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ORIGINAL

Consensus on identifying and ranking ventilator asynchronies in invasively ventilated ICU patients: a modified Delphi study (SYNAPsE)

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Abstract

Purpose: Despite extensive research, it remains unclear which patient–ventilator asynchronies are reliably detectable in clinical practice, most clinically relevant, and how they rank in severity.

Methods: Multiple-choice questions and 5-point Likert-scale statements were used in iterative Delphi rounds. Feedback was incorporated until stable consensus or dissensus was reached for all items. First series of rounds focused on identifying and classifying patient–ventilator asynchronies detectable from ventilator waveforms, second series assessed their associations with outcomes in three patient groups, and in the final rounds, asynchronies were ranked by severity within these patient groups and across three scenarios.

Results: In total, 11 panelists completed nine rounds. Consensus classified ineffective triggering, reverse triggering, double triggering, auto-triggering, insufficient flow, premature cycling, and delayed cycling as clinically relevant patient–ventilator asynchronies. Of these, auto-triggering and delayed cycling were deemed unlikely to be detectable using ventilator waveforms alone. Across all three patient groups, the panelists reached consensus that double triggering and ineffective triggering were the most clinically relevant. In acute respiratory distress syndrome, double triggering, ineffective triggering, and reverse triggering were all judged clinically relevant. In patients without acute respiratory distress syndrome and after cardiac surgery, asynchronies were classified as severe or mild and combined into two composite groups.

Conclusion: This Delphi study provides a consensus-based framework for identifying and ranking patient–ventilator asynchronies at the bedside, highlighting those most likely to be clinically relevant and offering a structured approach to support monitoring, intervention, and future research.

Keywords: Intensive care unit, Critical care, Mechanical ventilation, Invasive ventilation, Patient–ventilator asynchrony, Patient–ventilator dyssynchrony, PVA, Delphi

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Introduction

Patient–ventilator asynchronies (PVAs) are common in invasively ventilated critically ill patients and associated with higher mortality, prolonged ventilation, and hemodynamic instability [1–5]. Despite their importance, PVAs are frequently overlooked due to the complexity of their patterns, and the need for continuous, careful waveform monitoring, and their classification remains challenging [6], although focused training can improve recognition and management by all involved healthcare professionals [7–9]. Accurate identification can require additional monitoring such as esophageal pressure measurements, but in routine practice, clinicians must rely almost exclusively on standard ventilator waveforms, which limits the precision with which many PVAs can be recognized.

Evidence indicates that ineffective triggering and double triggering are most strongly associated with worse outcomes [10–13]. However, findings about the clinical relevance of PVAs are inconsistent, consensus remains lacking, and clearer guidance is urgently needed to move the field forward. The clinical impact of other PVAs has been studied only to a limited extent. Composite measures, such as the asynchrony index, integrate information and provide an overall severity of the occurrence of PVAs, but can obscure the contribution of individual PVAs [14–17]. Establishing a hierarchy of severity could enhance clinical relevance and enable refined statistical analyses, such as the win–ratio approach, which analyses composite endpoints by applying a hierarchical ranking to their components [18–20].

To reduce bias inherent in unstructured consensus [21, 22], we conducted a Delphi study with three aims: to identify PVAs detectable from ventilator waveforms alone, to determine which PVAs are most likely associated with adverse outcomes across three different patient groups, and to establish a hierarchy of PVAs based on considered severity and clinical context.

> **Take-home message**
>
> This international Delphi study addresses major knowledge gaps in patient–ventilator asynchrony by generating consensus on identification, associations with outcomes, and prioritization. It defines which asynchronies can be reliably detected from standard ventilator waveforms, which are most clinically relevant, and establishes a severity hierarchy in across three patient groups. These findings provide a structured framework to improve bedside monitoring, guide the prioritization of asynchronies during ventilation, and support future research.

Methods

Design and panelists

This Delphi study, titled 'StudY for coNsensus on Asynchrony in invasively ventilated PatiEnts' (SYNAPsE), invited 12 international clinicians with extensive experience in mechanical ventilation and PVA research (Supplemental Table S1), hereafter referred to as panelists, who were invited to participate via email. Given the complexity and specialized nature of the topic, patient or public involvement was not considered appropriate. As this was a qualitative expert–opinion Delphi study without patient involvement, and without human data or biological specimens through which individuals could be identified, formal ethical approval was not sought. Panelists participated anonymously and could not be identified from their responses. The Delphi process was overseen by an experienced consensus–methodologist (PN). The study's methodology and results are reported in accordance to the ACcurate COnsensus Reporting Document (ACCORD) guidelines (Supplemental Table S2) [23].

