Integration of HD-sEMG and Ultrasounds for the Assessment of Muscle Function

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Alberto Botter

***Abstract*— Electromyograms (EMGs) and ultrasound (US) images provide complementary information on muscle function. The integration of these two techniques may provide key insights into the electromechanical properties of skeletal muscles as well as into physiological adaptations due to ageing, pathologies, injuries or rehabilitation. From a technological point of view, the simultaneous acquisition of US and surface EMG from the same muscle region is challenging as the two detection systems may interfere with each other. This paper will describe these methodological issues and how they have been addressed to ensure high quality detection of both surface EMGs and US images. Finally, an overview on current and possible, future applications will be provided.**

I. Introduction

MUSCLE activation and the resulting tissue displacement are traditionally studied with surface electromyograms (sEMGs) and ultrasound (US) images, respectively. These two techniques are complementary both in terms of measured quantity (voltage and displacement) and in terms of detection volume and resolution. Surface EMG detection provides a high temporal resolution (or high spatio-temporal resolution in case of high-density sEMG) for the study of electrophysiological events occurring in the most superficial part of the muscle. Ultrasonographic devices sample images from planes broadly perpendicular to the skin, thus allowing for the detection of mechanical events in both superficial and deep muscle regions. With their high spatial resolution, US imaging has the potential to reveal fine spatial details of tissue displacement [1]. Recently, such spatial resolution is beginning to be complemented by increasing temporal resolution (>1,000 frames/s), enabling in vivo estimation of the mechanical properties of activated fiber bundles in localized muscle regions [2].

Combining sEMG and US has therefore the potential to provide a detailed description of muscle function, from the neural excitation to the resulting muscle tissue displacement. This approach can contribute to the study of muscle physiology/pathophysiology, to the refinement of musculoskeletal models, and to the assessment of rehabilitation outcomes.

Detecting US and sEMG from the same muscle region requires the development of appropriate electrode technology to suppress any mutual interferences. In this talk, the technological advancement for joint sEMG-US acquisition will be presented, together with examples of applications and future perspectives.

II. Electrode Technology

The integration of sEMG and US images may be obtained by positioning the two detection systems alongside each other. However, for some body regions with high muscle density, e.g. the forearm, this arrangement is not viable, as sEMG and US would possibly sample form different muscles. For large muscles, this issue seems to be less relevant. Nevertheless, even within the same muscle, sEMGs and US images detected from different portions may reflect distinct physiological and/or mechanical events due to possible, regional activation and fascicles' displacement [3], [4]. The optimal approach for a joint sEMG-US investigation seems therefore to demand the recording of both signals from the same muscle region, which requires the US probe to lie over the electrodes. This configuration implies the development of specific technological solutions to avoid artifacts in both US images (i.e. shadows due to high echogenic structures of the electrode) and sEMG signals (generation of low impedance paths between the electrodes through the US-coupling gel). In the following section the description on how these issues have been addressed is reported.

A. Electrode Design

The main functional requirement of an electrode for simultaneous acquisition of sEMG and US from the same muscle region is the transparency to ultrasounds. It is therefore required that the material constituting electrodes is: (i) homogeneous, thus reducing the number of transitions (and reflections) through different materials, (ii) with an acoustic impedance similar to that of biological, soft tissue, and (iii) with a good acoustic coupling with the skin. From the sEMG point of view, the electrodes must be insulated to avoid short circuits caused by the presence of the US-coupling gel between the electrodes.

Two technological solutions have been identified to meet these requirements. In the first one, electrodes and connections are embedded into a support of adhesive silicon rubber. Each electrode consists of a stainless-steel wire (0.1 mm diameter) exposed within a small, circular cavity (4 mm

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A. Botter is with the Laboratory for Engineering of the Neuromuscular System (LISiN), Department of Electronic and Telecommunications, Politecnico di Torino, Italy. (e-mail: alberto.botter@polito.it).

