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A new protocol to compare successful versus failed patients using the electromyographic diaphragm signal in extubation process

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Abstract— **In clinical practice, when a patient is undergoing mechanical ventilation, it is important to identify the optimal moment for extubation, minimizing the risk of failure. However, this prediction remains a challenge in the clinical process. In this work, we propose a new protocol to study the extubation process, including the electromyographic diaphragm signal (diaEMG) recorded through 5–channels with surface electrodes around the diaphragm muscle. First channel corresponds to the electrode on the right. A total of 40 patients in process of withdrawal of mechanical ventilation, undergoing spontaneous breathing tests (SBT), were studied. According to the outcome of the SBT, the patients were classified into two groups: successful (SG: 19 patients) and failure (FG: 21 patients) groups. Parameters extracted from the envelope of each channel of diaEMG in time and frequency domain were studied. After analyzing all channels, the second presented maximum differences when comparing the two groups of patients, with parameters related to root mean square ($p = 0.005$), moving average ($p = 0.001$), and upward slope ($p = 0.017$). The third channel also presented maximum differences in parameters as the time between maximum peak ($p = 0.004$), and the skewness ($p = 0.027$). These results suggest that diaphragm EMG signal could contribute to increase the knowledge of the behaviour of respiratory system in these patients and improve the extubation process.**

Clinical Relevance—**This establishes the characterization of success and failure patients in the extubation process.**

I. INTRODUCTION

Mechanical ventilation (MV) is a vital therapeutic procedure in the respiratory failure process. An inappropriate time to disconnect a patient from MV can lead to complications that increase morbidity, mortality, hospital stay, costs, among others [1]. Despite advances in mechanical ventilation and its clinical process, the optimal timing decision for a patient's extubation still presents up to 25% failure [2], [3]. The causes that can induce the use of MV can be both pathological and extreme physiological, impairing contractile activity of the respiratory system, either by inducing fatigue (permanent alteration), weakness (reversible alteration), or deterioration of the mechanical effectiveness of the diaphragm. The diaphragm is the main respiratory muscle, and its function implies mobilizing a volume of air through a distribution system, allowing gas exchange, due to its intermittent contracted and modifying the pressure, shape, and volume of the chest [4].

The electromyographic (EMG) signals are records of motor unit action potentials, which reflect the response to electrical activity that occurs within these units by shrinking or relaxing the fibers of a muscle [5]. One advantages of the surface EMG is that the activity of the muscle can be recorded superficially, not requiring an invasive device, placing the electrodes on the skin covering the muscle of interest [6].

Some studies based on the EMG signals have been used to the diagnosis of neuromuscular disorders [7], analysis of gait [8] and balance [9], recognition of hand gestures or movements [10], [11], recognition of emotions through facial recordings and statistical methods [12], automatic control of upper limb prostheses [13], among other interesting biomedical applications. The EMG of respiratory muscles is correlated with the intensity of dyspnea in acute in acute heart failure, mechanical ventilation, and chronic obstructive pulmonary disease [14], [15]. However, whether diaphragm muscles EMG is correlated with dyspnea in patients undergoing weaning from mechanical ventilation is unknown.

In our previous works, patients undergoing weaning process from mechanical ventilation through T-tube test were analyzed using the respiratory flow signal [16]. In this work, we propose a new protocol based on the EMG diaphragm signal among others, to discriminate patients in extubation process. The main objective is to define this protocol to capture the EMG activity through five channels, with surface electrodes placed equidistantly on the diaphragm. Parameters extracted from the envelope of these signals are used to classify patients successful versus failure in the weaning trial.

II. METHODS

A. Database

The protocol is based on the study of 40 patients on weaning trials from mechanical ventilation. These patients were

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recorded in the Department of Intensive Care Medicine at Foscal Hospital, Floridablanca, Colombia, according to the protocol approved by the local ethics committee, and after obtaining informed consent from the patient.

The patients were submitted under spontaneous respiration test (SBT) before to disconnected from the ventilator. Table I present demographic information of the patients, according to the result of the SBT process, successful (SG) and failure (FG) groups, number of female and male, age, and tidal volume (V_T) and respiratory rate (RR) of the clinical history.

