Given that PD alters the muscle stiffness and the SE is able to quantitatively assess the tissue stiffness, we hypothesized that the amplitude of muscle strain representing the muscle stiffness in patients with PD would be different from that in healthy controls. Ultimately, SE can be used as a quantitative biomarker in assessing resting muscle stiffness associated with the severity of muscle rigidity in PD.

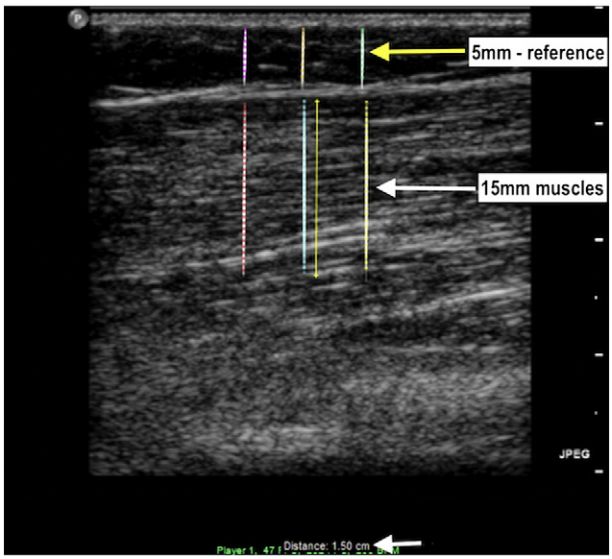

Fig. 2. Real-time ultrasound data of compression/release force sequence on longitudinal section of the BBM and reference tissue are processed with 2-D speckle tracking. The ROI for estimating the BBM strain is 15-mm axial region in the BBM (blue, red, and yellow dotted lines). The reference strain is the deformation in 5-mm axial region in the subcutaneous soft tissue that is the distance from the skin to the BBM (cyan, green, and orange dotted lines).

2. Material and methods

2.1. Subjects

The Institutional Ethics Committee approved the study, and written informed consent was obtained from all subjects.

This study included 14 patients (8 men and 6 women, age range 41–78 years, mean age 61 ± 10 years) diagnosed as having PD according to British Brain Bank clinical criteria [18]. The muscle rigidity in 14 patients with PD was classified using a five-point UPDRS (UPDRS, part III) motor score (0 = no rigidity, I = slight or detectable rigidity only when activated, II = mild to moderate rigidity, III = marked rigidity, and IV = severe rigidity) [2]. The rigidity assessment was performed when the patient was off medication (no antiparkinsonian medication for 12 h). Based on UPDRS criteria, muscle rigidity scores in 14 subjects with PD were 3 patients with high rigidity (UPDRS III–IV) and 11 patients with low rigidity (UPDRS I–II).

In addition, 10 healthy volunteers (5 men and 5 women, age range 54–82 years, mean age 60 ± 11 years) were enrolled as the controls. All 10 healthy controls had no history of neuromuscular disorders of any kind (e.g., stroke) and were not taking any medication. All healthy controls underwent neurological examination before their SE tests.

Two experienced neurologists performed rater-blinded UPDRS assessments of muscle rigidity in all patients with PD and healthy controls by using the UPDRS motor score (part III).

2.2. Real-time ultrasound data acquisition

All subjects were imaged in the supine position with the arm relaxed while the elbow is extended with the forearm supinated (Fig. 1). SE was performed using Logic E9 ultrasound scanner (General Electric, USA) equipped with L9-3 linear array transducer. Grayscale imaging settings for SE were optimized for speckle tracking. High frame rate (>40 frames per second), single focus, turn off speckle reduction, and low scanning frequency (6 MHz) are preferred [17]. We tied a sand bag (1.5 kg) onto the scanning transducer (Fig. 1) to create a constant compression force for performing SE in all subjects. Transmission gel as standard acoustic couplant for the ultrasound examination is placed on the anterior mid/lower arm where the biceps brachii muscle (BBM) belly is located. We used the longitudinal muscle echogenic line in the B-mode image corresponding to the best alignment of fibers [6]. The direction of compression with the transducer of the BBM and reference subcutaneous soft tissues was the same direction as the ultrasound beam, which was perpendicular to the skin and longitudinal section of the muscle fibers (Fig. 2). In addition, we held both the transducer and subject's arm steady to minimize out-of-plan motion while capturing real-time ultrasound data of the compression sequence [19]. These processes served to maximize the strain signal by measuring in the direction of maximum deformation and suppressing speckle decorrelation in ultrasound strain estimation [17].

A 5-s cycle was used to capture a full compression/release force sequence of tissue deformation and relaxation of the BBM and reference. We captured three deformations/relaxations in each subject (the time interval between compressions was 2 min).

Real-time ultrasound imaging data of BBM and reference were acquired in Digital Imaging and Communications in Medicine format and were stored in a backup plus portable drive (Seagate, Model SRD00F1-2 TB, Seagate Technology PLC, Cupertino, CA, USA). These data were copied to a PC for strain estimation.

A single observer, an ultrasound physician with experience in performing muscular ultrasound examination, scanned all subjects with PD. The observer performed three compressions in all subjects for examining the repeatability of this technique in assessment of