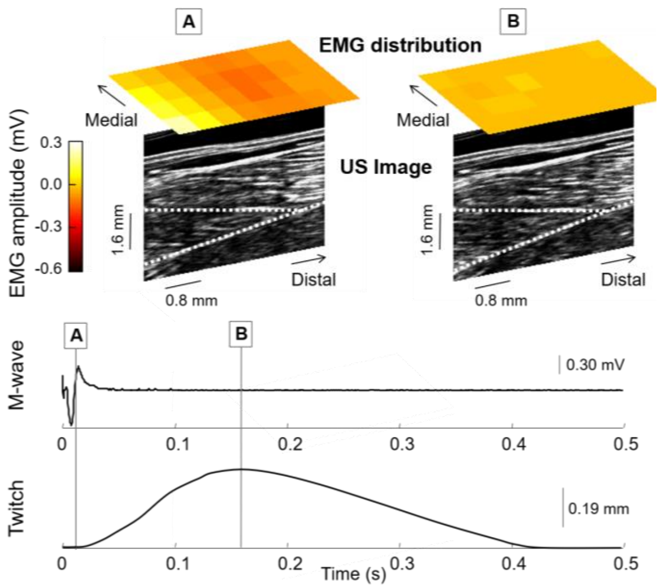

Fig. 1. Time evolution of activation (detected with a grid of 32 electrodes transparent to US) and architectural changes (detected with US imaging) in the medial gastrocnemius muscle during a single, electrically elicited twitch. The color maps shown in the top panel indicates the amplitude of M-waves detected by each electrode of the EMG-US grid. Such EMG image provides a clear view of the surface distribution of muscle activation in correspondence of the depth view of muscle tissue provided by the US images. A single M-wave detected by the most lateral and proximal electrode in the grid and the length change estimated from US are shown in the bottom panel. US and EMG frames reported in the upper panel correspond to time instants (A and B) indicated by vertical bars in the lower panels.

diameter) in the skin side of the silicon support. The contact between wire and skin is ensured by filling each cavity with conductive paste. This technological solution [5] is suitable to produce grids of electrodes for HD-sEMG, with different electrodes' configurations. The second solution identified is a layered structure of hydrogel sheets separated by thin, insulating structures used to define the sensing region(s) of the electrode [6]. Given the higher complexity of the overall electrode's structure, this solution is suitable for the design of detection systems with low electrode density (bipolar or few-electrodes systems).

B. *Electrode Testing*

Electrode prototypes described in Section A were tested to evaluate the effect of the proposed solutions on the quality of US images and sEMGs recorded simultaneously from the same muscle region. Key results indicate that, for both electrode solutions: 1) the electrode-skin impedance is similar to that of conventional electrodes with comparable size; 2) the reflection of US at the electrode-skin interface is negligible; 3) the likelihood of observing missing contacts, short-circuits, and artifacts in sEMGs is not affected by the presence of the US probe over the electrodes; 4) accurate estimation of changes in muscle architecture and movement can be obtained [5], [6].

III. APPLICATIONS

The proposed technology enables simultaneous assessment of muscle activation and mechanical tissue displacement (Fig. 1). To date, sEMG electrodes transparent to US have been used to discriminate between active and passive muscle movements of the two heads of gastrocnemius [7], to investigate the spatial relationship between excitation and muscle motion onsets in biceps brachii [8], and it is being used in studies aimed at further improving our understanding on how muscle anatomical features may affect the representation of motor units in the sEMGs. A promising clinical application concerns the study of fasciculation potentials (FPs), which are currently often studied from either intramuscular EMGs or US images. Both techniques, however, hardly suffice for the accurate identification and classification of FPs in large, muscle volumes. The approach based on sEMG-US integration was shown to increase the detection sensitivity to FPs in healthy subjects [9], opening promising fronts for the study of FPs in neuromuscular diseases. Prospectively, in combination with high frame rate US devices, an integrated sEMG-US system has the potential to allow electromechanical imaging of the neural output with high spatio-temporal resolution. This would allow to study the spatial and temporal evolution of electrical and mechanical events taking place during a contraction, and their possible adaptations with pathologies, injuries, training or rehabilitation.

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