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Original Paper

Influence of a Specified Probe Axial Preload on Strain Ultrasound Elastography for the Quantification of Rectus Femoris Muscle Elasticity

Hiroshi ISHIDA[*1] **and Tadanobu SUEHIRO**[*2]

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Abstract

A good understanding of the abnormal mechanical properties of skeletal muscles has important applications for clinicians in the sports medicine and rehabilitation fields. Ultrasound elastography can assess elasticity of the skeletal muscle. However, little is known about muscle elasticity changes induced by probe axial preload during strain elastography. This study aimed to quantify the influence of a specified probe axial preload on strain elastography for the quantification of muscle elasticity. Eleven healthy males (mean ± standard deviation, 20.5 ± 0.5 years) were recruited for this study. The thickness (mm) and strain (%) of the acoustic coupler, subcutaneous tissue, and rectus femoris muscle were measured in the following three conditions: with the probe in contact and with 0.5 and 1.0 N of probe axial preload. The relative elasticity of the right rectus femoris muscle compared with that of the acoustic coupler was denoted by Young's modulus using the strain ratio of elastography. The differences between the conditions of the normal and non-normal distribution measurements were determined using one-way repeated measures analysis of variance and the Friedman test, respectively. Significant effects were observed in the results of one-way repeated measures of variance and the Friedman test for all measurements, except the strain of the acoustic coupler. A slight increase or decrease of probe axial preload influenced the strain of the subcutaneous tissue and muscle during elastography, leading to an error in the measurement for the quantification of relative muscle elasticity using the strain ratio.

1. Introduction

A good understanding of the abnormal mechanical properties of injured or dysfunctional skeletal muscles has important applications for clinicians in the sports medicine and rehabilitation fields[1]. Ultrasound elastography can assess the elasticity of the skeletal muscle and help evaluate the condition of the skeletal muscle[1]. Some techniques, including strain elastography, shear wave elastography, transient elastography, and acoustic radiation force impulse imaging, were used to detect tissue displacement and construct the distribution of the tissue strain[2]. Manual compression-relaxation, used during strain elastography,

[*1] Department of Physical Therapist, Faculty of Rehabilitation
Kawasaki University of Medical Welfare, 288 Matsushima, Kurashiki, 701-0193, Japan
E-Mail: ishida@mw.kawasaki-m.ac.jp
[*2] Department of Rehabilitation, Faculty of Health Science and Technology
Kawasaki University of Medical Welfare

differs from the other techniques, because it requires considerable operator dependence[2]. Both manual compression-relaxation and axial preload of the probe can be related to measurement error. Previous research using shear wave elastography demonstrated the effect of the probe axial preload on skeletal muscle elasticity (shear wave velocity and Young's modulus)[3-5]. However, it is not clear how much probe axial preload was performed during the studies[3-5]. Accordingly, research that evaluated the reliability of strain elastography[6,7] and shear wave elastography[8,9] did not mention details of the probe axial preload used during the assessment of skeletal muscle elasticity. Therefore, little is known about muscle elasticity changes induced by probe axial preload during strain elastography. The aim of this study was to quantify the influence of a specified probe axial preload on strain elastography for the quantification of muscle elasticity.

2. Methods

2.1 Participants

Eleven healthy male volunteers were recruited for this study. The participants' age, height, weight, and body mass index (mean ± standard deviation) were 20.5 ± 0.5 years, 169.4 ± 6.9 cm, 61.6 ± 7.1 kg, and 21.5 ± 2.6 kg/m^2, respectively. Exclusion criteria were a history of limb surgery or neuromuscular diseases. The Ethics Committee of the Kawasaki University of Medical Welfare approved this study (18-103). Written informed consent was obtained from all participants.

