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Rehabilitation Monitoring After Bed Rest in Elderly: TD-NIRS and sEMG Preliminary Study

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Abstract: We report on a preliminary longitudinal study on 21 elderly patients to non-invasively quantify rehabilitation outcomes in skeletal muscle after bed-rest by a combined approach based on TD-NIRS (for hemodynamics) and sEMG (for myoelectric recordings).

1. Introduction

Elderly people are frail subjects, which present a high risk of falls resulting in femur fractures [1]. In most of the cases, after this traumatic event, surgical procedure is required. The subsequent bed-rest and immobility of the patient may induce a general deterioration of the muscles functionality, not only in the injured limb. Frequently, this can lead to the insurgence or worsening of the sarcopenia syndrome, which is characterized by a progressive and non-specific reduction of muscle mass and strength, resulting in an increased risk of adversities, physical disability and impaired quality of life. The surgically treated patients usually spend at least one month in a rehabilitation structure, in order to recover their impaired muscle functionality due to the forced bed-rest. However, there is still a lack of a quantitative and direct assessment of the effects of the rehabilitation process [2].

We propose a longitudinal study to non-invasively assess the functional alterations that occur into the non-injured limb of patients included in a rehabilitation path after surgery. In this work, the muscle oxidative metabolism during an isometric exercise was assessed by the Time Domain (TD) Near Infrared Spectroscopy (NIRS) technique [3]. It allows the estimation of absolute concentrations of oxygenated- (O_2Hb) and deoxygenated- (HHb) hemoglobin from which the total hemoglobin (tHb) concentration, together with the tissue oxygen saturation (SO_2), can be calculated. Moreover, surface electromyography (sEMG) allowed to non-invasively investigate the electrical activation of the muscles of interest [4] assessing, among other things, the fatigue condition of a muscle. Our hypothesis is that a comparison of combined featured extracted from TD-NIRS and sEMG measurements at two different time points (i.e. at the beginning and at the end of the rehabilitation treatment) could provide useful biomarkers of the muscles functionality status to better plan and guide the rehabilitation process.

2. Materials and Methods

2.1 Subjects and experimental protocol

The study was approved by the Ethical Committee of ASST Gaetano Pini CTO, and conducted in accordance with the Declaration of Helsinki. Twenty-eight subjects (age: 78 ± 6.5 years old) in rehabilitation after surgery for femur fracture were recruited for the study and signed an inform consent. Oxygenation changes and surface electrical activity in the *vastus lateralis* muscle of the non-injured leg were evaluated by TD-NIRS and sEMG during voluntary isometric contractions. TD-NIRS measurements were performed with a medical device, previously developed at the Department of Physics, Politecnico di Milano [7]. A custom designed probe for skeletal muscles with two channels was employed (source-detector distances: ρ_1 = 15 mm and ρ_2 = 30 mm) and the TD-NIRS signal was sampled at 1 Hz. sEMG acquisitions were performed with a 16 channels wireless commercial system (*Cometa, Italy*). The electrical activity of five superficial muscle heads of the quadriceps muscle (2 anatomical landmarks on the *Vastus Lateralis* muscle, 2 on the *Rectus Femoris*, 1 on the *Vastus Medialis*) were registered by means of five bipolar electrodes at a sampling frequency of 2 kHz. In addition, the thickness of the leg subcutaneous adipose tissue and the *vastus lateralis* fibers pennation angle were evaluated by means of ultrasound (US) measurements.

To guarantee controlled experimental conditions, the subjects were seated on a custom designed chair, equipped with safety belts, handlebars, and a leg holder to maintain a knee angle of 120° (180° corresponding to full extension). The subject's ankle was strapped onto the holder and connected to a load cell. This allowed the exertion of the maximum quadriceps contraction,

guaranteeing the isometric condition. A visual feedback of the actual force exerted by the limb and measured by the load cell was real-time presented to the subject during the experiment.

The experimental protocol consisted in a first assessment of the maximum voluntary contraction (MVC). Successively, the subjects were asked to perform a series of 20 sustained isometric contractions at 80% of MVC, lasting 10 s each and followed by 5 s of relaxation. The contraction-relaxation sequence was dictated by an auditory stimulus (Presentation®, Neurobehavioral Systems Inc.), synchronized with the TD-NIRS and sEMG acquisitions. In addition, TD-NIRS signal was recorded also for 1 minute of baseline and 5 minutes of recovery at rest.

