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Scientific Letter

Signal Filtering in Polygraphy Under Non-Invasive Ventilation: A SomnoNIV Position on AASM Recommendations

Home non-invasive ventilation (NIV) is a standard of care for chronic respiratory failure in conditions like neuromuscular diseases, restrictive disorders, and COPD [1–3]. Monitoring has been recommended during initiation and follow-up. Monitoring setups vary by resources and expertise but typically involves breath-to-breath flow and pressure curves monitored via pneumotachographs, ventilator software, or full polygraphy with effort surrogates like respiratory belts or parasternal electromyography (EMG). Non-invasive measures of blood gases (oxygen saturation, transcutaneous CO_2) and eventually sleep (electroencephalogram – EEG–) are also important [4–7].

Signals like pressure, flow, and belts have high amplitudes and match breathing slow frequencies (0.2–0.3 Hz), while EMG and EEG have smaller amplitudes and much higher frequencies (up to 500 Hz). Sampling frequency, based on the Nyquist theorem [8], and filtering techniques enhance signal readability by isolating relevant data and reducing noise. Low-pass filters (LPF) allow the lower frequencies to pass through while eliminating high-frequency noise, and high-pass filters (HPF) do the opposite, letting higher frequencies pass through while removing drifts and low-frequency artifacts and in high-frequency, low-amplitude waves (EMG, EEG).

The American Association of Sleep Medicine (AASM) guidelines [8] for sleep studies suggests to apply to the flow waveform a high cutoff of LPF at 100 Hz for detecting snoring and a low cutoff of HPF at 0.03 Hz to suppress low-frequency drifts, but these thresholds haven't been validated for polygraphy under non-invasive mechanical ventilation. The objective of the study was to determine whether the filter settings recommended by the AASM for flow-time waveforms result in the loss of critical information about patient–ventilator interactions.

For this study, clinical and bench tracings from a previously validated library were selected to represent the following events:

- Normal tracings: native waveforms acquired at the exit of the ventilator, before intentional leakage.
- Tracings with continuous, intermittent, and asymmetrical unintentional leakage.
- Tracings with partial or complete upper airway obstruction.
- Tracings with asynchronies (ineffective efforts, auto-triggering, double triggering, short and long cycle) non secondary to leaks or obstructions.
- Tracings with artifacts.

The effect of filtering was analyzed separately, three different cut-off points were selected, based on the AASM recommendations: for the HPF (low cutoff), the three cut-off points selected were: 0.02 Hz, 0.03 Hz, and 0.04 Hz and for the LPF (high cutoff), the cut-off points selected were: 25 Hz, 50 Hz, and 100 Hz. Data analysis was performed using a custom-developed MATLAB script based on the Fourier transform. Briefly, the Fourier transform is a mathematical algorithm that converts a time-domain signal (e.g., the flow-time waveform) into its frequency-domain representation, decomposing it into its constituent sinusoidal components. These components are defined by their frequency and amplitude: the frequency indicates the speed of oscillations, while the amplitude reflects the intensity of each frequency component in the original signal (see Figs. E1–E5 to illustrate the decomposition using the Fourier transform).

The main results were as follows: the application of high-pass filters (HPF) resulted in the elimination of frequencies below the cutoff threshold, which had relevant consequences for signal interpretation. Information related to leaks was lost, while false information suggesting air trapping was introduced. Specifically, the drift caused by the continuous flow of intentional expiratory leakage was suppressed (Fig. E1, online supplement), and the upward displacement of flow during unintentional leakage, whether continuous or intermittent, was also eliminated (Figs. E2 and E3). In the case of asymmetric leaks, the suppression of lower frequencies by HPF led to an overestimation of tidal volume and to the appearance of a flow waveform with more negative values at the onset of inspiration, closely resembling air trapping (Fig. E4). Similarly, the squared flow waveform typically associated with leaks [4] was suppressed, being transformed into an exponential shape (Figs. E5 and E6). In contrast, no major distortions were observed when HPF were applied to signals corresponding to obstructions or asynchronies (Figs. E7–E12).

