

# Measuring respiratory surface EMG with ECG electrode leads

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*Abstract: Surface electromyography (sEMG) offers potential for analyzing patient-ventilator interactions and respiratory effort. Despite being promising, it is not yet clinically established, unlike electrocardiography (ECG), which shares the same physiological principles for cardiac monitoring. This study investigates ECG leads for capturing respiratory muscle signals in 20 healthy subjects during quiet and resistance breathing. Performance was quantified by signal-to-noise ratios between inspiratory activity and (1) baseline noise / (2) expiratory activity. ECG leads were suitable for monitoring respiration, with performance enhanced by combining ECG electrodes with respiratory sEMG electrodes. The findings support integrating respiratory sEMG into clinical practice using ECG electrodes without compromising cardiac monitoring.*

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## I. Introduction

Respiratory surface electromyography (sEMG) non-invasively records the electrical activity of respiratory muscles using skin electrodes. While being promising for analyzing patient-ventilator interactions and patient respiratory effort in mechanical ventilation, it has not yet been established clinically due to challenging signal acquisition and processing [1].

In contrast, electrocardiography (ECG) is a well-established non-invasive method recording the heart's electrical activity to diagnose heart diseases [2]. It has been firmly established in clinical practice over the years and is recommended in intensive care guidelines for hemodynamic monitoring [3, 4].

Since intensive care ECG electrodes are in proximity to the respiratory muscles, they offer the potential of recording respiratory muscle activity alongside cardiac monitoring. To this end, we systematically investigated ECG leads and differential electrode lead combinations between one ECG electrode and one intercostal or diaphragmatic electrode regarding their performance in respiration monitoring.

## II. Material and methods

The data used in the present evaluation were derived from our larger dataset containing 64 electrodes from 20 healthy subjects acquired for a comprehensive evaluation of electrode leads for measuring respiratory sEMG [5].

### II.1. Measurement setup and study protocol

Briefly, surface EMG was acquired for a total of 64 unipolar electrode channels at a sampling rate of 2000 Hz.

An overview of our applied electrode scheme, based on anatomical landmarks, is depicted in Figure 1. Airway flow and airway pressure were synchronously recorded at 2000 Hz. Additionally, a respiratory trainer (POWERbreathe KH2, POWERbreathe International Ltd., Southam, UK) was integrated into the measurement setup to perform maximum inspiratory pressure (MIP) maneuvers and resistance breathing with an inspiratory load.

A total of three breathing maneuvers were carried out consecutively. Before each of them, a 60 s baseline measurement was performed during which subjects had to relax and breathe quietly without the measurement setup. The first breathing maneuver comprised 300 s of quiet tidal

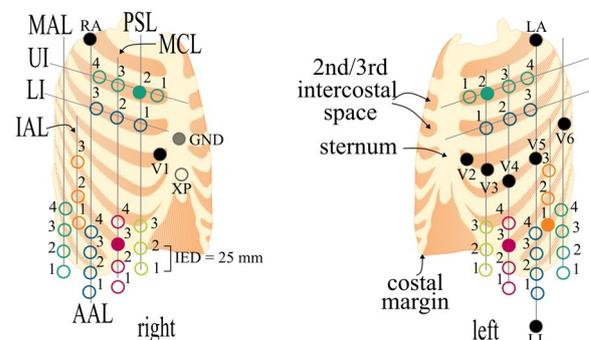


Figure 1: Applied electrode scheme in [5] for quantitative evaluation of electrode leads. Electrodes used in this work are color filled. - MAL: midaxillary line; IAL: interaxillary line; AAL: anterior axillary line; MCL: midclavicular line; PSL: parasternal line; UI: upper intercostal line; LI: lower intercostal line; GND: ground electrode; XP: xiphoid process electrode; IED: inter-electrode distance in vertical direction.

breathing using the measurement setup. In the second step, five maximum inspiratory pressure maneuvers were performed. Subsequently, the inspiratory load was set to 20 % of the highest MIP and subjects performed 15 deep inspirations.

## II.1. Data analysis

A subset of 17 electrode leads were investigated, including ECG leads from Einthoven and Wilson of the common 12-lead ECG (I, II, III, V<sub>1</sub>-V<sub>6</sub>) [2]. Further, we selected eight differential leads, combining one ECG electrode with one chest electrode, which are commonly used for measuring intercostal or diaphragmatic muscle activity (RA with RUI2, LA with LUI2, V<sub>3</sub>, V<sub>4</sub>, V<sub>5</sub> with LMCL3 or LIAL1). The best performing lead in [5], i.e., the differential lead between LMCL3 and RMCL3, were used as reference.

