Journal of Mechanical Ventilation

Positive end-expiratory pressure as a potential modulator of patient-ventilator interaction: A physiological perspective

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DOI: https://doi.org/10.53097/JMV10151

Cite: Gallardo A. Positive end-expiratory pressure as a potential modulator of patient-ventilator interaction: A physiological perspective. J Mech Vent 2026; 7(2):58-68.

Abstract

Background
Patient–ventilator dyssynchrony is a frequent and clinically relevant phenomenon during mechanical ventilation and has been associated with increased work of breathing, longer duration of ventilation, and worse outcomes. Although positive end-expiratory pressure (PEEP) is a cornerstone of ventilatory management to improve oxygenation and alveolar stability, its potential role in modulating of patient–ventilator interaction patterns and dyssynchrony has received comparatively little attention.
Objective
To provide a narrative review of the physiological mechanisms by which PEEP may influence patient–ventilator interaction patterns and dyssynchronies, integrating the available clinical and experimental evidence, including indirect data derived from studies on respiratory mechanics, auto-PEEP, and ventilatory interaction.
Methods: A non-systematic narrative review of the literature was conducted, focusing on studies addressing patient–ventilator interaction, auto-PEEP, respiratory mechanics, and the clinical consequences of dyssynchrony. When direct evidence linking PEEP to specific patterns of dyssynchrony was lacking, physiological inferences were drawn from related studies, and the rationale for these extrapolations is explicitly discussed.
Results
PEEP influences key determinants of patient–ventilator interaction, including end-expiratory lung volume, transpulmonary pressure, inspiratory threshold load, and expiratory time. Appropriately titrated PEEP may reduce ineffective efforts by partially counterbalancing intrinsic PEEP, stabilizing alveolar units, and attenuating excessive inspiratory effort. Conversely, excessive or insufficient PEEP may exacerbate dyssynchrony by promoting air trapping, flow limitation, or premature cycling. Although most of the available evidence is indirect, consistent physiological principles support a significant modulatory role of PEEP in the development and resolution of various patient-ventilator interaction patterns and dyssynchronies.
Conclusion
PEEP should be considered not only as a tool for oxygenation and respiratory mechanics, but also as a potential modulator that should be personalized to improve patient-ventilator interaction. Prospective studies specifically designed to evaluate the impact of PEEP on dyssynchrony are needed to guide more individualized ventilatory strategies.

Keywords: PEEP, Dyssynchronies, Patient-Ventilator Interactions

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Conflict of interest/Disclosures: None

Introduction

The interaction between the patient and the mechanical ventilator is a critical determinant of the effectiveness and tolerability of ventilation in critically ill patients. Mechanical ventilation, particularly in assisted modes, requires adequate synchronization between the patient's respiratory activity and the ventilator's performance to achieve effective ventilation and reduce the work of breathing. When a mismatch exists between the patient's requirements and the ventilator's response, what is known as patient–ventilator interaction (PVI) dyssynchrony occurs. This condition may involve discrepancies in timing, flow, volume, and/or pressure between the patient's effort and the ventilator's actions. Such mismatch occurs with highly variable frequency, with reported rates ranging from 10% to 85% of mechanically ventilated patients, depending on the diagnostic criteria and measurement techniques used, and may include events such as ineffective efforts, auto-triggering, double triggering, and premature or delayed cycling, among other forms of PVI patterns. [1]

Positive end-expiratory pressure (PEEP) is a fundamental parameter in mechanical ventilation with a well-recognized impact on lung mechanics and oxygenation. PEEP can keep alveoli open at the end of expiration, increase functional lung volume, and prevent atelectasis. However, its role in modulating patient–ventilator interaction and particularly in the development or resolution of dyssynchronies has received comparatively less attention in the scientific literature. The aim of this work is to synthesize the available evidence on how PEEP may influence the occurrence, patterns, and consequences of dyssynchronies, integrating solid physiological principles with relevant clinical findings.

Applied PEEP generates a positive pressure that is maintained at the end of expiration. This pressure can improve the distribution of ventilation and reduce intrapulmonary shunt, resulting in improved oxygenation and carbon dioxide elimination. However, by increasing end-expiratory lung volume (EELV), PEEP also modifies the mechanical starting point from which the patient initiates the next inspiratory effort, thereby altering overall respiratory mechanics, diaphragmatic workload, and interaction with the ventilator.

Studies selection and eligibility criteria

This narrative review is based on a targeted literature search focused on clinical and physiological studies evaluating the impact of Positive End-Expiratory Pressure (PEEP) on patient-ventilator interaction. A search in PubMed and Google Scholar was conducted for relevant articles published up to December 2025. Search terms included "PEEP," "asynchrony," "dyssynchrony," "work of breathing," "triggering," and "intrinsic PEEP."

Given the physiological nature of this review, studies were primarily selected based on their contribution to the understanding of the mechanical underpinnings of dyssynchrony. Inclusion criteria were focused on seminal bench studies and clinical reports that provided high-fidelity physiological measurements (e.g., esophageal pressure monitoring, flow-time waveform analysis, or diaphragmatic electrical activity), and studies specifically evaluating the modulatory effect of PEEP on the different phases of the respiratory cycle (triggering, inspiration, and cycling).

