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● *Original Contribution*

ADVANCES IN QUANTITATIVE MUSCLE ULTRASONOGRAPHY USING TEXTURE ANALYSIS OF ULTRASOUND IMAGES

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Abstract—Musculoskeletal ultrasound imaging can be used to investigate the skeletal muscle structure in terms of architecture (thickness, cross-sectional area, fascicle length and fascicle pennation angle) and texture. Gray-scale analysis is commonly used to characterize transverse scans of the muscle. Gray mean value is used to distinguish between normal and pathologic muscles, but it depends on the image acquisition system and its settings. In this study, quantitative ultrasonography was performed on five muscles (biceps brachii, vastus lateralis, rectus femoris, medial gastrocnemius and tibialis anterior) of 20 healthy patients (10 women, 10 men) to assess the characterization performance of higher-order texture descriptors to differentiate genders and muscle types. A total of 53 features (7 first-order descriptors, 24 Haralick features, 20 Galloway features and 2 local binary pattern features) were extracted from each muscle region of interest (ROI) and were used to perform the multivariate linear regression analysis (MANOVA). Our results show that first-order descriptors, Haralick features (energy, entropy and correlation measured along different angles) and local binary pattern (LBP) energy and entropy were highly linked to the gender, whereas Haralick entropy and symmetry, Galloway texture descriptors and LBP entropy helped to distinguish muscle types. Hence, the combination of first-order and higher-order texture descriptors (Haralick, Galloway and LBP) can be used to discriminate gender and muscle types. Therefore, multi-texture analysis may be useful to investigate muscle damage and myopathic disorders. (E-mail: filippo.molinari@polito.it)

Key Words: **Muscle ultrasonography, Texture analysis, Muscle characterization, Musculoskeletal ultrasound, Haralick features, Galloway features, Local binary pattern, Gray-scale mean value, MANOVA.**

Ultrasound imaging is proven to be effective in the investigation of the skeletal muscle structure (Pillen et al. 2008; Pillen and van Alfen 2011; Walker et al. 2004). The main advantages of ultrasounds are portability, low associated costs of the examination and non-invasiveness of the method. Moreover, the acoustic power levels used in diagnostic equipment minimize the probability of biological negative effects. Ultrasound imaging is, however, an operator-dependent technique. In order to lower the intra- and inter-reader variability, a quantitative approach is needed.

The quantitative features most commonly extracted from ultrasound images to investigate muscle size are cross-sectional area, thickness, fascicle length and fascicle pennation angle (Chow et al. 2000; Narici et al. 1996; Reeves et al. 2004). The muscle quality is commonly assessed through the quantification of the mean echo intensity by gray-scale analysis of a region of interest (ROI). This numerical parameter is highly dependent on the ultrasound scanner settings (Pillen et al. 2009b; Zaidman et al. 2008).

Contrary to the mean echo intensity and other first-order descriptors, higher-order texture features that can be extracted from ultrasound images are intensity invariant (Acharya et al. 2012d, 2012e, 2012f) and have

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already proven informative in the analysis of intramuscular fat content in animals (Kim et al. 1998), as well as in the characterization of arterial surface roughness (Acharya et al. 2012a; Niu et al. 2013), breast (Singh and Singh 2010) and ovarian tumors (Acharya et al. 2012c, 2013), thyroid lesions (Acharya et al. 2012b, 2014a) and liver images (Acharya et al. 2015; Gao et al. 2014) in human studies. Moreover, in a recent review focused on thyroid cancer, Acharya et al. 2014 reported that high characterization performance can be achieved only when sonographic features from the ultrasound images are merged to non-clinical features extracted from the ultrasound images using statistical and data mining techniques (Acharya et al. 2014b). They have also found that higher-order and non-linear descriptors offer better characterization performance than histogram-based parameters (Acharya et al. 2012c, 2014b).

To the best of our knowledge, in previous studies, only linear and first-order descriptors are used to characterize the texture of different skeletal muscles. In this paper, we characterized the image texture of five skeletal muscles of healthy men and women using different texture features. We show that Haralick features (second-order statistical descriptors), Galloway features and texture descriptors based on the local binary pattern (LBP) are unique for gender and muscle type. It can be seen from our results that the texture features are superior to the first order descriptors (based on the echo intensity histogram) in classifying the muscle type.

METHODS

Patients

Twenty healthy volunteers (10 females: aged 26.0 ± 2.3 y; body mass index 20.7 ± 2.2 kg/m^2 and 10 males, aged 30.2 ± 5.6 y; body mass index 23.3 ± 2.6 kg/m^2) participated in this study. Health status was assessed by medical history, clinical examination and electrocardiogram. The "Waterloo Handedness and Footedness Questionnaires—Revised" (Elias et al. 1998) was used to assess side dominance. Among them, three patients were left-side dominant. Before participating in the study, the patients were instructed about the aims and then they signed a written informed consent. The study conformed to the guidelines of the Declaration of Helsinki and was approved by the local ethical committee.

Ultrasound procedures and equipment

During a single experimental session, we acquired ultrasound B-mode images of the following five muscles from each subject: biceps brachii, vastus lateralis, rectus femoris, medial gastrocnemius and tibialis anterior. Images were acquired on both sides of the patients.

The same experienced sonographer (MAM) conducted the clinical examinations and acquired all the images. Three consecutive scans were acquired in the transverse plane of each muscle. After each scan, the subject moved and then the transducer was repositioned. To increase the repeatability of the acquisitions and to ensure that the insonation was orthogonal to the bone, the optimal insonation angle was selected by maximizing the representation of the bone boundary.

The medial gastrocnemius was insonated with the patients in prone position, whereas for all other muscles the supine position was maintained. In all measurements, the arms and legs were extended and the patients were asked to completely relax their muscles. Ultrasound coupling gel (Ultrasound transmission gel, REF: 907137475, PBpharma, Torino, Italy) was used to ensure optimal image quality while limiting the transducer pressure on the skin. All scans were performed by placing the transducer in correspondence to the largest muscle diameter at the following anatomic sites: The biceps brachii was measured at two thirds of the distance from the acromion to the antecubital crease; the rectus femoris halfway along the line from the anterosuperior iliac spine to the superior border of the patella; the vastus lateralis halfway along the line from the anterosuperior iliac spine to the superolateral border of the patella; the tibialis anterior at one quarter of the distance from the inferior border of the patella to the lateral malleolus; the medial gastrocnemius from the mid-sagittal line of the muscle, midway between the proximal and distal tendon insertions.

We used a MyLab Twice ultrasound device (Esaote, Genoa, Italy) equipped by a linear-array transducer (code LA533) with a bandwidth from 3–13 MHz. Gain was set at 50% of the range, dynamic image compression was turned off, and time gain compensation was maintained in the same (neutral) position for all depths. All system-setting parameters were kept constant throughout the study for each subject. The depth setting (initially set at 44 mm) was adapted for each participant during examination in order to display the entire muscle. The conversion factor was equal to 0.92 mm/pixel. The pictures in DICOM format were transferred to a computer for offline processing.

Texture feature extraction

All images were visually inspected and analyzed by the same experienced operator (CC), who positioned a ROI in each image as shown in Figure 1. One ROI was chosen in the median portion of the biceps brachii, vastus lateralis and medial gastrocnemius, whereas two equal-sized ROIs were chosen in the rectus femoris (Fig. 1a) and tibialis anterior (Fig. 1c) to include most of the muscle without the central aponeurosis (white arrow in Fig. 1a) and the internal fascia (white arrow in Fig. 1c). Figure 1b