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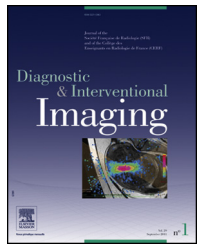

ORIGINAL ARTICLE /*Osteoarticulation*

Ultrasound shear wave velocity in skeletal muscle: A reproducibility study

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Shear wave imaging;
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Reproducibility of the results;
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Abstract
Purpose: The purpose of the study was threefold: to assess the reliability of shear wave velocities (SWV) measurements in normal skeletal muscles; to evaluate intra- and inter-operator reproducibility of measurements for a specific site of the muscle and for the mean value in the whole muscle.
Materials and methods: Two sets of measurements were performed at three weeks intervals of each other on 16 volunteers by two radiologists on medial gastrocnemius and tibialis anterior muscles. Each muscle was evaluated in 5 different sites, with three measurements for each site in the transverse and longitudinal planes. Reliability of SWV measurements was assessed by means of intraclass correlation coefficient (ICC).
Results: Reliability of the three independent SWV measurements was excellent, slightly better in the longitudinal plane. Inter/intra-operator reproducibility per site was fair to good in the longitudinal plane and poor to fair in the transverse plane. For global values of the whole muscle, ICC showed good agreement in the longitudinal plane and fair agreement in the transverse plane.
Conclusion: Quantitative SWV measurements are reliable when performed in rigorous conditions. In conditions that mirror clinical practice, inter/intra-operator reproducibility is moderate, better for longitudinal compared to transverse plane.

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Ultrasonography is a powerful technique whose potential in detecting musculoskeletal abnormalities has been growing during the past decade. The dynamic aspect of the exam is crucial in assessing traumatic diseases. Doppler ultrasonography technique offers additional sensitivity for the detection of muscle or tendon lesions. However, muscle ultrasonography has limitations. In traumatic injuries, edema and recent hemorrhagic infiltration or residual long standing lesions may result in subtle abnormalities that may be hardly visible. Similarly, ultrasonography clearly identifies the fatty content in advanced muscle degeneration but not at the early stage. Based on research in other tissues, it has been hypothesized that elastography assessment could be complementary to morphological for skeletal muscle exploration by ultrasonography.

Shear wave imaging (SWI) [1—3] is an elastography technique that calculates shear elastic modulus via the measurement of the velocity of a local shear wave produced by a remote mechanical source. This technology is integrated in some commercial medical ultrasound device, thus permitting elastographic assessment complementarily to conventional ultrasound B-mode images. As it generates its own wave-front, the device does not require external compression from the operator and allows for real time quantitative measurements. SWI is already used in the breast [4—8], thyroid [9,10], liver [11,12], lymph nodes [13], prostate [14], heart [15] and eye [16].

Ultrasound elastography is an imaging method that can directly measure the mechanical properties of the muscle [17—28], is like a ''virtual palpation''[18]. However, the elastic, anisotropic and mobile nature of the tissue complicates the muscle analysis. SWI was assessed during muscle contraction [17,20—23]. Gennisson et al. [17] evaluated the anisotropic nature of the muscle using SWI during the contraction of the muscle as well as in a passive extension in a group of healthy volunteers. Nordez et al. [20] demonstrated that shear wave velocities (SWV) were highly related to muscle activity level, drawing a parallel with electromyography activity. Koo et al. [24] provided evidence of a force-length relationship, one of the most fundamental characteristics of the muscle, that can be derived from in vivo imaging with shear wave imaging (SWI).

Other studies showed the importance of elastography in the diagnosis or monitoring [25—27] of muscle diseases and their treatment [28]. These studies are very interesting in their physiological and biomechanical aspects, but elastography assessment of muscle at rest would allow for the characterization of intrinsic properties of the muscle in cases of muscle injury [29] or myositis [30].

Few studies have focused on the assessment of resting muscle using SWI [17,19,24,31—33], and only one recent study was focused specifically on reproducibility assessments at various muscular sites [23]. In another recent study, reliability inter- and intra-operator has been verified [33], but with a manual compression elastography device and in conditions away from clinical practice of ultrasound. To consider SWI for clinical application, measurements have to be reproducible, with an identified level of precision to establish normal values. This is a mandatory prerequisite for the evaluation of stiffness differences between normal and pathological muscle. It is also important to assess several sites of the muscle to see if measurements and reproducibility are homogeneous within the muscle and to assess the global value of the muscle SWV values and reproducibility. The purpose of the present study was threefold: (1) to assess the reliability of SWI in normal skeletal muscle in optimal conditions and to evaluate the intra- and inter-operator reproducibility of mean SWV measurements (2) for a specific site of the muscle and (3) for the mean value in the whole muscle. The measures were carried out in the longitudinal plane and in the transverse plane to ascertain the reproducibility in each orientation.

Materials and methods

Population

Sixteen healthy volunteers, 7 men and 9 women, were enrolled in the study. The participants provided informed consent after they received information regarding the goal and the design of the study. The mean ± SD (min—max) age was 25 ± 12 (19—61) years, with a mean BMI of 23.2 ± 2.97 (17.3 to 29.6). The mean weight was 67.4 ± 13 (50—95) kg, the average height of 170 ± 9 (156-182) cm.

Shear wave elastography system

We used a system equipped with the Supersonic Shear Imaging module (SSI) with a SL15-4 high frequency linear probe (Aixplorer, Supersonic Imagine, Aix-en-Provence, France) providing a spatial resolution of 1 mm × 1 mm in elastography and 0.3 mm × 0.3 mm in classical B-mode. This system includes an ultra-fast ultrasonographic mechanism that remotely generates a transient mechanical force into tissue via the acoustic radiation force of focused ultrasound beams as fully described by Tanters et al. [34].

Acquisition protocol

Measurements were performed independently by one junior and one senior radiologist having three and seven years of experience respectively. Both were trained on at least 10 healthy subjects before enrolling the first participant. To avoid changes in muscle elastography related to physical activity, the participants were asked to stay in resting conditions for the two days prior to the acquisition. Moreover, before starting the acquisition process, the subjects were laid on the examination table for ten minutes to relax the muscle. The right leg was explored, focusing on the tibialis anterior (TA) and gastrocnemius medialis (GM). For tibialis anterior analysis, patients were positioned in a supine position leg extended and heel on the examination table (Fig. 1a). For gastrocnemius medialis analysis, patients were also placed in a supine position with knee flexed and hip in external rotation so that the lateral side of the leg was resting on the examination table (Fig. 1b). To avoid muscle deformation that could artificially increase the SWV measurements, minimum pressure was applied on the probe to obtain sufficient image quality and shear wave signals. A large amount of gel was used to ensure the best possible contact of the probe with the skin.

Five standardized anatomical sites were studied within each muscle to explore the whole area. The distance