2.2 Procedures

While in a left side-lying posture, the participants had both hips and both knees positioned at 90° flexion and towels placed between the knees that were adjusted to maintain the position of both hips at 0° of abduction. An ultrasound unit (Noblus, Hitachi Ltd., Tokyo, Japan) including an 18-5 MHz linear probe (L64) connected to an acoustic coupler (EZU-TECPL1) was used to measure muscle elasticity. Young's modulus of 22.6 kPa served as a reference material to perform ultrasound elastography. The depth setting of the image was set to include the anterior of the femur. To image the maximum anterior-posterior diameter of the right rectus femoris muscle, the probe was first oriented in the transverse plane at 60% of the distance from the greater trochanter to the lateral epicondyle of the femur (Figure 1)[10]. Then, the probe was rotated to be parallel to the muscle fascicle direction. A custom-made holder was used, which could maintain a probe axial preload of approximately 0.5 and 1.0 N[11]. Without the constant force spring, the axial preload of the probe depends on the inclination of the linear motion guide. The probe was positioned to clearly image the rectus femoris muscle epimysium. The linear motion guide was fixed to an approximately horizontal level. One set of measurements was performed with the following three conditions in a random order: with

Figure 1　Position of probe

a: Probe; b: Acoustic coupler; c: Constant force spring the probe in contact without the constant force spring, and with 0.5 and 1.0 N of probe axial preload. The region of interest (ROI) was extended to include the acoustic coupler, rectus femoris, and vastus intermedius muscles without including the femur. An experimenter manually applied slight rhythmical compression-relaxation cycles to the ROI. The strain feedback was monitored to be within ± 0.4% for conducting consistent experiments. Two sets of elastographic images were recorded in the 3 aforementioned conditions during a relaxed state. The thickness (mm) and strain (%) of the acoustic coupler, subcutaneous tissue, and rectus femoris muscle were measured. Strain had a low value if the measured tissue was hard. Square of the ROIs were placed in the rectus femoris muscle and acoustic coupler (Figure 2), and the relative elasticity of the muscle compared with that of the acoustic coupler was denoted by Young's modulus using the strain ratio (Young's modulus of rectus femoris muscle (kPa) = Young's modulus of acoustic coupler (22.6 kPa) $\times \frac{\text{strain of acoustic coupler (\%)}}{\text{strain of rectus femoris muscle (\%)}}$). Young's modulus had a high value if the measured tissue was hard. The average of two measurements for each condition was used for analysis.

2.3 Data Analysis

Statistical analyses were performed using SPSS software, version 23.0 (IBM Japan Inc., Tokyo, Japan). The Shapiro-Wilk test was used to detect data normality. The differences among the conditions of the normal and non-normal distribution measurements were determined using one-way repeated measures analysis of variance and the Friedman test, respectively. The level of statistical significance was set at $p < 0.05$.

3. Results

Typical elastographic images are shown in Figure 2. The measurement values are shown in Table 1. Significant effects were observed in the all results of one-way repeated measures of variance and the Friedman test except strain of the acoustic coupler.

4. Discussion

To the best of our knowledge, this study is the first to demonstrate the influence of a specified probe axial preload on strain elastography for quantification of the rectus femoris muscle elasticity. A previous study showed that the shear wave velocity and Young's modulus were significantly higher depending on the degree of probe axial preload[5]. With greater pressure applied on the skin, elasticity of the rectus

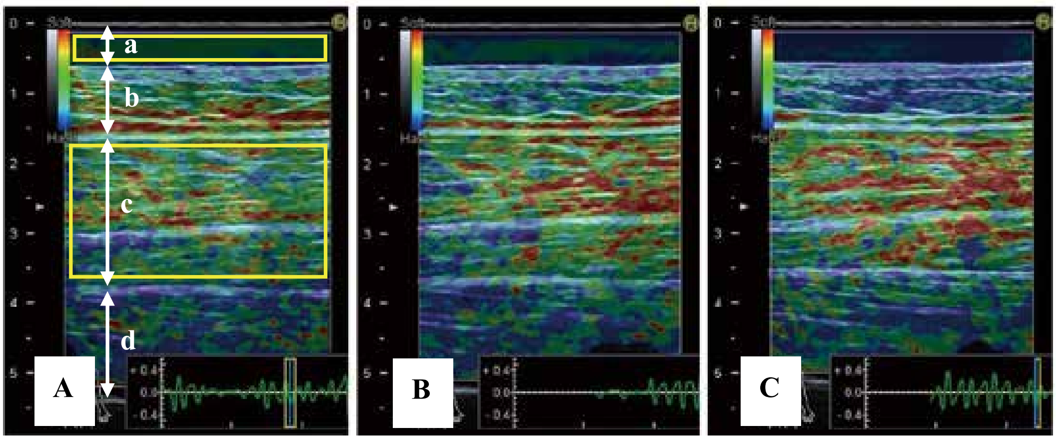

Figure 2 Typical elastographic images in the (A) contact, (B) 0.5 N, and (C) 1.0 N conditions