2.2 TD NIRS data analysis

The hemodynamic parameters of diffusive biological tissues can be derived from the raw TD-NIRS signal exploiting the Lambert-Beer's law. In this approach, the accurate estimation of absolute O_2Hb and HHb concentrations depends on the correct determination of both absorption and scattering properties of the tissue. However, TD-NIRS signal in skeletal muscles is greatly contaminated by the superficial layer, especially when the skin and the subcutaneous adipose tissue are significantly perfused in response to physical activity [5]. With TD-NIRS, the absorption and reduced scattering coefficients (μ_a and μ'_s) of these two different tissues, i.e. the subcutaneous fat and the skeletal muscle, can be quantitatively estimated exploiting the analytical solution of the Diffusion Equation (DE) for a bilayer diffusive medium [6]. To increase the robustness of this model, we set up a two-step approach exploiting the different depth information carried by the two acquisition channels. Firstly, the DE solution for a homogeneous medium was applied separately to the shortest channel (ρ_1) and to the furthest one (ρ_2) to retrieve the optical properties belonging mainly to the superficial and the deeper layer, respectively. The coefficients thus obtained were used to initialize the final bilayer approach, in which the signals from both the inter-optode distances were combined and the knowledge of the superficial layer thickness (measured by ultrasonography) was added as an "a-priori" information. With this method, the μ_a and μ'_s of both layers were retrieved with increased accuracy and, consequently, the hemoglobin concentrations of interest.

1.3 sEMG data analysis

First, the raw sEMG signals were preprocessed to achieve the EMG envelope. The EMG envelope was used to identify the onset and offset of each of the 20 contractions with a double threshold algorithm. This allowed to synchronize and compare the electrical signal to the corresponding force signal acquired with the load cell. The EMG signal was further analyzed to extract the mean RMS and Median Frequency (MF) on each contraction epoch and their time course, as typical measures related to muscle fatigue.

3. Results

In Fig. 1, the different acquired parameters are shown for a representative subject. The sEMG temporal raw signal and its envelope (blue and red lines, respectively) acquired from the *superior vastus lateralis* head during the two measurement sessions, at the beginning (a) and the end (b) of the rehabilitation period, are shown superimposed to the force signal (yellow line) for a subject. The correspondence between the electrical muscle activation and the force exerted at the ankle is observed. From both signals, we notice that, in the second half of the exercise performed at the beginning of the rehabilitation session, the subject was not able to maintain the sustained initial force (see Fig. 1a). On the contrary, the same difficulties seem not to be present at the end of the rehabilitation period (Fig. 1b), where the subject was able to keep a constant strain.

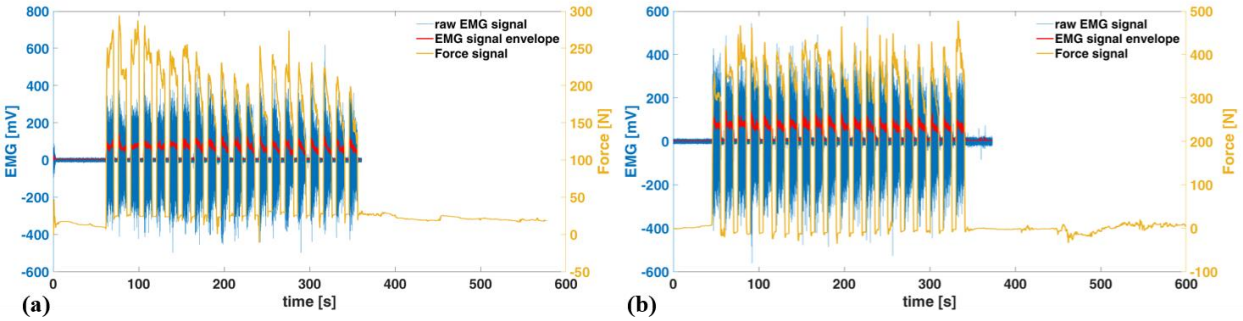

Fig. 1. Force signal (yellow line) recoded by the load cell during the experimental superimposed to the raw EMG temporal signal (blue line) and its low-pass filtered envelope (red line) of one representative subject. (a) First measurement session at the beginning of the rehabilitation and (b) second session at the end of the rehabilitation.