TABLE I. PATIENT DEMOGRAPHIC INFORMATION

	SG	FG
# Patients (%)	19 (47.5%)	21 (52.5%)
Age (years) (mean ± sd)	53.7 ± 23.3	68.6 ± 15.7
Female, n (%)	7 (17.5%)	8 (20.0%)
Male, n (%)	12 (30.0%)	13 (32.5%)
V_T (ml) (mean ± sd)	539 ± 151.0	498.3 ± 100.5
RR (rpm) (mean ± sd)	18.7 ± 3.2	21.2 ± 3.6

SG: successful group; FG: failure group; VT: tidal volume; RR: respiratory rate

B. Clinical Protocol

All patients included in the study underwent mechanical ventilation for at least 48 hours and selected to disconnection from ventilator according to clinical criteria:

- Resolution of the underlying cause of respiratory failure, without the need for vasopressors or sedatives (suspended 24 hours before the study)
- Adequate oxygenation, $PaO_2 > 60$ mmHg with an inspired oxygen fraction (FiO_2) < 0.4 and a positive pressure at the end of the expiration (PEEP) < 8 cm H_2O and PaO_2 / FiO_2 > 150
- Cardiovascular stability: heart rate < 130 beats per minute and average blood pressure > 60 mm Hg
- Afebrile and hemodynamically stable
- Adequate hemoglobin level > 8 g / dl
- Adequate respiration muscle function
- Normal basic acid and electrolytes measurements

Patients who met these criteria were undergoing the SBT test using pressure support ventilation (PSV) mode. PSV is an assisted ventilatory mode that is patient-triggered (by pressure, airflow, or both), pressure-limited and flow cycle. In the process of withdrawal of mechanical ventilation, the support level should be reduced as quickly as the patients clinical. This reduction must be made on an individual basis. Therefore, as the patient adapts to this pressure, the support levels are lowered by different steps (between 2 and 4 cmH_2O per step) until can breathing spontaneously, and with this pressure at a minimum level.

Positive end-expiratory pressure (PEEP) was established at 5 cm H_2O, the inspired oxygen fraction concentration at 40%, the flow trigger sensitivity at 2 l/min, and the final pressure support ventilation at 8 cm H_2O. At the end of the extubation test respiratory rate, tidal volume, heart rate and blood gases were measured in all patients, and the performance of weaning criteria was verified. The mean time of the SBT protocol was 60 minutes, and the final weaning decision was made by the clinical specialist.

C. Signal registration

The proposed protocol included the recording of ECG (128 Hz), respiratory (38.4 KHz) and diaphragm EMG (1 KHz) signals for 30 minutes. This work is based on the analysis of the diaphragm EMG (diaEMG) signal obtained with a wireless system (BTS FREEEMG 100 RT).

Diaphragm EMG signals were recorded by placing five equidistant surface electrodes around the diaphragm muscle. First channel corresponds to the electrode on the right. Figure 1 is a schematic representation of the surface electrodes position to diaEMG signal acquisition.

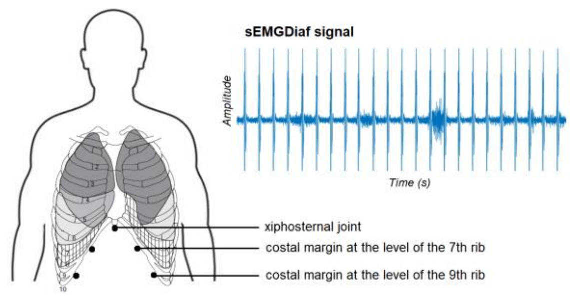

Figure 1. Scheme acquisition of diaEMG signal (adapted to [19]).

All patients were registered in two times: The first record, when according to clinical criteria, the resolution of the etiology of respiratory failure, the hemodynamic stability and the respiratory muscle function were suitable for weaning trial. Then, the patient was undergoing to SBT test using PSV method. The second record, when the patient was candidate to maintain the respiratory function with a PSV level at 8 cmH_2O. In both cases, all signals were recorded for 30 minutes.

According to the results the patients were classified into two groups:

- SG: successful group, patients who maintained the spontaneous breathing after 48 hours.
- FG: failure group, patients who failed in the SBT test (for 30 minutes), or who successful SBT test, but before 48 hours needed to reconnect to mechanical ventilation.

D. Diaphragm EMG signal processing

To analyze the 5–channels of diaEMG signals, linear trend was removed, and in-house preprocessing tools were used to reduce noise, artifacts, and spikes. For the processing signals, a band pass filter with cutoff frequencies of 0.5 Hz and 300 Hz was applied. To characterize these signals their envelopes were obtained, calculating the maximum peaks, with spline interpolation, and after, they were smoothed using a quadratic polynomial, by a moving window of 9 ms [17]. In addition, a signal reconstruction process was applied to replace artifacts and events unrelated to its physiological response and maintain its dynamic [18]. Figure 2 is an example of diaEMG signal and its envelope.