Exclusion criteria were applied to maintain a narrow focus on interaction mechanics; therefore, we excluded studies that addressed PEEP solely in the context of oxygenation or ARDS mortality without analyzing patient-ventilator interaction, were purely epidemiological or observational without reporting physiological variables, and were published in languages other than English or Spanish.

This expert-based selection was intended to ensure that the evidence discussed provides a robust framework for the physiological insights presented, prioritizing mechanistic clarity over a systematic exhaustive tabulation of the literature.

Pathophysiological bases of PEEP and dyssynchrony

Patient–ventilator dyssynchronies, on the other hand, result from a mismatch between the patient's neural respiratory drive and the ventilator's mechanical response. This mismatch may arise from factors related to ventilator settings (e.g., trigger sensitivity, inadequate flow delivery, or inappropriate inspiratory time), patient-related factors (e.g., altered respiratory drive due to sedation, increased airway resistance, or respiratory muscle dysfunction), or a combination of both. The literature describes multiple forms of dyssynchrony, including ineffective triggering, premature or delayed cycling, auto-triggering, and reverse triggering, among other entities, all of which may negatively impact patient comfort and ventilatory efficiency. [1]

It is important to note that, although there is a limited number of clinical studies specifically designed as controlled trials to examine the direct impact of different PEEP levels on the frequency and types of dyssynchronies, physiological understanding and several studies some of them related to the presence of auto-PEEP or expiratory flow dynamics allow relevant mechanisms and clinical effects to be inferred.

Auto-PEEP, for example, is a condition in which air exhalation is insufficient before the onset of the next inspiration. This situation leads to an elevated residual pressure at end expiration that is not attributable to the PEEP set on the ventilator. This condition is particularly prevalent in patients with expiratory flow limitation, such as those with chronic obstructive pulmonary disease (COPD), and may precipitate dyssynchronies, mainly ineffective efforts, because the patient must initially overcome this residual pressure to initiate a new inspiratory cycle. This phenomenon is commonly referred to as elastic threshold load and increases respiratory effort if not appropriately addressed with adequate PEEP.

Impact of peep on dyssynchronies

To understand how PEEP may influence the development or resolution of patient-ventilator interactions, it is useful to analyze the various dyssynchrony phenomena considering ventilatory physiology and the effects of PEEP on respiratory mechanics. Although clinical studies directly investigating the effects of PEEP are limited, indirect and physiological evidence exists that allows inference of how PEEP may interact with each type of patient-ventilator interaction patterns.

Effects of PEEP on trigger dyssynchronies

In dyssynchronies related to ventilator triggering, one of the main physiological mechanisms contributing to ineffective efforts is the presence of auto-PEEP. When a patient with auto-PEEP attempts to initiate an inspiration, alveolar pressure must first be reduced to reach the ventilator's trigger threshold. This phenomenon creates a higher effective inspiratory threshold load and may result in many efforts not being detected by the ventilator, leading to ineffective efforts or delays in the initiation of support (delayed triggering). Classic studies have documented that the application of external PEEP in patients with auto-PEEP can reduce the elastic threshold load, thereby facilitating ventilator triggering, provided that the set PEEP is approximately 80% of the measured auto-PEEP. These findings suggest that an optimized PEEP level reduces the time-delay between diaphragmatic effort and the onset of mechanical support. [2,3] This observation has been described in physiological studies showing that external PEEP can partially "counterbalance" auto-PEEP and reduce the work of breathing; however, these results derive from patients under controlled ventilation without active spontaneous breathing and therefore require cautious extrapolation. [4]

Therefore, although randomized trials in patients with dyssynchrony directly comparing different PEEP levels to correct ineffective efforts are lacking, the physiological principles derived from studies on auto-PEEP indicate that an appropriate level of external PEEP can reduce inspiratory threshold load and, consequently, decrease ineffective efforts and delayed triggering (Figure 1), which would translate into a lower incidence of this type of PVI pattern.

However, the clinical translation of these physiological advantages remains a subject of ongoing investigation. Recently, Sottile et al. [5] evaluated the effect of PEEP titration on asynchrony prevalence in a heterogeneous cohort of critically ill patients. Their findings indicated that increasing PEEP did not result in a significant reduction of the overall asynchrony index. This suggests that while PEEP can effectively mitigate specific mechanisms like the inspiratory threshold load related to auto-PEEP, its impact on the total burden of dyssynchrony may be limited by the coexistence of multiple phenotypes and the complexity of the patient's respiratory drive in clinical settings.