Delphi rounds

A focused literature search on PVA identification, classification, and outcome associations guided the development of the questionnaire, and the results of this search were shared with panelists during the Delphi rounds (Supplemental Table S3). Delphi rounds were conducted via online questionnaires on Google™ Forms. Statements appeared as multiple–choice questions or on a 5-point Likert scale, with scores of 1 and 2 representing disagreement (or unlikely) and scores of 4 and 5 representing agreement (or likely), with 3 being neutral.

Additional feedback from the panelists was gathered through free-text responses provided after each statement and in the comment sections of each round. Panelists voted anonymously, and their anonymous comments and responses were included in iterative reports without any identifying information. Engagement of the panelists was ensured through strict timelines and periodic reminders via multiple communication methods.

The Delphi study comprised three series with multiple rounds (Supplemental Figure S1). The first series focused on identifying and classifying PVAs detectable using ventilator waveforms alone, in the absence of esophageal pressure. The second series explored consensus on the association between specific PVAs and adverse outcomes, namely duration of ventilation and mortality, in patients with acute respiratory distress syndrome (ARDS). For patients without ARDS, consensus was sought on the impact of PVAs on ventilation duration and patient discomfort, while in post-cardiac surgery patients, the outcomes of interest were discomfort and hemodynamic instability. The final series sought consensus on severity of PVAs, ranking them across the three patient categories and three clinical scenarios: (1) undetected and unresolved PVAs: PVAs of high intensity, defined as occurring with high frequency (asynchrony index > 10%) or over a prolonged duration (e.g., at least 8 h in a 24-h period), that remains undetected and is not addressed; (2) identified and resolved PVAs: PVAs of high intensity (as defined above), which is detected and successfully addressed after applying an appropriate intervention, and (3) PVAs persisting despite intervention: PVAs of high intensity (as defined above) that is detected but not adequately resolved despite appropriate interventions being applied.

Consensus and stability

Consensus was predefined as ≥ 70% of votes for any option in multiple-choice questions and as disagreement (or unlikely) or agreement (or likely) on Likert-scale questions [22]. Questions were carried forward in iterative Delphi rounds until the responses demonstrated stability, and fewer than two of panelists suggesting changes or modifications. The Delphi rounds were continued until all questions reached stability. Position statements were then drafted from the questions that reached consensus and stability. All panelists reviewed these position statements, together with the identified knowledge gaps and research priorities requested at the end of the Delphi process.

Statistical analysis

Descriptive analysis was conducted to calculate the percentage votes for all questions after each round. The median (interquartile range [IQR]) was used to evaluate the dispersion of responses. Stability of responses between two consecutive rounds was assessed using the Chi-square test for multiple-choice questions, and the Kruskal–Wallis test for Likert-scale questions [22].

The statistical analysis was performed using Microsoft Excel (Microsoft 365, v16.0, Microsoft Corp, WA, USA). When appropriate, hierarchical clustering analysis of votes for questions was conducted to assess the strength of voting, using R statistics version 4.0.4 (Core Team, Vienna, Austria, 2021). A p value ≥ 0.05 indicated stability.

Results

Of 12 invited panelists, 1 did not respond; and 11 participated in all Delphi rounds conducted between August 2024 and April 2025. The median age was 49 (IQR 37–59) years, six (55%) were female, and two (18%) were from middle-income countries, representing three continents. All but one was university-affiliated, with a median of 17 years (IQR 8–30) of experience. Stability was achieved for all statements (Supplemental Table S4), with consensus initially reached for nine statements. Two virtual meetings following rounds five and eight helped resolve disagreements and defined the final series for the severity-ranking strategy, ultimately leading to consensus (Supplemental Figure S1). Detailed reports of each round are provided in the appendix (Supplemental File 2).