Low-pass filters (LPF), on the other hand, did not introduce major issues when applied to leaks, obstructions, or asynchronies. Their effects were mainly noticeable in signals containing artifacts. Since the cutoff points recommended by the AASM are designed to preserve the snoring signal in diagnostic studies, they were not always effective in eliminating artifacts. In fact, the application of LPF at 100 and 50 Hz did not adequately suppress artifacts, whereas the use of lower cutoffs around 25 Hz proved more effective without altering the morphology of the signal (Figs. E13 and E14).

The main findings are summarized in Table 1.

This study demonstrates the safety of using LPF at frequencies even lower than those recommended by the AASM. However, the use of HPF (lower limit) close to 0 Hz can cause distortions in the flow signal, potentially limiting the interpretation of patient–ventilator interactions, particularly with respect to leaks. In contrast, their influence on other interactions, such as obstructions and asynchronies, appears negligible.

Understanding the differences in the tracings generated in diagnostic sleep studies and polygraphy under ventilation is crucial for interpreting the results. While in diagnostic sleep studies it

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Table 1
Summary of the main findings from applying high-pass and low-pass filters to different patient–ventilator interactions.

Event	Filter	Consequence
No event-Normal tracing	HPF	Intentional leakage suppressed
Increased intermittent leakage	HPF	Upward displacement of the flow suppressed
Asymmetric leakage	HPF	• Overestimation of tidal volume + false air trapping image
Continuous severe leakage	HPF	• Waveform transformed into an exponential shape
Obstructions	HPF	• No effect
Rhythm Asynchronies	HPF	• No effect
Intracycle Asynchronies	HPF	• No effect
Noise	HPF	• No effect
No event-Normal tracing	LPF	• No effect
Increased intermittent leakage	LPF	• No effect
Asymmetric leakage	LPF	• No effect
Massive leakage	LPF	• No effect
Obstructions	LPF	• No effect
Rhythm Asynchronies	LPF	• No effect
Intracycle Asynchronies	LPF	• No effect
Noise	LPF	Cleaned only if LPF < 25 Hz

is important to avoid drifts to facilitate reading, in polygraphy under ventilation, the monitoring system itself imposes a drift even at baseline, which is the intentional leak in single-limb systems. Moreover, the performance of this drift is variable in the most predominant event in NIV, such as leaks. Another noteworthy finding is the modification of the flow waveform in certain situations, which may lead to a false diagnosis of air trapping (characterized by markedly negative flow at the onset of inspiration). The underlying hypothesis for this phenomenon is that the high-pass filter (HPF) attempts to eliminate any drift; in specific scenarios with leakage, the inspiratory portion of the flow (where leakage is greater) may contain a hidden drift that the HPF compensates for. Figs. E2 and E3 clearly illustrate this phenomenon.

Some of the concepts related to filters could also be applicable to built-in software. It has been reported that in cases of asymmetric leakage, there is an overestimation of tidal volume that may even compromise the functioning of pressure systems with assured volume [9,10]. The underlying mechanism for this overestimation could be related to the application of a non-removable HPF close to zero.

The findings of this study also have implications for selecting specific polygraphs for ventilation. Some models may include non-removable electronic high-pass filters (embedded in the hardware) rendering these polygraphs unsuitable for NIV monitoring. Figs. E15 and E16 provide an example and the procedure for its detection.

A limitation of our approach relates to the use of Fourier transformation for signal analysis. Flow signals during non-invasive ventilation are not strictly linear or stationary, and therefore Fourier methods cannot fully represent transient or non-linear phenomena. To mitigate this, we focused our analysis on shorter signal segments to capture specific events under well-defined conditions. Still, this strategy cannot completely overcome the methodological constraints, and we acknowledge that complementary approaches (e.g., wavelet transform) may be more suitable in future studies.

In conclusion, the most prudent recommendation during polygraphy under NIV is to avoid applying HPF to prevent information loss and to use an LPF with a cutoff frequency around 25 Hz and. Additionally, polygraphs with non-removable hardware-implemented HPF should not be used for monitoring patients receiving non-invasive ventilation.

Authors' contributions

- The idea for the manuscript was developed during meetings of the SomnoNIV group.
- ML developed the software for automatic analysis.
- CL and ML wrote the first draft.
- AL, AC, CR, FL, BL, JPJ, JCW, JGB, CLL, and JS contributed substantial intellectual content to the final version.