In clinical scenarios where auto-triggering is observed, proper PEEP titration may also have a significant clinical impact. Increasing PEEP appears to exert a stabilizing effect on the respiratory system, acting as an effective preventive mechanism against auto-triggering. Research has shown that elevating PEEP increases the baseline circuit pressure, making it more difficult for unwanted pressure and flow oscillations particularly those of cardiogenic origin or produced by condensation in the tubing—to reach the trigger sensitivity threshold. Consequently, PEEP may reduce the incidence of erroneous mechanical cycles, allowing for a more precise interaction without the need for excessively high sensitivity settings that could increase the patient's work of breathing. [6]

Work shifting and dynamic flow mismatch

A more mechanistically accurate concept than "flow insufficiency" is work shifting, which refers to the redistribution of inspiratory work between patient and ventilator when delivered assistance does not match neural demand. In volume-controlled modes, flow is preset and pressure adapts, whereas in pressure-controlled modes pressure is preset and flow results from the interaction between pressure and respiratory mechanics. By increasing end-expiratory alveolar pressure, PEEP may modify the dynamic mechanics of the respiratory cycle, optimizing the shape of the flow waveform (when pressure-controlled continuous mandatory ventilation is used) and influencing how the ventilator perceives the patient's effort. Although no clinical trials have directly evaluated whether different PEEP levels modify the incidence of this form of dyssynchrony, principles of patient–ventilator interaction suggest that PEEP adjustment may influence the balance between patient flow demand and ventilator flow delivery, particularly when respiratory mechanics are altered by conditions such as hyperinflation or partial alveolar collapse. Mancebo et al. describe how intrinsic PEEP acts as an elastic threshold load that delays flow delivery. In this context, optimizing external PEEP reduces the work performed by the diaphragm before the ventilator responds, thereby mitigating the periods of work shifting that occur during the trigger delay and improving overall synchrony. [2] In this regard, review studies on the management of dyssynchronies indicate that fine adjustments of ventilatory parameters—including inspiratory time and level of support—are commonly used to correct flow-related dyssynchronies, with PEEP constituting a potential component of this integrative ventilatory adjustment, even when not examined as an isolated variable. [7]

In addition to the mechanical aspects of synchrony, the clinical relevance of optimizing PEEP lies in protecting the respiratory muscles. As described previously, the diaphragm is often 'caught in the cross-fire' between systemic inflammation and mechanical stress. Inadequate PEEP levels that fail to counteract intrinsic loads can exacerbate diaphragmatic work-shifting and eccentric contractions, contributing to ventilator-induced diaphragmatic dysfunction (VIDD) and subsequent weaning failure. [8]

These effects remain physiologically plausible but have not been directly quantified in controlled clinical studies.

Early or late cycling

The timing of the transition from inspiration to expiration is primarily determined by operator-set parameters; however, PEEP significantly modulates this interaction by altering end-expiratory volume and lung mechanics. In pressure-targeted modes, PEEP level influences the time required to reach the cycling threshold by modifying the respiratory system's time constants. Specifically, inadequate PEEP may reduce lung compliance and shorten these constants, often precipitating premature cycling. Conversely, excessive PEEP can prolong expiratory time constants and promote dynamic hyperinflation, which favors delayed cycling. While physiological evidence suggests that an optimized PEEP level improves lung volume stability and reduces inappropriate cycling events, much of this understanding stems from clinical observations of respiratory mechanics rather than trials specifically designed to measure dyssynchrony as a primary outcome.

In patients with airflow limitation, PEEP plays an even more critical role in preventing delayed cycling. In these cases, the presence of intrinsic PEEP (PEEPi) generates an additional elastic load that not only hinders triggering but also slows the decay of inspiratory flow toward the programmed cycling threshold. Under these conditions, the mechanical inspiratory time exceeds the neural effort, potentially forcing the patient into an active expiratory muscle contraction before the insufflation phase ends. By counteracting the level of PEEPi, the application of extrinsic PEEP helps reduce air trapping and normalizes expiratory flow kinetics, facilitating a more synchronous transition toward exhalation. This intervention, when combined with adjustments to the cycling criterion (e.g., increasing the flow-cycle threshold from 25% to 40-50%), can mitigate the complications of active expiration and significantly reduce the imposed work of breathing during the late inspiratory phase. [9]

Reverse triggering and PEEP

Phenomena such as reverse triggering—where the ventilator induces a neural inspiratory effort that is out of phase with the ventilatory cycle—have been described particularly in sedated patients or in those with altered breathing patterns. Although the specific literature is still emerging and the underlying physiological mechanisms are not yet fully elucidated, it has been proposed that ventilatory settings, including PEEP, may influence the neural–mechanical interaction of the respiratory cycle. Studies describing reverse triggering emphasize the complexity of these interactions and the need to tailor ventilatory parameters to minimize such phenomena, although there is no direct evidence linking specific PEEP levels to changes in the prevalence of reverse triggering. [10] This interaction is thought to be mediated by the entrainment of the respiratory centers, where the mandatory breath triggers a reflex neural response, potentially linked to the activation of pulmonary stretch receptors and the Hering-Breuer reflex. [11]

