Proceedings on Automation in Medical Engineering
Proc AUTOMED, 2026, Vol. 3, No 1, Article ID 2478, 2 Pages

Infinite Science Publishing

Detecting excessive and insufficient breathing effort with respiratory surface EMG

T. Lerg[1*], N. M. Carbon[2], J. Graßhoff[1], S. Weber-Carstens[3] and P. Rostalski[1,4]

[1] *Fraunhofer Research Institution for Individualized Medical Technology and Engineering IMTE, Lübeck, Germany*
[2] *Department of Anesthesiology, Universitätsklinikum Erlangen, Friedrich-Alexander Universtität Erlangen-Nürnberg (FAU), Erlangen, Germany*
[3] *Department of Anesthesiology and Critical Care Medicine, University Hospital Berlin, Charité – Universitätsmedizin Berlin, Berlin, Germany*
[4] *Institute for Electrical Engineering in Medicine, University of Lübeck, Lübeck, Germany*
[*] *Corresponding author, email: tjorben.lerg@imte.fraunhofer.de*

Abstract: During mechanical ventilation risks for excessive and insufficient breathing effort directly determine patient outcomes through distinct injury mechanisms. Respiratory surface electromyography (sEMG) holds potential for monitoring breathing effort, however measurement of electrical activity in comparison to conventional pressure measurement exhibits systematic differences in timing and amplitude of inspiratory activity. In this article influences of neuromechanical delay (NMD) and coupling (NMC) on detection performance using sEMG compared to pressure measurements are investigated. Results indicate excellent performance if sEMG measurements are corrected for both NMD and NMC. However, using generalized values for NMD and NMC do not achieve improvements, highlighting the importance of individualized calibration.

I. Introduction

Mechanical ventilation is a cornerstone of intensive care therapy, yet it poses risks for both the lung and the diaphragm. While excessive breathing effort may increase the risk of self-inflicted lung injury as well as contribute to diaphragm fatigue, an insufficient level of breathing activity may lead to diaphragm atrophy [1, 2].

Currently, the measurement of esophageal pressure P_{es} is considered the gold standard in assessing breathing effort [3]. When corrected for the elastic properties of the chest wall, Pes measurements allow for derivation of the pressure generated by the patient's muscle activity P_{mus}.

Respiratory surface electromyography (sEMG) represents a non-invasive alternative to monitor respiratory muscle activity without the need for uncomfortable and expensive single-use catheters [4]. However, with sEMG as a new way of assessing breathing effort, new parameters affecting the transferability of electrical to pressure measurements are introduced, namely the neuromechanical delay (NMD) and coupling (NMC). NMD is defined as the inherent delay between neural activity and exerted force [5] and NMC as the proportionality factor between the two [6]. In this article, sEMG acts as a surrogate for neural activity and the deflection in P_{mus} for the exerted force.

To better understand the influence of NMD and NMC on sEMG as a detector for insufficient and excessive effort, we investigate detection performance for isolated, combined and generalized correction of NMD and NMC.

II. Material and methods

The analysis was based on data from ARDS patients, collected at Charité – Universitätsmedizin Berlin. Each measurement comprised airway and esophageal pressure, airway flow and two sEMG leads, one for diaphragm and one for intercostal muscles [7]. Cardiac activity was removed from P_{es} and sEMG computationally [7]. We excluded recordings 1.) without inspiratory activity, where 2.) sEMG measurements were not available or P_{es} was not calibrated correctly and 3.) expiratory activity was present in any signal. In total, 19 recordings from 13 patients with 2068 breaths were included for further analysis.

II.I. Neuromechanical delay and coupling

For each recording and sEMG lead, NMD was identified as the lag of the maximum in the cross-correlation of sEMG envelopes and P_{mus} [5]. NMC was estimated via a linear model using robust regression. To improve robustness, for NMC estimation, the time integral of only inspirations, identified via airflow, were considered [6].

With thresholds of $P_{mus} < 3$ mbar for insufficient and $P_{mus} > 12$ mbar for excessive effort [1] sEMG was applied as detector using 1.) no correction 2.) correction for NMD, 3.) correction for NMC or 4.) correction for NMD first and NMC second. Lastly, the average NMD and NMC for each channel were applied investigating the possibility of potential standardization, while losing the individual calibration.

III. Results and discussion

The receiver-operator-curves (ROC) for detection of insufficient and excessive effort in either sEMG channel are depicted in Fig. 1. Together with the results for the area under curve (AUC) of each ROC in Table 1 an expected performance gain can be observed for any correcting measure, with the combination of both NMC and NMD reaching the best performance with AUC > 0.95 for either channel in detecting excessive and AUC > 0.85 for insufficient effort.

