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Ultrasound elastography–based assessment of the elasticity of the supraspinatus muscle and tendon during muscle contraction

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Background: Although elasticity of the supraspinatus muscle and tendon is a useful parameter to represent the conditions of the supraspinatus muscle and tendon, assessment of the elasticity in clinical settings has not been established. The purpose of this study was to determine the elasticity of the supraspinatus muscle belly and tendon under different muscle contraction conditions using ultrasound real-time tissue elastography (RTE).
Methods: Twenty-three healthy individuals participated in this study. Ultrasound RTE was used for elasticity measurements of the muscle belly and tendon of the supraspinatus muscle. The elasticity was defined as the ratio of strain in the tissues to that in an acoustic coupler (reference). A greater ratio indicated that the tissue was softer. Measurements were performed with study subjects in the lateral decubitus position at 10° of shoulder abduction under conditions of (1) no contraction, (2) isometric contraction without a weight, and (3) isometric contraction with a 1-kg weight.
Results: The intraclass correlation coefficient ($ICC_{1,3}$) of 3 measurements under each condition ranged from 0.931 to 0.998, showing high intraobserver reliability. Strain ratios for both the supraspinatus muscle belly and tendon significantly decreased with increases in muscle contraction ($P < .001$).
Conclusions: Ultrasound RTE with the acoustic coupler has the potential to noninvasively detect changes in the elasticity of the supraspinatus muscle belly and tendon that accompany varying levels of muscle contraction in clinical practice.
Level of evidence: Basic Science Study, Biomechanics, Imaging.

Keywords: Rotator cuff; ultrasound elastography; supraspinatus muscle; elasticity; shoulder; muscle contraction; strain

The elasticity of human tissue is a parameter that indicates tissue quality or condition. In cadaveric shoulders or animal models, the elasticity of the supraspinatus tendon has been investigated under normal[8,14] and pathologic[6,16] conditions. Although elasticity could be an important parameter in assessing the condition of the tendon and determining the

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healing process after injury and repair, real-time in vivo measurement of tissue elasticity has not been reported yet.

Measurement of elasticity could also be useful in assessing the activity of skeletal muscle. Although electromyography remains the gold standard for the assessment of muscle activation, fine-needle electromyography to measure the activation of deep muscle layers has a disadvantage of being invasive. Instead, noninvasive measurements of elasticity using magnetic resonance imaging and ultrasound have the potential to detect muscle activity. A previous study showed that elasticity of muscle obtained from magnetic resonance elastography (MRE) linearly correlated with the activity of the muscle.[7] Theoretically, MRE is capable of measuring elasticity of various tissues that conventional magnetic resonance imaging can depict. However, MRE is affected by the measurement environment, such as place, space, and subject positioning.

Ultrasound elastography appears to be more suitable for measuring muscle activity than MRE in clinical settings because it offers real-time measurement with patients in less restricted postures and joint positions. Ultrasound real-time tissue elastography (RTE) is one of the elastography techniques and uses light tissue compression with an ultrasound transducer. The compression is applied to generate strain in living tissues, and then, RTE shows mapping of strain distribution within the tissues in real time. Elasticity in a target tissue can be calculated by comparing the strain in the tissue with that in another tissue. Previous studies reported using RTE to measure the elasticity of the Achilles tendon[2,3] and the biceps brachii muscle.[12,17] However, similar measurements of elasticity for the supraspinatus muscle and tendon have not been established.

The purpose of this study was to measure the elasticity of the supraspinatus muscle belly and tendon using ultrasound real-time elastography and determine the changes in elasticity that occur with muscle contraction.

Methods

Subjects

Twenty-three healthy individuals (13 male and 10 female subjects) participated in this study. The mean age, height, and weight were 26 years (SD, 3 years), 168.1 cm (SD, 7.9 cm), and 61.5 kg (SD, 9.6 kg), respectively. The right arm was the dominant arm in all participants. The subjects had no history of orthopaedic disease or trauma around the shoulder joint, including rotator cuff tear, and no participant was involved in any physical training programs during the study. All participants provided written informed consent before RTE measurement.