In this context, PEEP may modulate the frequency and pattern of reverse triggering by stabilizing the functional residual capacity (FRC) and altering regional lung mechanics. Inadequate PEEP levels can lead to alveolar cyclic collapse and mechanical instability, which may disturb sensory feedback to the brainstem and facilitate reflex inspiratory efforts. Conversely, excessive PEEP leading to overdistension could theoretically influence pulmonary stretch receptor activity and thereby modulate neural respiratory timing. However, optimized PEEP may improve lung compliance and reduce regional heterogeneity, potentially stabilizing the stretch receptor activation threshold. The response to PEEP adjustments remains highly variable; while increasing PEEP could theoretically suppress reverse triggering by maintaining a higher end-expiratory lung volume thereby inhibiting the inspiratory drive, it may also be insufficient to break an established 1:1 or 1:2 entrainment pattern without concurrent adjustments in sedation or tidal volume. Consequently, PEEP should be viewed as a potential modulator within a comprehensive strategy to minimize reverse triggering and its associated complications, such as breath stacking and increased pendelluft flow.

Clinical evidence and consequences of dyssynchronies

Several studies have documented that the presence of patient–ventilator dyssynchrony is associated with adverse clinical outcomes. [12,13] The asynchrony index (AI), an indicator that quantifies the proportion of dyssynchronous events relative to the total respiratory rate, has shown that high values are associated with prolonged mechanical ventilation and longer stays in the intensive care unit. For example, prospective studies have observed that approximately 46–48% of mechanically ventilated patients exhibit severe dyssynchrony, defined by an AI >10%, with ineffective efforts and cycles with insufficient flow among the most frequent findings.

These dyssynchronies have been associated with abnormalities in arterial blood gases and with negative impacts on respiratory parameters and possibly on the duration of mechanical ventilation, although a causal relationship has not yet been fully established and may be influenced by multiple concomitant clinical factors. [14]
The literature also indicates that recognition and management of dyssynchrony can improve clinically relevant parameters. Specific protocols for monitoring and addressing dyssynchrony have shown in controlled studies that their implementation is associated with a reduction in the duration of mechanical ventilation, shorter ICU stays, and higher rates of successful weaning, which indirectly supports the importance of optimizing patient–ventilator interaction. Although these studies did not focus exclusively on PEEP as an isolated element, they highlight the importance of a global adjustment of ventilatory parameters to improve synchrony. [15]
The physiological mechanisms and the current strength of evidence for PEEP as a modulator of different dyssynchrony patterns are summarized in Table 1.

Future perspectives

The field of patient–ventilator interaction continues to evolve. A major limitation of the current evidence is the lack of controlled studies that directly evaluate the impact of specific PEEP levels on the prevalence and types of dyssynchrony (Table 2). Most conclusions are based on physiological principles extrapolated from research on auto-PEEP, respiratory mechanics, and the clinical management of dyssynchrony. Future studies should ideally include prospective designs that assign different PEEP strategies and systematically measure the occurrence of dyssynchrony using standardized methods such as the AI and ventilator waveform analysis, as well as the assessment of auto-PEEP and other respiratory mechanics parameters. In addition, the implementation of emerging technologies such as artificial intelligence algorithms for automated detection of dyssynchrony could enable more robust studies that are less dependent on subjective clinical interpretation. Finally, personalization of PEEP based on individual patient mechanical characteristics integrating measurements such as esophageal pressure or electrical impedance tomography to guide titration represents a promising area of research that could optimize both oxygenation and synchrony. [16]