All events except excessive flow were classified as PVAs: ineffective triggering, reverse triggering, double triggering, auto-triggering, insufficient flow, premature cycling, and delayed cycling. Consensus was unanimous that double triggering can be identified from ventilator waveforms alone, and 73% of panelists agreed that this also applies to ineffective triggering, reverse triggering, insufficient flow, and premature cycling (Fig. 1). No consensus was reached on defining excessive flow as a PVA, as it was considered a ventilator setting that may lead to PVAs rather than a PVA itself. In patients with ARDS, consensus identified double triggering, ineffective triggering, and reverse triggering as the most clinically relevant, given their association with higher mortality and prolonged ventilation (Fig. 2). In patients without ARDS, ineffective and double triggering were considered most relevant as they are both associated with longer duration of ventilation, while double triggering, ineffective triggering, insufficient flow, delayed cycling, and premature cycling were also considered relevant for their associations with patient discomfort. Among patients after cardiac surgery, double triggering and reverse triggering were considered clinically relevant, for their associations with hemodynamic instability, and all PVAs except reverse triggering were considered important for causing patient discomfort.

In patients with ARDS, consensus ranking on PVAs associated with prolonged ventilation in undetected and unresolved scenarios was: (1) double triggering, (2) ineffective triggering, and (3) reverse triggering. Consensus on a complete ranking of PVAs associated with mortality was not reached, although for double triggering, 82% of panelists agreed that it should be ranked first. For patients without ARDS and patients after cardiac surgery, there was initial disagreement on rankings for all outcomes. However, following a face-to-face online meeting, PVAs were classified as severe or mild based on their likely association with the chosen outcome, with PVAs for which there was consensus on a strong association being classified in the severe group and PVAs for which there was no consensus being classified in the mild group. Consensus on the composites was achieved in the final round for both patient groups (Fig. 1 and Supplemental Figure S2).

Eleven position statements were developed, addressing the identification and classification of PVAs, their associations with outcomes, and severity ranking across