In Fig. 2, the relative changes of concentrations of HHb, O_2Hb, tHb and SO_2 with respect to the baseline values are reported for the two measurement sessions. No relevant changes in the magnitude of tHb variation seems to occur during the experiment. On the contrary, a slight decrease of HHb and an increase of O_2Hb values at the end of the exercise can be noticed in the second session with respect to the first one. Moreover, looking at the SO_2 time-course in the first measurement session, we can observe a rapid decrease of about 8% with respect to the baseline followed by a constant behavior. On the other hand, during the second session, we observed a slower initial slope followed by an increase of the saturation level in the second half of the exercise. Finally, concerning the recovery phase, we can observe that for the first measurement session, all the hemodynamic parameters quickly return to the baseline values. On the contrary, at the end of the rehabilitation, only the HHb returns to the baseline after 5 min from the end of the exercise, while O_2Hb, tHb and SO_2 maintain higher values. This suggests a hyperemia following the exercise, a physiological response that should be expected in the healthy muscle.

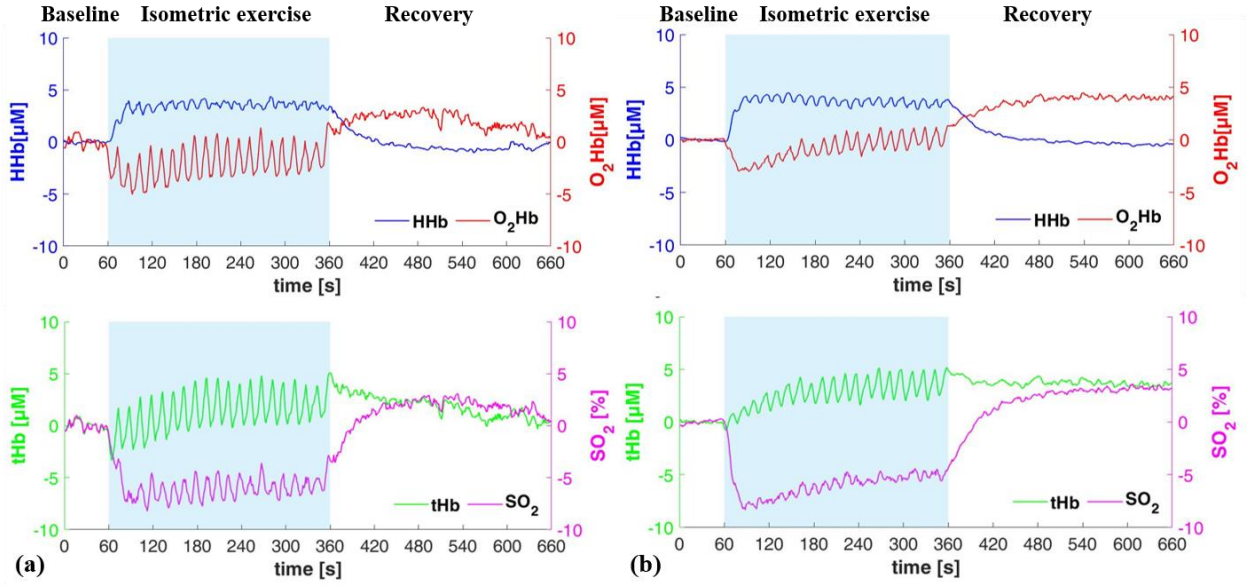

Fig. 2. Representative subject's *vastus lateralis* hemodynamic parameters time-courses during the isometric contraction exercise, for both the acquisition sessions at the beginning (a) and at the end (b) of the rehabilitation.

4. Conclusion

The combination of findings from TD-NIRS and sEMG signals reported are compatible to an improvement in the *vastus lateralis* performance during isometric exercise after rehabilitation. In fact, it seems that the muscle can consume a low oxygen amount (lower HHb, higher O_2Hb and higher SO_2) recalling the same amount of blood (no changes in tHb). The force performances improved as well since a higher sustained force and constant sEMG for longer period is shown. Further analysis of the shown time-courses is running to provide a set of quantitative features upon which a group analysis will be performed. These first results are promising in view of retrieving useful information about the rehabilitation process in bed-rested patients.

5. References

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