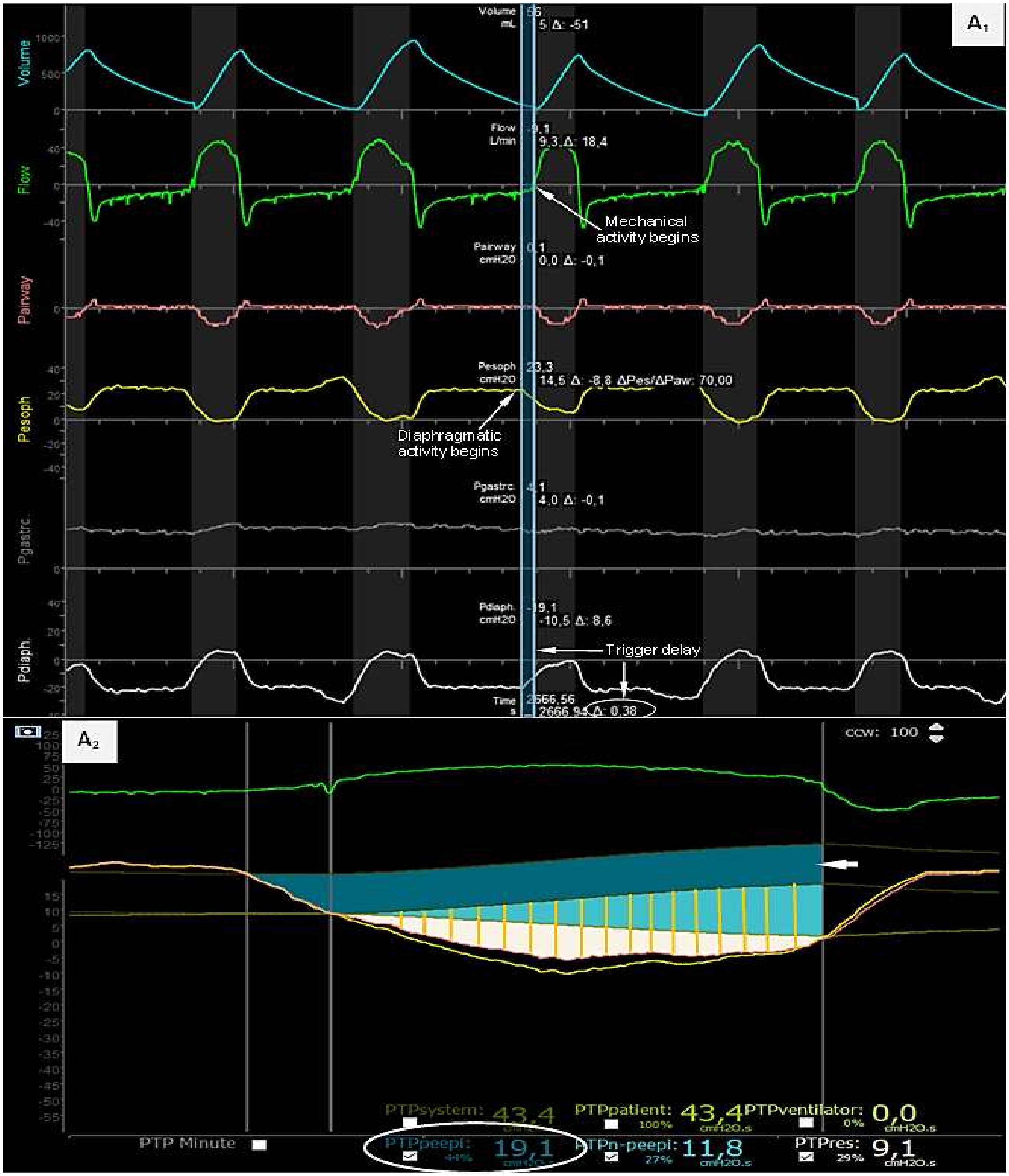

Figure 1. Trigger delay secondary to inadequate PEEP setting. In Image A1, the patient exhibits an inspiratory effort that is 'rewarded' with a delay by the ventilator. The presence of intrinsic elastic threshold load (white arrow in Figure A2) hinders the transmission of the pressure generated by the diaphragm to the airway; consequently, the opening of the inspiratory valve is activated late. This excessive effort is reflected in the detailed work of breathing values, where a total PTP of 43.4 cmH_2O/seg is observed, corresponding entirely to the patient's effort. Notably, 44% of that total effort (19.1 cmH_2O) is performed solely to reach the trigger threshold (the ventilator only responds once this threshold is met). The area marked with lines represents the non-PEEP associated elastic work (11.8 cmH_2O) and the remaining resistive work (9.1 cmH_2O).