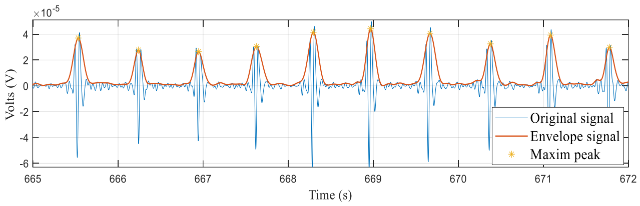

Figure 2. diaEMG signal and envelope of a successful patient.

Due to the oscillatory character of envelope signal, the Welch method was used for the spectral analysis. This method is based on the modified periodogram allowing for overlapping data segments using the temporal Hanning window. After normalized the power in the window function, the power spectral density (PSD) was estimated by averaging these modified periodograms using windows of 300 s overlapping 50% [17]. Figure 3 is an example of PSD of a) a successful patient and b) a failure patient.

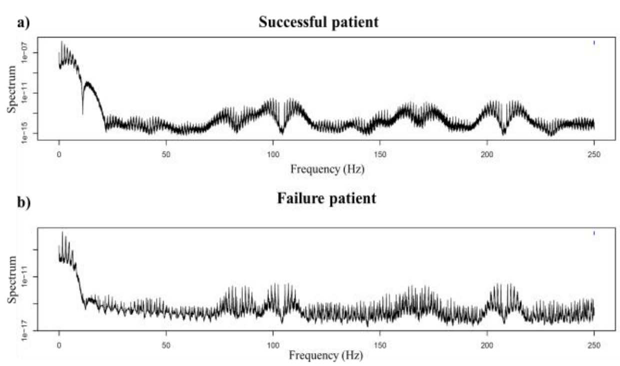

Figure 3. Excerpt of envelope of diaEMG signals – channel 4 corresponding to a) a successful patient, and b) a failure patient.

E. *Parameter extraction*

The envelopes of the diaEMG signals were characterized, in time domain, through statistical descriptive indices: mean (M), standard deviation (SD), kurtosis (K) and skewness (Sk). Additionally, parameters related to root mean square (RMS) to quantify the energy of the signal, moving average (MA) to determine variations in amplitude, and time between maximum peaks (Tp) to quantify the variability of the diaphragm muscle contractility were calculated.

In frequency domain, parameters related to central frequency [fc (Hz)] (power 50%), mean frequency [fm (Hz)], frequency peak [fp (Hz)], amplitude of fp [A_{max} (V^2/Hz)] standard deviation of frequency peak [fpsd (Hz)], upward (UpS) and downward (DpS) slopes were obtained (Figure 4).

To analyze differences between the two groups of patients, Kolmogorov-Smirnov non-parametric statistical tests was applied, with p-value $\leq$ 0.05 to determine statistically significant differences.

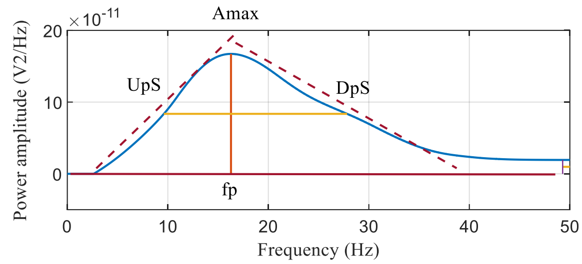

Figure 4. Frequency parameters of the PSD envelope. fp: frequency peak; A_{max}: amplitude of fp; UpS and DpS: upward and downward slopes.

III. RESULTS

This study was carried out on 40 patients in the process of withdrawal form mechanical ventilation, classified into successful or failure groups, according to their weaning trial outcome. In this work, the electromyographic diaphragm activity of these patients was analyzed, recording the EMG signal of diaphragmatic muscle in 5–channels (Ch1 to Ch5 from right to left position). The envelopes extracted from each channel presented different amplitudes in function of their position. The results showed a lower amplitude in the channels of more extreme position (Ch1 and Ch5) in both groups of patients. On the other hand, the highest amplitudes were obtained mostly, in Ch3 for successful patients and in Ch4 for failure patients. Figure 5 presents an excerpt of the envelopes of each diaEMG channels of a successful patient, and a failure patient. Figure 6 presents the power spectral density of these same signals.