Measurement of elasticity

To measure elasticity, all participants were kept in the left lateral decubitus position. The knee and hip on both sides were flexed so that participants felt comfortable in maintaining the required body position. The right shoulder was abducted 10° by placing a rolled towel under the forearm.

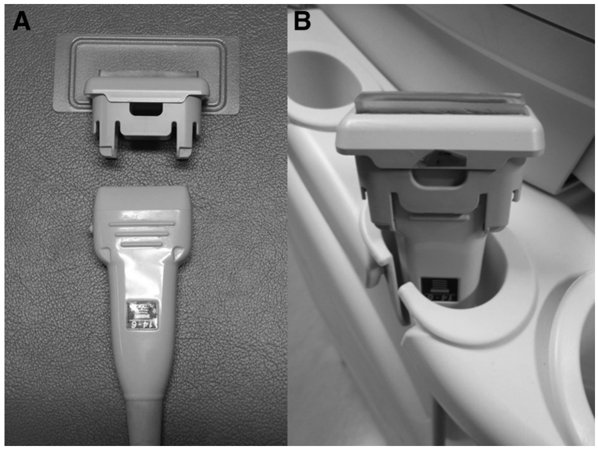

Figure 1 Transducer and acoustic coupler with custom attachment. (**A**) The head of the transducer was inserted into the attachment. (**B**) The transducer was attached to the coupler.

A diagnostic ultrasound system (HI VISION Avius; Hitachi Aloka Medical Japan, Tokyo, Japan) with a linear array transducer (14-/6-MHz EUP-L65; Hitachi Aloka Medical Japan) was used in this study. As reference material, an acoustic coupler (EZU-TECPL1; Hitachi Aloka Medical Japan) was placed onto the transducer with a plastic attachment (EZU-TEATC1; Hitachi Aloka Medical Japan) (Fig. 1). The elasticity of the acoustic coupler was 22.6 ± 2.2 kPa according to material testing performed by the manufacturer.

First, the shoulder was scanned to display longitudinal images of the supraspinatus muscle belly and tendon in B-mode imaging. The transducer was placed on the center of the supraspinous fossa for imaging of the supraspinatus muscle belly. For imaging of the supraspinatus tendon, the transducer was placed so that the anterior edge of the superior facet of the greater tuberosity appeared. To realize constant measurement, the locations of the transducer were marked with oil-based ink on the skin (Fig. 2). While keeping images of the supraspinatus muscle tissue, we turned on the RTE mode, and another B-mode image appeared next to the original B-mode image. After selection of the rectangular region of interest (ROI), an elastogram was superimposed on the second B-mode image by repeating manual compression with the transducer. With each compression, an elastogram appeared and was recorded. The mean strain in the ROI was monitored in a strain graph to adjust and maintain the force and frequency of the compression. The frequency was adjusted from 2 Hz to 4 Hz depending on each individual and condition so that the elastogram was sufficiently superimposed on the ROI. On the elastogram, areas of low and high strain were displayed in blue and red, respectively. Repetitive compression continued until more than 3 RTE images were obtained. The ultrasound system is capable of saving the RTE images automatically with a frame rate of 15 frames per second during measurement. Thus, we could review the images after the measurement and could choose the last 3 images in which the elastogram was completely superimposed.

After the RTE image was obtained, the elasticity was calculated using the ratio of the strain in the supraspinatus muscle tissue to that in the acoustic coupler, which was used as the reference. On the basis of the principle that tissues with low elasticity deform more than those with high elasticity,[13] a higher strain ratio indicates lower elasticity. By using the acoustic coupler, the supraspinatus tendon and muscle tissues could be compared with the material in which a constant elasticity was obtained. This method allowed a more