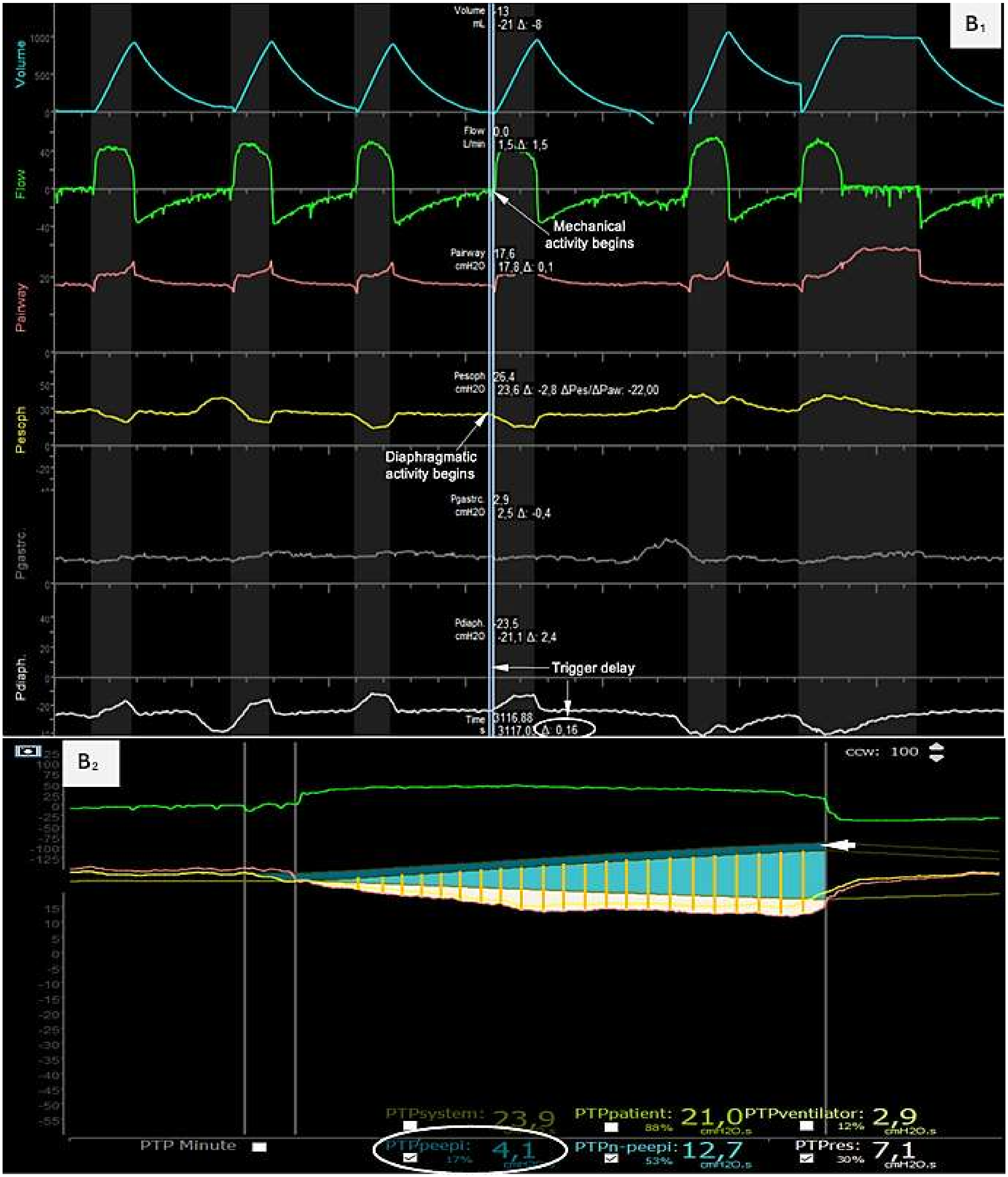

Figure B1 illustrates an increase in PEEP (18 cmH_2O) and a significant reduction in trigger delay (0.16 sec). The PEEP adjustment substantially reduces the intrinsic elastic threshold load (white arrow, Figure B2) and the patient's work of breathing (PTP 21.0 cmH_2O/seg). Furthermore, there is a marked decrease in the effort required to counteract this initial load, which now represents only 17% of the total respiratory work (4.1 cmH_2O/seg). Pairway: airway pressure. Pesoph: esophageal pressure. Ptransp: transpulmonary pressure. PTPpeepi: pressure-time product associated to intrinsic PEEP. PTPn-peepi: pressure-time product non-associated to intrinsic PEEP. PTPres: resistive pressure-time product.