Use of artificial intelligence

Artificial intelligence was used solely for style and grammar corrections.

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Conflicts of interest

- As president/past president of the French Society of Pneumology (SPLF), JGB has no personal conflicts of interest outside his roles at the university and the SPLF since June 2022. He is the principal investigator of the *Rescue2Monitor* trial (since 2019), sponsored by BREAS, L3 Medical, AIR LIQUIDE, SPLF, and SEPAR.
- The remaining authors declare no conflicts of interest that could directly or indirectly influence the content of this manuscript.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.arbres.2025.09.007.

References

[1] Khan A, Frazer-Green L, Amin R, Wolfe L, Faulkner G, Casey K, et al. Respiratory management of patients with neuromuscular weakness: an American College of Chest Physicians Clinical Practice Guideline and Expert Panel Report. Chest 2023;164:394–413, http://dx.doi.org/10.1016/j.chest.2023.03.011.

[2] Wolfe LF, Benditt JO, Aboussouan L, Hess DR, Coleman JM. ONMAP technical expert panel. Optimal NIV Medicare access promotion: patients with thoracic restrictive disorders: a technical expert panel report from the American College of Chest Physicians, the American Association for Respiratory Care, the American Academy of Sleep Medicine, and the American Thoracic Society. Chest 2021;160:e399–408, http://dx.doi.org/10.1016/j.chest.2021.05.075.

[3] Ergan B, Oczkowski S, Rochwerg B, Carlucci A, Chatwin M, Clini E, et al. European Respiratory Society guidelines on long-term home non-invasive ventilation for management of COPD. Eur Respir J 2019:54, http://dx.doi.org/10.1183/13993003.01003-2019.

[4] Gonzalez-Bermejo J, Perrin C, Janssens JP, Pepin JL, Mroue G, Léger P, et al. Proposal for a systematic analysis of polygraphy or polysomnography for identifying and scoring abnormal events occurring during non-invasive ventilation. Thorax 2012;67:546–52, http://dx.doi.org/10.1136/thx.2010.142653.

[5] Janssens J-P, Borel J-C, Pépin J-L, SomnoNIV Group. Nocturnal monitoring of home non-invasive ventilation: the contribution of simple tools such as pulse oximetry, capnography, built-in ventilator software and autonomic markers of sleep fragmentation. Thorax 2011;66:438–45, http://dx.doi.org/10.1136/thx.2010.139782.

[6] Gonzalez-Bermejo J, Janssens J-P, Rabec C, Perrin C, Lofaso F, Langevin B, et al. Framework for patient–ventilator asynchrony during long-term non-invasive ventilation. Thorax 2019;74:715–7, http://dx.doi.org/10.1136/thoraxjnl-2018-213022.

[7] Sayas J, Lalmolda C, Corral M, Flórez P, Hernández-Voth A, Janssens JP, et al. Measurement of thoraco-abdominal synchrony using respiratory inductance plethysmography: technical aspects and a proposal to overcome its limitations. Expert Rev Respir Med 2024;18:227–36, http://dx.doi.org/10.1080/17476348.2024.2363058.

[8] Berry RB, Budhiraja R, Gottlieb DJ, Gozal D, Iber C, Kapur VK, et al. Rules for scoring respiratory events in sleep: update of the 2007 AASM Manual for the Scoring of Sleep and Associated Events. Deliberations of the Sleep Apnea Definitions Task Force of the American Academy of Sleep Medicine. J Clin Sleep Med 2012;8:597–619, http://dx.doi.org/10.5664/jcsm.2172.

[9] Sogo A, Montanyà J, Monsó E, Blanch L, Pomares X, Lujàn M. Effect of dynamic random leaks on the monitoring accuracy of home mechanical ventilators: a bench study. BMC Pulm Med 2013;13:75, http://dx.doi.org/10.1186/1471-2466-13-75.
[10] Luján M, Sogo A, Grimau C, Pomares X, Blanch L, Monsó E. Influence of dynamic leaks in volume-targeted pressure support noninvasive ventilation: a bench study. Respir Care 2015;60:191–200, http://dx.doi.org/10.4187/respcare.03413.

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