a: Acoustic coupler; b: Subcutaneous tissue; c: Rectus femoris muscle; d: Vastus intermedius muscle
Yellow squares show the regions of interest of the rectus femoris muscle and acoustic coupler for calculating the relative elasticity of the muscle compared with that of the acoustic coupler. According to the increase of the probe axial preload, the blue area increased in the subcutaneous tissue, and the red area increased in the rectus femoris muscle.

Table 1 Measurement values

		Contact	0.5 N	1.0 N	Main effect
Thickness (mm)	Acoustic coupler[†]	5.6 (5.5-5.6)	5.3 (5.2-5.4)	5.2 (5.0-5.2)	$p < 0.001^{b}$
	Subcutaneous tissue[§]	6.9 ± 2.2	6.5 ± 2.1	6.2 ± 2.0	$p < 0.001^{a}$
	Rectus femoris muscle[§]	18.8 ± 3.9	18.1 ± 3.9	17.0 ± 3.8	$p < 0.001^{a}$
Strain (%)	Acoustic coupler[†]	0.11 (0.11-0.16)	0.11 (0.08-0.15)	0.10 (0.08-0.14)	$p = 0.290^{b}$
	Subcutaneous tissue[§]	0.21 ± 0.07	0.15 ± 0.07	0.12 ± 0.03	$p = 0.016^{a}$
	Rectus femoris muscle[§]	0.16 ± 0.06	0.28 ± 0.12	0.48 ± 0.15	$p < 0.001^{a}$
Strain ratio	$\frac{\text{strain of acoustic coupler}}{\text{strain of rectus femoris muscle}}$ [†]	0.76 (0.71-0.87)	0.41 (0.37-0.46)	0.21 (0.17-0.30)	$p < 0.001^{b}$
Young's modulus (kPa)	Rectus femoris muscle[†]	17.2 (15.9-19.6)	9.3 (8.4-10.3)	4.7 (3.8-6.8)	$p < 0.001^{b}$

[§]: Data presented in mean ± standard deviation; [†]: Data presented in median (first-third quartile); [a]: Results of one-way repeated measures analysis of variance; [b]: Results of Friedman test femoris muscle will increase because the total elastic modulus comprises the pressure applied by the external load[5]. In this study, the thickness of the rectus femoris muscle significantly decreased as the probe axial preload was increased, because the pressure of the external load acted on the elasticity of the rectus femoris muscle. However, during increased axial preload of the probe, Young's modulus of the rectus femoris muscle was significantly decreased in this study. A possible reason for these findings is that the probe axial preload might decrease the strain of the subcutaneous tissue more than that of the rectus femoris muscle. In strain elastography, red is used to denote soft tissue, blue for hard tissue, and green for tissue of intermediate elasticity. According to the increase of the probe axial preload, the blue area increased in the subcutaneous tissue changed from green to blue, and the red area increased in the rectus femoris muscle because the strain of each area was compared with that of the remaining tissue within the ROI (Figure 2). Axial preloads may have decreased the strain of the subcutaneous tissue more than that of the rectus femoris muscle, and strain of the rectus femoris muscle was relatively increased. Therefore, according to the increase of the probe axial preload, the strain ratio and Young's modulus of the rectus femoris muscle might decrease. These results indicated that a slight increase or decrease of probe axial preload influenced the strain of the subcutaneous tissue and muscle during elastography, leading to an error in the measurement for quantification of relative muscle elasticity using the strain ratio. When using a probe, the examiner should make an effort to maintain light contact of the probe axial preload with the skin during strain elastography to evaluate and monitor muscle elasticity.

This study has limitations, such as a small sample size that included only young males. Therefore, the influence of age and sex remains unknown. The probe axial preload used in the three conditions was not measured during the experiment. Further study is needed to determine the influence of a specified probe axial preload on muscle elasticity by ultrasound elastography.

Conflict of interest

The authors declare that there was no external funding obtained for and no conflict of interest regarding this study.

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