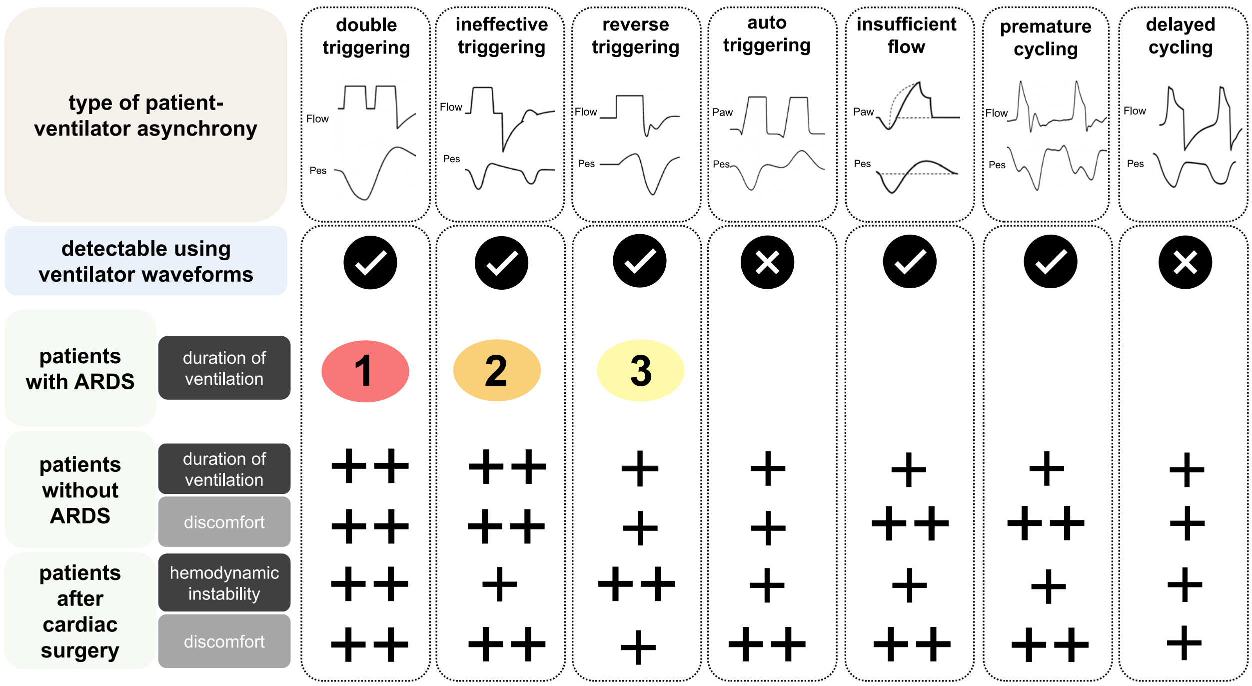

Fig. 1 Summary figure illustrating waveform examples of PVAs, their detectability, and severity ranking. The top panels show representative flow or airway pressure (Paw) waveforms and corresponding esophageal pressure tracings. Below, consensus is indicated on whether each PVA can be detected using only flow or Paw waveforms in the absence of esophageal pressure. A tick symbol denotes consensus that detection is possible; a cross indicates no consensus. The lower panels display the consensus regarding severity rankings across three different patient groups. In ARDS, PVAs associated with prolonged ventilation in undetected and unresolved scenarios were ranked as: (1) double triggering, (2) ineffective triggering, and (3) reverse triggering. In patients without ARDS, PVAs were ranked in a composite as severe (two plus symbols: + +) or mild (one plus symbol: +) for duration of ventilation and discomfort. In post–cardiac surgery patients, the same severity categories regarding rankings were applied for hemodynamic instability and discomfort. *ARDS* acute respiratory distress syndrome, *PVA* patient-ventilator asynchrony

the three patient groups (Panel 1). Thematic analysis of the panelists' comments further identified key knowledge gaps and research priorities for future investigation (Fig. 3).

Discussion

This international Delphi study makes a meaningful contribution to the field of PVA by identifying key knowledge gaps and generating consensus on detection, clinical relevance, and ranking of PVAs. Using a structured multi-round process, we evaluated multiple PVA types, achieved consensus on waveform-detectable PVAs, and identified those most strongly associated with patient-centered outcomes. A severity hierarchy was established for ARDS, while composite groupings were recommended for patients without ARDS and after cardiac surgery. The findings support experienced clinicians' view that ineffective and double triggering relate to worse outcomes [3, 10, 13], while offering novel insights through systematic comparison of all PVAs. PVAs were assessed within patient categories using outcomes, such as discomfort [24–26] and hemodynamic instability [11]. Although not empirical proof, this expert consensus derived from literature and clinical experience fills a key research gap and provides a structured framework to guide future studies, monitoring, and prioritization of PVAs.

(See figure on next page.)

Fig. 2 Heat maps showing consensus in percentage regarding the association of PVAs with outcomes across three patient groups. For patients with ARDS (top panels), consensus was sought regarding associations with mortality and prolonged ventilation. For patients without ARDS (middle panels), consensus was sought for duration of ventilation and discomfort, and for post-cardiac surgery patients (bottom panels), for hemodynamic instability and discomfort. Darker colors indicate a higher likelihood of association. *ARDS* acute respiratory distress syndrome, *PVA* patient-ventilator asynchrony

