Handheld Tissue Hardness Meters for Assessing the Mechanical Properties of Skeletal Muscle: A Feasibility Study

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Abstract

Objectives: The purpose of this study was to examine the feasibility of using handheld tissue hardness meters to assess the mechanical properties of skeletal muscle.

Methods: This observational study included 33 healthy men (age, 22.4 ± 4.4 years) and 33 healthy women (age, 23.7 ± 4.2 years). Participants were placed in a supine position, and tissue hardness overlying the rectus femoris and the shear modulus of the muscle were measured on the right side of the body at 50% thigh length. In the same position, subcutaneous adipose tissue thickness and muscle thickness were measured using B-mode ultrasonography. To examine the associations of subcutaneous adipose tissue thickness, muscle thickness, and muscle shear modulus with tissue hardness, linear regression using a stepwise bidirectional elimination approach was performed.

Results: Stepwise linear regression revealed that subcutaneous adipose tissue thickness ($r = -0.38$, $P = .002$) and muscle shear modulus ($r = 0.27$, $P = .03$) were significantly associated with tissue hardness.

Conclusions: Significant associations among adipose tissue thickness, muscle shear modulus, and tissue hardness show the limitations and feasibility of handheld tissue hardness meters for assessing the mechanical properties of skeletal muscles. (J Manipulative Physiol Ther 2016;39:518-522)

Key Indexing Terms: *Elastic Modulus; Rectus Femoris; Skinfold Thickness; Elasticity Imaging Techniques; Ultrasonography*

Introduction

Handheld tissue hardness meters (myotonometers) are electromechanical devices that can noninvasively quantify the subjective estimates of manual palpation made by clinicians.[1-3] Hardness meters are small, portable, and applicable to any part of the body, making them suitable for routine physical examinations.[1] It has been reported that tissue hardness measured by hardness meters increases with muscle lengthening and after repetitive exercise[4-7] but decreases after acupuncture or massage therapy.[8,9] These findings indicate the feasibility of using hardness meters to assess muscle hardness, which is a transverse mechanical property of skeletal muscle.[10] Conventional handheld tissue hardness meters apply a compressive force perpendicularly to the skin overlying the target muscle and then derive hardness from measurements of tissue displacement.[1-3] The force-displacement curve consists of the following 3 sections: the initial curvilinear section describing compliance of the skin and subcutaneous adipose tissue, the intermediate section representing the muscle response, and the final plateau section relating to thickness of adipose tissue and muscle.[1] Thus, tissue hardness measured by handheld tissue hardness meters would indicate muscle hardness, but it is likely that the influence of subcutaneous adipose tissue and muscle thickness is also included in the measurement values.

Ultrasound shear-wave elastography can quantitatively measure tissue elasticity in vivo.[11,12] A shear wave is induced by an acoustic radiation force created by a focused ultrasound beam, which propagates transversely to the radiation force. The propagation speed of the shear wave (c) in the region of interest (ROI) is captured, from which tissue elasticity (shear modulus: μ) is derived: $\mu = \rho c^2$, where ρ is the density of soft tissues (1000 kg/m^3). Such measurement principles indicate that shear-wave elastography assesses muscle shear modulus based on shear-wave propagation in the target muscle, enabling assessment of the mechanical properties of skeletal muscle without the influence of subcutaneous adipose tissue or muscle thickness. Therefore, in this study, we assessed muscle shear modulus using shear-wave elastography and then examined the association

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of muscle shear elastic modulus with tissue hardness assessed using a handheld tissue hardness meter to investigate the feasibility of using handheld tissue hardness meters to assess the mechanical properties of skeletal muscle.

Methods

Subjects

A total of 33 healthy men (age, 22.4 ± 4.4 years; height, 165.3 ± 8.0 cm; body mass, 58.7 ± 9.6 kg) and 33 healthy women (age, 23.7 ± 4.2 years; height, 162.4 ± 7.0 cm; body mass, 56.5 ± 9.3 kg) voluntarily participated in this study. Participants were recruited from local universities and our institute using flyers and word of mouth. All participants were free of orthopedic and neuromuscular problems in their right legs and did not perceive muscle soreness during manual palpation to their right rectus femoris. Participants were informed about the purpose of the study and the experimental protocol before providing written consent to participate. This study was approved by the Ethics Committee of the Japan Institute of Sports Sciences.