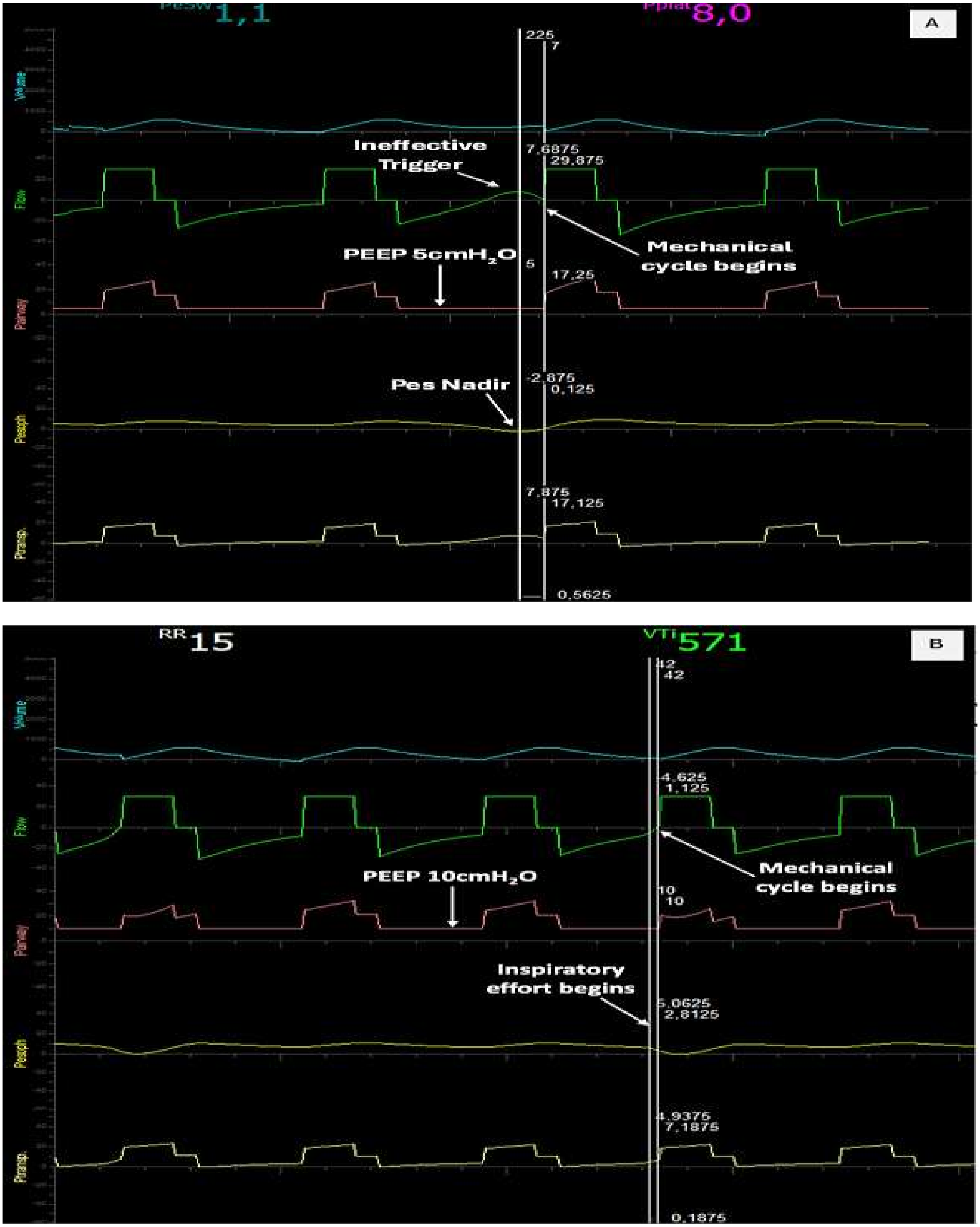

Figure 2: Panel A shows an ineffective trigger secondary to incorrect trigger sensitivity settings and low PEEP levels. Upon adjusting the ventilatory parameters (PEEP and trigger), a better mechanical response to diaphragmatic effort is observed, demonstrating effective triggering and a significant reduction in mechanical response time (Panel B). Pairway: airway pressure. Pesoph: esophageal pressure. Ptransp: transpulmonary pressure.

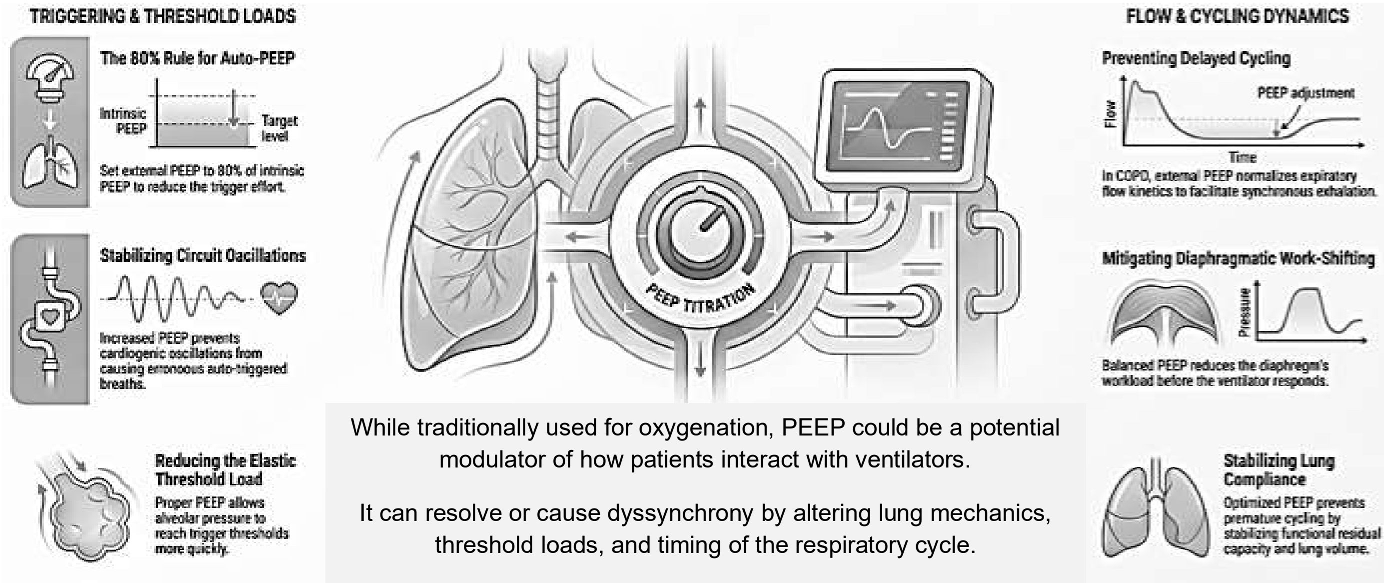

Table 1: Summary of PEEP effects on respiratory dyssynchronies: proposed mechanisms and strength of clinical evidence