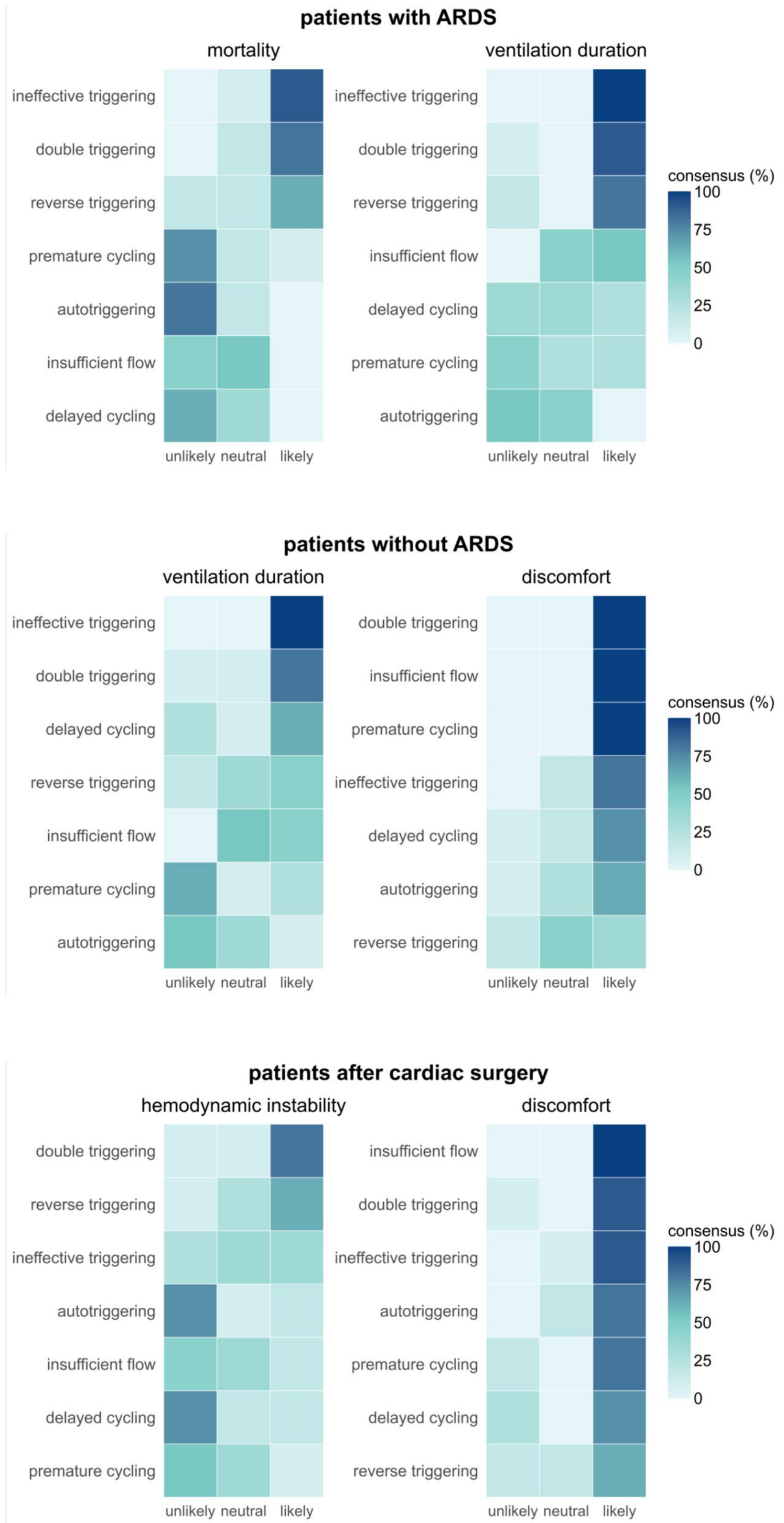

Fig. 2 (See legend on previous page.)