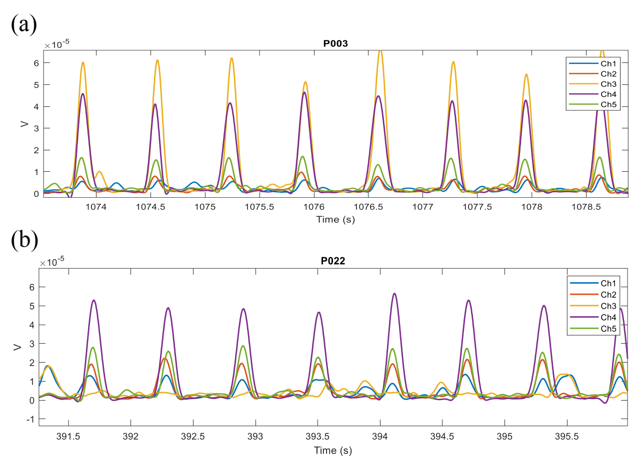

Figure 5. Excerpt of envelope of the 5–channels of diaEMG signals corresponding to a) a successful patient, and b) a failure patient

The parameters obtained to describe the behavior of the diaEMG signals in the two groups of patients were analyzed considering the same channel in each group. Channel 2 presented statistically significant differences in parameters related to root mean square, moving average and the upward slope of the PSD signal. In addition, channel 3 also presented significant differences with parameters as the time between peaks of the envelope and the skewness (Table II). Channels Ch2, Ch3 and Ch4 are the ones that can best record the contraction and relaxation of the diaphragm muscle, and possible differences between a successful and failure patient.

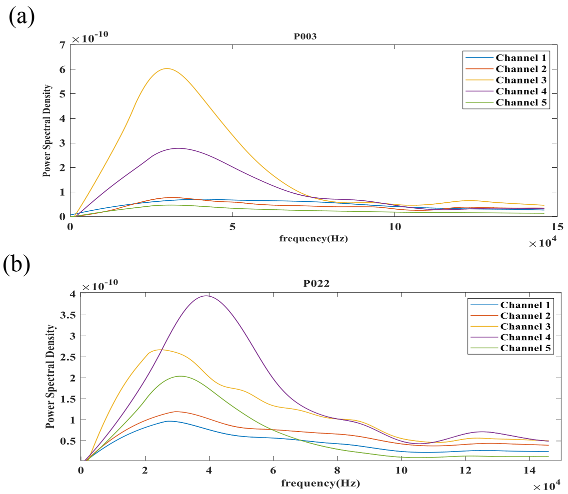

Figure 6. PSD of the envelopes of the 5–channels diaEMG signals from a) a successful patient and b) a failure patient

TABLE II. SIGNIFICANT PARAMETERS

Ch		SG	FG	*p*-value
Ch2	RMS (V)	$(6.28 \pm 3.38) \times 10^{-6}$	$(1.40 \pm 1.60) \times 10^{-5}$	0.005
	MA	$(4.10 \pm 2.29) \times 10^{-6}$	$(8.68 \pm 9.37) \times 10^{-6}$	0.001
	UpS	$(4.86 \pm 2.07) \times 10^{-12}$	$(1.03 \pm 1.18) \times 10^{-11}$	0.017
Ch3	Tp (ms)	986.50±165,5	952.01±115.3	0.004
	Sk	1.85±0.4	2.51±2.3	0.027

Ch: Channel; SG: Successful group; FG: Failed group; RMS: Root Mean Square; MA: Moving Average; UpS: upward slope; Tp: time between peaks; Sk: skewness.

IV. DISCUSSION AND CONCLUSION

The diaEMG signals allow to measure the effort of patients to breathing. This effort is directly related to the capacity of the patient to recover his spontaneous breathing. Our results suggesting that the channels Ch2 and Ch3 could quantify these differences, with parameters that describe the dynamic and the dispersion of the respiratory patterns. Differences between the maximum peaks of the envelope suggest a high correlation with the variability respiratory rate. On the other hand, the differences between upward slope parameters of the power spectral density of the two groups of patients, can be related to the respiration power.

In conclusion, this new protocol can contribute to improve the extubation process, with new indices to analyze the respiratory pattern of this patients. However, these results should be validated with a greater number of patients, and to apply other methods to characterize these signals, and to obtain new indices to classify these patients.

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