The applied signal processing chain, including filtering, ECG removal and outlier detection, is comprehensively described in [5]. As a result, we obtained sEMG envelopes (sEMG<sub>env</sub>) for each evaluated lead. Breaths were segmented into inspiratory (insp) and expiratory (exp) phases using the flow signal. To perform a quantitative comparison of selected leads, we calculated two signal-to-noise ratios on a breath-by-breath basis [5]. Firstly, the ratio

$$\text{SNR}_{\text{base}}(\text{dB}) = 20 \cdot \log_{10} \frac{Q_{75}(\text{sEMG}_{\text{env,insp}})}{Q_{25}(\text{sEMG}_{\text{env,baseline}})} \quad (1)$$

between amplitudes of inspiratory activity, quantified as the third quantile of inspiratory values, and baseline noise values, determined as the first quartile of baseline measurement envelopes, was formed. Secondly, for quantifying expiratory crosstalk the amplitude reached during inspiratory phases in relation to amplitude reached during expiratory phases was calculated via

$$\text{SNR}_{\text{exp}}(\text{dB}) = 20 \cdot \log_{10} \frac{Q_{75}(\text{sEMG}_{\text{env,insp}})}{Q_{75}(\text{sEMG}_{\text{env,exp}})} \quad (2)$$

To check for statistical differences ( $p < 0.05$ ) in the performance metrics, pairwise t-tests with Bonferroni-Holm correction were performed between the reference lead and the 17 evaluated leads.

## III. Results and discussion

In our study, we enrolled 20 healthy subjects with an age of  $26.7 \pm 3.33$  years and a BMI of  $24.00 \pm 2.91$  kg/m<sup>2</sup>. Figure 2 depicts the performance metrics results as violin plots for the selected electrode leads for quiet and resistance breathing. The bilateral reference lead MCL3 reached an SNR<sub>base</sub> of  $6.00 \pm 3.04$  dB and  $17.42 \pm 4.71$  dB, and an SNR<sub>exp</sub> of  $2.78 \pm 1.66$  dB and  $9.05 \pm 2.71$  dB, respectively.

Our results indicate that most of the evaluated standard ECG leads were able to monitor respiratory muscle activity with average SNR<sub>base</sub> and SNR<sub>exp</sub> higher than 1 dB in quiet and resistance breathing. This may enable a process-orientated integration of respiratory sEMG measurements into clinical practice by using ECG leads and adding an sEMG signal processing chain. However, significant performance differences between the reference lead and the Einthoven and Wilson leads can be observed in resistance

breathing. In this case, our results support the application of differential leads with one ECG electrode and one additional chest electrode, i.e. V<sub>3</sub>-LMCL3 or RA-RUI2. Since RA and V<sub>3</sub> are part of guidelines [3], the workload in everyday clinical practice is kept to a minimum.

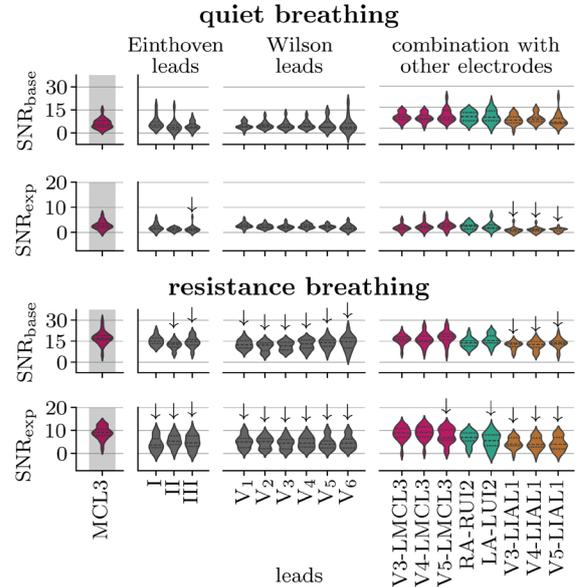


Figure 2: Quantitative evaluation of selected electrode leads: The distribution of performance metrics (in dB) is shown as violin plots for quiet (upper part) and resistance breathing (lower part). Arrows indicate statistically significant ( $p < 0.05$ ) differences. MCL: midclavicular line; UI: upper intercostal line; IAL: interaxillary line; L: left torso; R: right torso.

## IV. Conclusion

The results obtained in this work are promising to pave the way for respiratory sEMG into clinical practice by using ECG electrode positions. However, they need to be validated with an intensive care subject cohort in the future.

### AUTHOR'S STATEMENT

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