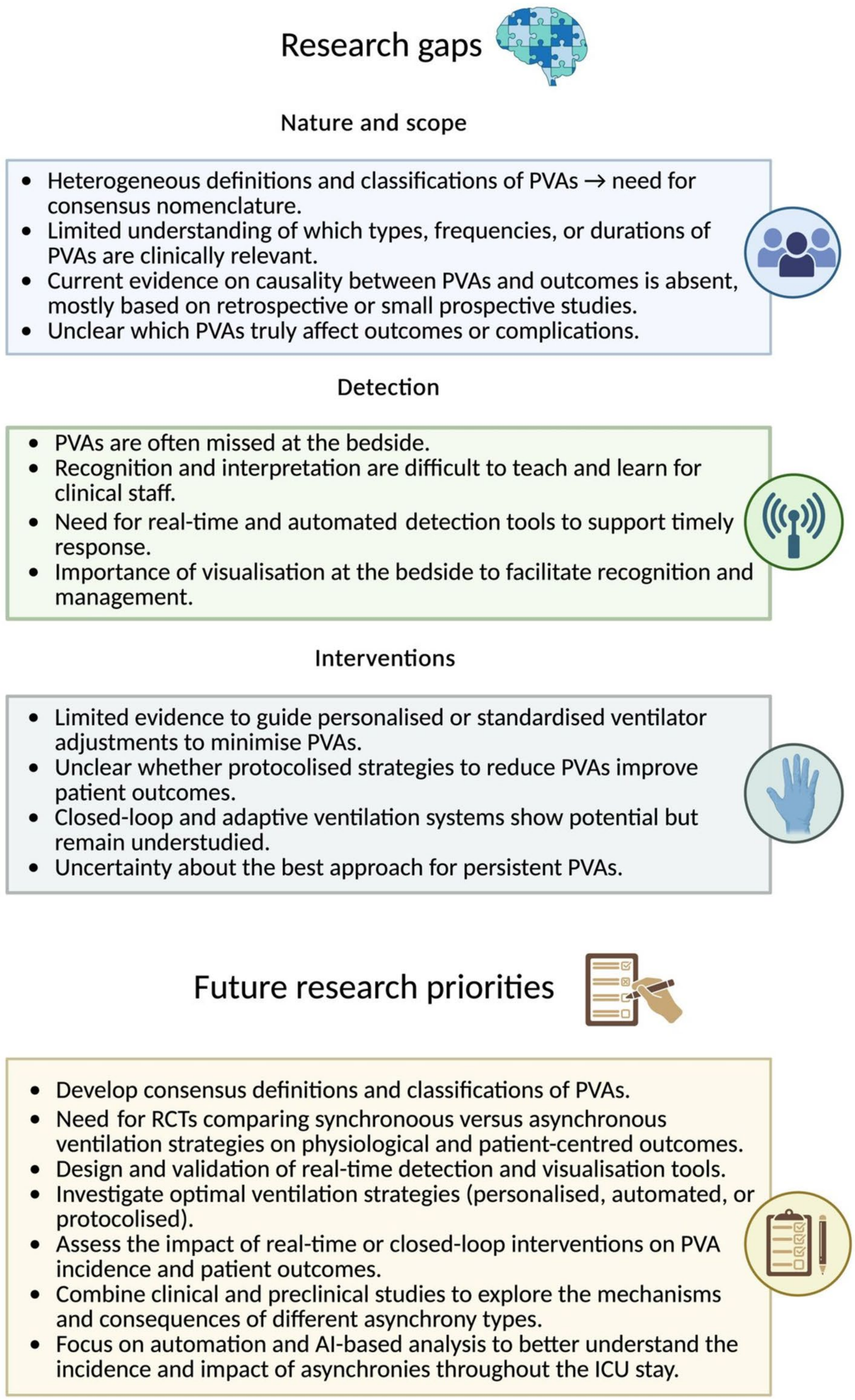

Fig. 3 Knowledge gaps and research topics in the field of PVAs. *PVA* patient-ventilator asynchrony

Detection of PVAs

Detection of PVAs in routine clinical practice remains challenging, despite increasing insight into their physiological mechanisms. Most existing evidence is derived from studies using esophageal pressure monitoring, which provides detailed insight into patient effort and timing. However, this technique is invasive, technically demanding, time-consuming, and rarely used at the bedside, limiting the clinical applicability of much of the current knowledge. In response to this, we focused on PVAs that can be identified from standard ventilator waveforms alone, reflecting the realities of bedside practice.

Even when PVAs can be reliably identified using standard waveforms, real-time recognition remains challenging in clinical practice [8, 9]. Accurate detection requires specialized knowledge, sustained attention to the ventilator display, and repeated assessment, which is often impractical in busy Intensive Care Units (ICUs) [7]. As a result, PVAs frequently go unrecognized, and when identified, the associated cognitive demands add substantially to clinician workload. Detection alone is only the first step: determining the appropriate intervention, whether adjusting ventilator settings, modifying sedation, or addressing underlying physiological factors, represents a distinct and complex challenge. Automated detection tools could help bridge this gap by timely and consistent identification of PVAs without increasing workload. Although current technologies typically focus on individual PVAs or are not yet suitable for routine bedside use, they hold considerable potential for accurate real-time detection [27, 28].

Association of PVAs with adverse outcomes

Various pathophysiological mechanisms underlie the association between PVAs and adverse outcomes. The relationship is likely to be causal, with PVAs such as double triggering and reverse triggering probably causing lung injury by increasing distending pressures and impairing venous return through elevated intrathoracic pressure during breath-stacking [29]. A large observational study reported that the volume of stacked breaths was 10–15 ml/kg, often twice the set tidal volume [30].

In many cases, however, PVAs may act more as 'biomarkers' of underlying conditions contributing to adverse outcomes [31]. PVAs, such as double triggering, premature cycling, and insufficient flow, indicate high respiratory drive, which may result from metabolic acidosis, shock, hypoxemia, pain, altered respiratory mechanics, or systemic inflammation, ultimately leading to respiratory distress, prolonged ventilation, and higher mortality [32]. Notably, double triggering and premature cycling are the most frequent PVAs observed post-cardiac surgery [33], while pneumonia, sepsis, or ARDS are identified as risk factors for double triggering [34].

Ineffective triggering is the PVA most frequently associated with adverse outcomes [1–5, 11]. It likely causes eccentric diaphragmatic contraction and a mismatch between brain afferent and efferent signals, leading to dyspnea [35]. These efforts typically occur with weak inspiratory drive, due to muscle weakness, dynamic hyperinflation, excessive sedation, or high ventilatory assist, with the underlying conditions likely mediating the observed outcomes.