Experiment Setup

Participants were placed in a supine position with knee joints fully extended. They relaxed their muscles during measurements. The measurements were carried out on the right side of the body at the midthigh position (50% of the way from the greater trochanter of the femur to the articular cleft between lateral condyles of the femur and tibia).[13] The measurements were performed 5 times, and the 3 values with the lowest coefficient of variance were selected for further analysis.[14] To ensure that the tissue hardness meter and the ultrasound transducer were placed at the same site on the skin, the location of the rectus femoris was identified by B-mode ultrasonography (Aixplorer; SuperSonic Imagine, Aix-en-Provence, France) and marked on the skin with a felt-tip pen.

Measurement of Tissue Hardness

Tissue hardness overlying the rectus femoris was measured by a handheld tissue hardness meter (PEK-1; Imoto Machinery, Kyoto, Japan; Fig 1). This hardness meter has been used in several previous studies,[2,4,5,7,8,15] and the measurement principle has been described in detail by Kato et al.[2] Briefly, this hardness meter consists of 2 parts: an outer hollow cylinder flanging a flat ring, and an inner cylindrical shaft located concentrically within the outer cylinder. When the hardness meter is pressed on the skin, both the outer cylinder and the inner shaft are displaced toward the body of the meter. The inner shaft has a stiffer spring constant compared with the outer cylinder, and thus the inner shaft experiences less displacement. When the outer cylinder reaches 10 mm displacement, tissue hardness is registered on the digital display of the hardness meter as a percentage of inner shaft displacement to outer cylinder displacement.

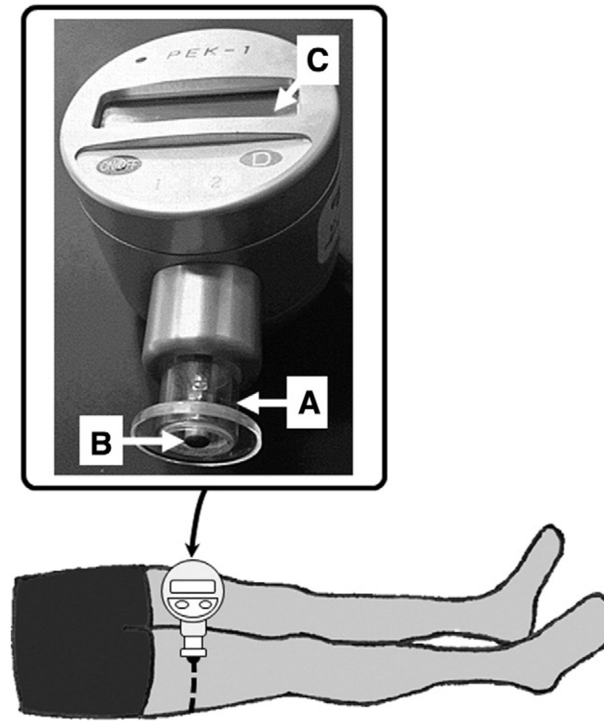

Fig 1. *Handheld tissue hardness meter used in this study. When the hardness meter is pressed onto the skin overlying the target muscle, an outer hollow cylinder flanging a flat ring (A) and an inner cylindrical shaft (B) are displaced toward the body of the meter. Tissue hardness is quantified from their displacements and registered on the digital display of the hardness meter (C). Measurements were carried out on the right side of the body at 50% of thigh length.*

Measurements of Shear Modulus, Muscle Thickness, and Subcutaneous Adipose Tissue Thickness

Shear modulus of the rectus femoris was measured by shear-wave elastography (Aixplorer; SuperSonic Imagine) with a 4- to 15-MHz linear array transducer (SL 15-4; SuperSonic Imagine; Fig 2). A 10 mm × 10 mm elastography ROI was set in the rectus femoris, and a 5-mm diameter circular tool used to automatically quantify shear modulus was positioned at the center of the ROI.[14] Subcutaneous adipose tissue thickness overlying the rectus femoris (distance between skin surface and fat–muscle tissue interface) and the muscle thickness (distance between the subcutaneous adipose tissue–muscle interface and the intermuscular interface) were obtained from a B-mode ultrasound image superimposed on the elastography image (Fig 2). Measurements of these thicknesses were carried out using a virtual caliper in the ultrasound software.

Statistical Analysis

Linear regression using the stepwise bidirectional elimination method ($\alpha_{in} = 0.05$, $\alpha_{out} = 0.10$)[16] was used