Dyssynchrony Type	Suggested PEEP Mechanism	Evidence Strength	Reference
Ineffective Effort / Delayed Trigger	Reduces elastic threshold load by counteracting intrinsic PEEP in obstructed patients.	Strong (Direct physiological evidence)	Mancebo J, et al. [2]
Auto-triggering	Increases system stability; higher PEEP can dampen circuit oscillations that prematurely trigger the breath.	Moderate (Clinical observation / Bench studies)	Imanaka H, et al. [6]
Double Triggering	Prevents recruitment/derecruitment cycles and improves EELV, potentially stabilizing neural inspiratory time.	Low/Moderate (Indirect evidence)	Thille AW, et al. [12]
Work Shifting	Improves lung compliance and functional residual capacity, potentially reducing the initial peak flow demand.	Moderate (Physiological rationale)	Mancebo J, et al. [2]
Early Cycling (Premature Exhalation)	By increasing EELV and alveolar stability, PEEP may lengthen the neural inspiratory time in some phenotypes.	Low (Mainly mechanistic inference)	Gentile MA. [9]

Table 2: Mechanistic role of PEEP in different types of Patient–Ventilator Dyssynchrony. PEEP: positive end-expiratory pressure. * Optimization refers to physiologically titrated PEEP adjusted according to intrinsic PEEP, compliance, and dynamic mechanics

Type of Dyssynchrony	Dominant Mechanism	Physiological Role of PEEP	Direct Evidence	Indirect / Physiological Evidence
Ineffective efforts / Delayed triggering	Increased inspiratory threshold load due to intrinsic PEEP (auto-PEEP)	External PEEP may partially counterbalance intrinsic PEEP, reduce elastic threshold load and facilitating trigger detection when appropriately titrated (~80% of measured auto-PEEP)	No randomized trials specifically evaluating PEEP titration for dyssynchrony correction	Physiologic studies on auto-PEEP demonstrating reduced work of breathing with applied external PEEP [2-4]
Auto-triggering	Excessive trigger sensitivity, circuit leaks, or cardiogenic oscillations	PEEP may influence baseline pressure stability but does not directly correct the primary mechanism	No direct studies linking PEEP level to incidence of auto-triggering	Physiological understanding of trigger mechanics and baseline pressure effects
Work shifting (dynamic flow mismatch)	Mismatch between neural inspiratory demand and delivered mechanical assistance; redistribution of inspiratory work between patient and ventilator	By modifying end-expiratory lung volume and compliance, PEEP alters the pressure–flow relationship and may influence the balance of inspiratory workload between patient and ventilator	No clinical trials isolating PEEP effect on work shifting	Physiological principles of pressure–flow interaction and compliance-dependent flow dynamics [2,7]
Early cycling	Shortened time constant ($\tau = R \times C$), reduced compliance, early termination of inspiratory flow	Low PEEP may reduce compliance and shorten time constants, promoting premature cycling; adequate PEEP may stabilize lung units and normalize cycling	No direct interventional studies focused on PEEP and cycling dyssynchrony	Physiological interaction between compliance, time constants, and flow-cycling criteria
Delayed cycling / Dynamic hyperinflation	Prolonged expiratory time constant, air trapping, increased intrinsic PEEP	Excessive PEEP may prolong expiratory time constants, increase air trapping, and favor delayed cycling or dynamic hyperinflation	No direct randomized data	Studies on hyperinflation and auto-PEEP physiology; threshold load dynamics
Reverse triggering	Neural–mechanical entrainment between ventilator-delivered breath and patient respiratory drive	PEEP may influence neural–mechanical coupling by modifying lung stretch and phase relationships; excessive PEEP may activate pulmonary stretch receptors and alter neural timing	No direct evidence linking specific PEEP levels to reverse triggering prevalence	Observational studies describing reverse triggering mechanisms [9] neurophysiological principles of stretch receptor activation
High Asynchrony Index (>10%)	Aggregated burden of multiple dyssynchrony mechanisms	PEEP optimization* may reduce certain trigger-related dyssynchronies but does not address all mechanisms contributing to AI	Association studies linking high AI with prolonged ventilation and mortality [11,12]	Observational outcome studies on dyssynchrony burden and ventilator outcomes [13]

Conclusions

Current physiological rationale and indirect evidence suggest that PEEP could acts as a potential modulator of patient–ventilator interaction. Based on this rationale, PEEP should be conceptualized as a dynamic regulator of neural–mechanical coupling and patient–ventilator interaction, rather than merely as an oxygenation or mechanical parameter. Ignoring its role in dyssynchrony may lead to incomplete ventilatory optimization. PEEP is an essential component of mechanical ventilation that not only affects oxygenation and lung mechanics but may also influence patterns of patient–ventilator interaction and the occurrence of dyssynchrony. Although there is no direct evidence from clinical trials evaluating the impact of specific PEEP levels on the frequency and types of dyssynchrony, respiratory physiology and studies on auto-PEEP suggest that careful adjustment of PEEP may reduce elastic threshold load, improve ventilator triggering, and potentially decrease certain types of dyssynchrony. Moreover, the application of structured dyssynchrony management strategies has demonstrated clinically relevant benefits, underscoring the importance of considering patient–ventilator interaction when titrating PEEP and other ventilatory parameters. Further research is needed to more clearly define the direct effects of PEEP on synchrony and patient–ventilator interaction. This conceptual framework should be interpreted as physiologically grounded but hypothesis-generating, pending direct interventional validation.

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