Reverse triggering is a PVA in which diaphragmatic contraction follows a passive, ventilator-delivered breath [36]. Its clinical impact remains uncertain, preclinical studies suggest divergent physiological effects depending on inspiratory effort: low effort may be protective, whereas high effort often lead to double triggering [37, 38]. Reverse triggering is also linked to improved oxygenation and higher chances of successful extubation [39, 40]. In our Delphi, consensus showed that reverse triggering is clinically important, because it may affect outcomes, possibly reflecting its occurrence in deeply sedated patients, where responses such as increased sedation or neuromuscular blockade may worsen outcomes, while sedation reduction could be an alternative.

The quantitative burden of PVA is also significant, as prolonged exposure and clusters of PVAs have been shown to be more associated with outcomes [3, 11]. Persistent PVAs may result not only from the patient–related factors that are difficult to treat, but also by limitations in available time or expertise at the bedside, both of which can adversely affect patient outcomes.

PVA ranking by severity

Achieving consensus on the ranking of PVA severity proved more difficult than identifying associations between PVAs and clinical outcomes, likely reflecting the limited number of studies comparing the impact of specific PVAs. Panelists noted that the relative impact of each type of PVA varies with patient context, including ventilatory mode, level of sedation, and inspiratory effort. For patients with ARDS, consensus on a severity ranking was reached for duration of mechanical ventilation when PVAs remain unresolved, but not for mortality. While several studies report longer ventilation in patients with significant PVAs [2, 4, 41], the association with mortality is inconsistent. One study using waveform recordings found an association with mortality [5], whereas another study using the same system did not [2], and a recent meta-analysis also found no association [13]. Consensus on severity ranking was not reached for patients without ARDS or post-cardiac surgery, panelists agreed on grouping PVAs into 'severe' and 'mild' categories, reflecting expert consensus linked to clinically relevant outcomes. Of note, this severity framework is derived from a relatively small panel and requires further validation, given the available limited data.

Most panelists identified double triggering as the most important PVA in ARDS, likely because it can cause breath-stacking, generate large tidal volumes, and compromise protective ventilation [42]. Consensus was not reached, possibly because ineffective triggering, identified as the most prevalent type of PVA, was prioritized accordingly, reflecting its high prevalence in several observational studies [2, 4, 5], while the clinical impact of reverse triggering remains less well understood [43, 44].

Knowledge gaps and research priorities

Panelists noted that clinicians' ability to recognize PVAs is generally low [45]. Automated systems based on artificial intelligence are being developed, but not yet commercially available. Future research should prioritize automated detection, which would enable collection of large datasets over extended monitoring periods and allow stronger correlations between PVAs and patient clinical status and outcomes.

Key knowledge gaps regarding PVAs are particularly their potential causal relationship with patient outcomes [1, 4, 41, 46–49], and ventilator-induced lung injury, and their impact across different patient populations remains poorly understood [50]. Evidence is limited, because most studies use short observation periods. One study continuously analyzed PVAs using dedicated software for over 80% of ventilation time [5], showing that patients with an asynchrony index > 10% had similar reintubation and tracheostomy rates but higher ICU and hospital mortality, with a trend toward longer ventilation. Nevertheless, these associations do not establish causality.

Strengths and limitations

Our study has several strengths. All Delphi rounds were completed with a diverse international panel representing multiple disciplines. The process was rigorously and fully anonymized until the last round to minimize bias, and panelists engaged actively in resolving disagreement. Clinical context was provided to support severity assessments, enhancing the relevance of findings to daily practice. We also extended the scope beyond standard clinical endpoints to include outcomes of direct importance to patients, such as discomfort, and hemodynamic effects.

Our study also has limitations. We used a modified Delphi approach with a carefully selected group of independent clinicians. While a larger panel might have increased robustness and generalizability, all participants were highly invested and recognized authorities in the field. Our results represent the consensus of this panel, reflecting the best available evidence in the absence of direct empirical data. This was also the aim of our Delphi. However, definitive evaluation of the results, regarding detection of PVAs and validation of the severity framework, requires dedicated studies. Patients and members of the public were not included, as the topics were considered too complex for those without specialist knowledge of mechanical ventilation. Finally, the study did not seek consensus on specific ventilator interventions to prevent or reduce PVAs, which remains a key focus for future research.

Conclusions and future directions

This Delphi study established a consensus-based framework for identifying and ranking PVAs at the bedside, emphasizing the most clinically important asynchronies and providing a structured approach to guide monitoring, management, and future research across diverse patient populations. Future work should focus on translating this framework into practice through the development and validation of reliable, real-time bedside detection tools. It is crucial to determine the causal impact of PVAs on patient-centered outcomes and to evaluate whether standardized, personalized interventions can reduce them and improve lung-protective ventilation. Implementation studies should also investigate how PVA monitoring can be integrated into routine ICU workflows without increasing staff workload.