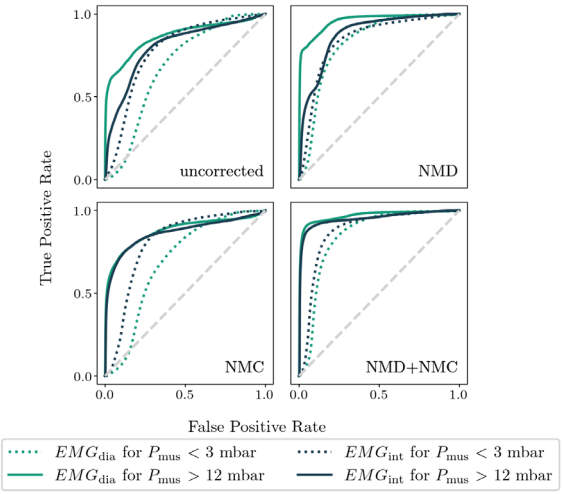

Figure 1: ROCs for detecting insufficient and excessive breathing effort with sEMG corrected for NMD, NMC or both. Applied for diaphragm (blue) and intercostal muscles (green).

Although NMC links the amplitude of sEMG and P_{mus}, correction of NMD resulted in a larger improvement of AUC. Since NMD leads to partly overlapping expiration and inspiration phases between sEMG and P_{mus}, detection performance degrades if not corrected for NMD, even if corrected for NMC.

Table 1: Area under curve (AUC) for excessive and insufficient effort for diaphragm and intercostal sEMG signals.

	AUC (P_{mus} > 12 mbar)		AUC (P_{mus} < 3 mbar)	
	diaphr.	intercost.	diaphr.	intercost.
uncorrected	0.86	0.80	0.68	0.78
NMC	0.87	0.86	0.69	0.81
NMD	0.96	0.88	0.83	0.84
NMC+NMD	0.97	0.95	0.85	0.87

Higher baseline noise in sEMG pressure and sensitivity of both sEMG and P_{es} measurements against movement artifacts may account for the generally lower detection performance for insufficient in either channel. Interestingly, diaphragmatic sEMG consistently outperformed intercostal sEMG for detection of excessive but showed inferior in detecting insufficient effort. This difference may result from more cardiac activity present in the diaphragmatic channel as it is closer to the heart, resulting in decreased performance in detecting low activity near the sEMG baseline.

To investigate standardization capabilities, an averaged NMD of 200 ms (both channels) and NMC of 2.87 mbar/µV for the diaphragm and 3.47 mbar/µV for intercostal muscles were applied, but only resulted in a minor performance increase (AUC < +0.05) for either target and signal. This underlines the variation of NMC and NMD between patients and thus highlight the necessity of individualized correction for NMD and NMC for each patient and recording in clinical use.

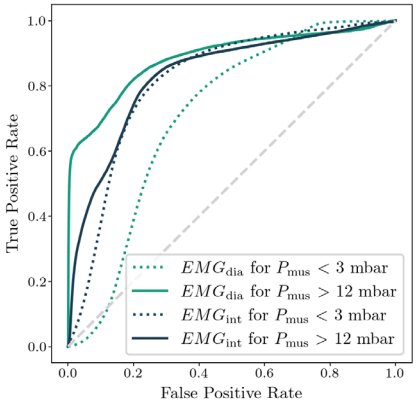

Figure 2: ROC for detecting insufficient and excessive breathing effort in sEMG with an average correction for NMC and NMD.

IV. Conclusions

Excessive and insufficient breathing effort can be reliably detected using respiratory sEMG. Detection performance greatly increased by correcting NMD and NMC, however a standardized approach did not result in relevant improvements. Nonetheless, sEMG might be a viable tool for non-invasively monitoring breathing effort, if calibrated correctly.

Author's Statement

Research funding: The Federal Ministry of Research, Technology and Space (BMFTR) is funding this project: "Verbundprojekt: Protektive Beatmungstherapie basierend auf Elektromyographie (PreVent)", Funding code: 13GW0717B. Conflict of interest: Jan Graßhoff and Philipp Rostalski hold multiple patents with Drägerwerk AG & Co. KGaA and have received research grants and speaking fees from Drägerwerk AG & Co. Informed consent: Informed consent has been obtained from all individuals included in this study. The underlying study was approved by the local ethics committee (EA4/005/19) and registered at the German Clinical Trials Register (DRKS00017138).

References

[1] E. C. Goligher et al., *Lung- and Diaphragm-Protective Ventilation*, American Journal of Respiratory and Critical Care Medicine, vol. 202, no. 7, 2020.

[2] E. C. Goligher et al., *Evolution of Diaphragm Thickness during Mechanical Ventilation. Impact of Inspiratory Effort*, American Journal of Respiratory and Critical Care Medicine, vol. 192, no. 9, 2015.

[3] A. H. Jonkman et al *The oesophageal balloon for respiratory monitoring in ventilated patients: updated clinical review and practical aspects*, European Respiratory Review, vol. 32, no. 168, 2023.

[4] A. H. Jonkman et al., *Analysis and applications of respiratory surface EMG: report of a round table meeting*, Critical Care, vol. 28, no. 1, 2024.

[5] R. Krätschmer et al., *The neuromechanical delay of the quadriceps shortens with increasing contraction intensity*, Scientific Reports, vol. 15, no. 1, 2025.

[6] J. Grashoff et al., *Model-Based Estimation of Inspiratory Effort Using Surface EMG*, IEEE Transactions on Biomedical Engineering, vol. 70, no. 1, 2023.

[7] J. Sauer et al., *Automated characterization of patient–ventilator interaction using surface electromyography*," Annals of Intensive Care, vol. 14, no. 1, 2024.