Supplementary Information

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Author contributions

MAM, PN, MJS, and LABK contributed to the conceptualization, design of the work, methodology, data curation, analysis, verification of underlying data, and drafting of the manuscript. PN did the formal analysis. MAM and LABK contributed to the project administration, literature search, and prepared the figures. LFP, JCF, AI, FP, LP, MS, ASN, ET, and KV contributed to data acquisition, data interpretation, and drafting of the manuscript. All authors contributed

to reviewing and editing of the manuscript for intellectual content and are responsible for the final version of this manuscript.

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Availability of data and materials
Not applicable.

Declarations

Conflicts of interest
LFD reports a grant from Agencia Nacional de Investigacion y Desarrollo, Grant Fondecyt Regular 2022/Folio 1220853 and fees from Stimit AG, outside the submitted work. JCF reports grants from CNPq (Brazilian federal funding agency) and the ATS Foundation, outside the submitted work. LP reports payment from Getinge, Löwenstein, Fisher and Paykel, GE Healthcare and Air Liquid Medical System, outside the submitted work. The other authors declare no competing interests.

Ethics approval and consent to participate
As this was a qualitative expert-opinion Delphi study without patient involvement, and without human data or biological specimens through which individuals could be identified, formal ethical approval was not sought. Panelists participated anonymously and could not be identified from their responses. The Delphi process was overseen by an experienced consensus–methodologist (PN). The study's methodology and results are reported in accordance to the ACcurate COnsensus Reporting Document (ACCORD) guidelines. The study and the analysis were conducted in accordance with the Declaration of Helsinki.

Panel 1: Position statements including the classification of PVAs, their association with outcomes, and ranking of severity

- Patient-ventilator asynchronies (PVAs) encompass a spectrum of mismatched interactions between patient respiratory effort and ventilator delivery, and include the following events: (1) ineffective triggering; (2) reverse triggering; (3) double triggering; (4) auto-triggering; (5) insufficient flow; (6) premature cycling, and (7) delayed cycling.
- PVAs that can be reliably detected using ventilator waveforms alone, (i.e. without esophageal pressure monitoring), include double triggering, ineffective triggering, reverse triggering, insufficient flow, and premature cycling.
- In patients with acute respiratory distress syndrome (ARDS): double triggering, ineffective triggering, and reverse triggering are associated with prolonged duration of mechanical ventilation, and double triggering and ineffective triggering are associated with increased mortality.
- In patients without ARDS, double triggering, ineffective triggering, insufficient flow, delayed cycling, and premature cycling are associated with patient discomfort, while double triggering and ineffective triggering are associated with prolonged duration of mechanical ventilation.
- In patients after cardiac surgery, all PVAs except reverse triggering are associated with discomfort, and double triggering and reverse triggering are associated with hemodynamic instability.
- The severity ranking of PVAs in patients with ARDS, for undetected and unresolved asynchronies associated with prolonged duration of ventilation, is as follows: (1) double triggering, (2) ineffective triggering, and (3) reverse triggering.
- For patients without ARDS and post-cardiac surgery patients, PVAs should be categorized into severity-based composite groups (severe vs. mild) rather than individual rankings, to facilitate clinical prioritization, because individual PVA hierarchies could be established.
- For patients without ARDS, the composite of severe PVAs regarding duration of mechanical ventilation includes ineffective triggering and double triggering, whereas mild PVAs are categorized as delayed cycling, reverse triggering, insufficient flow, premature cycling, and auto-triggering.
- For patients without ARDS, the composite of severe PVAs regarding discomfort includes double triggering, insufficient flow, premature cycling, and ineffective triggering, whereas mild PVAs are categorized as delayed cycling, auto-triggering, and reverse triggering.
- For patients after cardiothoracic surgery, the composite of severe PVAs regarding hemodynamic instability includes double triggering and reverse triggering, whereas mild PVAs are categorized as ineffective triggering, auto-triggering, insufficient flow, delayed cycling, and premature cycling.
- For patients after cardiothoracic surgery, the composite of severe PVAs regarding patient discomfort includes insufficient flow, double triggering, ineffective triggering, auto-triggering, and premature cycling, whereas mild PVAs are categorized as delayed cycling and reverse triggering.

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