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# Patient-Ventilator Asynchrony and Duration of Mechanical Ventilation: An Observational Study

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## Abstract

Patient-ventilator asynchrony (PVA) is defined as a mismatch between the patient's respiratory demand and the ventilatory support delivered during mechanical ventilation (MV). Although common, PVA is associated with adverse outcomes, including prolonged MV and increased morbidity. **Methods:** This cross-sectional observational study included adult ICU patients receiving invasive mechanical ventilation for more than 24 hours. PVA was assessed through visual analysis of pressure-time, flow-time, and volume-time waveforms recorded in two-minute videos. The asynchrony index (AI) was calculated and classified as <10% or ≥10%. Clinical and ventilatory variables were analyzed using nonparametric tests, logistic regression, and ROC curve analysis. **Results:** Eighty-three patients were included. PVA was identified in 21.7% of patients, with 14.5% presenting AI ≥ 10%. Patients with PVA had longer MV duration (18.5 vs. 8.0 days; $p < 0.01$). MV duration was associated with PVA (OR 1.29; 95% CI 1.15 - 1.46; $p < 0.01$). ROC analysis demonstrated high discriminatory capacity (AUC 0.91). However, this finding should be interpreted cautiously due to the bidirectional relationship between MV duration and PVA. **Conclusion:** PVA is frequent and associated with prolonged mechanical ventilation. These findings highlight the importance of systematic monitoring and optimization of ventilatory support.

## Keywords

Mechanical Ventilation, Asynchrony, Intensive Care, Physiotherapy

## 1. Introduction

Mechanical ventilation (MV) is a ventilatory support frequently used in the intensive care unit (ICU), being indispensable for maintaining life in cases of acute respiratory failure (ARF). Regardless of the etiology of ARF, the goal of therapy will be to maintain gas exchange at adequate levels and reduce the work of breathing until the clinical condition that led to the indication for MV is resolved or compensated [1].

Ventilatory adjustments are made to achieve the best patient-ventilator interaction, which is effective when there is good dynamics between the patient's inspiratory effort and the triggering of the device; between ventilatory demand and flow and tidal volume deliveries; and between the moment the patient's inspiration is interrupted and the device's cycling [2], patient-ventilator asynchronies (PVA) will occur when this balance between the patient and the mechanical ventilator is not achieved.

Asynchrony can be defined as an imbalance between the patient's demands—regarding time, flow, volume, and/or pressure of their respiratory system—and the ventilatory support provided during mechanical ventilation. It can occur when the patient's respiratory drive is high or low. Asynchronies are common, but when not detected and treated, they can be associated with adverse outcomes, including prolonged mechanical ventilation, higher weaning failure rates, and increased morbidity and mortality [3].

Asynchronies are detected through the volume-time, flowtime, and pressure-time curves of the mechanical ventilator. The most common types of APV are trigger, cycling, and flow asynchronies (**Table 1**).

**Table 1.** Main patient-ventilator asynchronies and associated factors.

| Asynchrony | Identification | Determining factors | |
|---|---|---|---|
| Shot | Assessment | Patient | Fan |
| Ineffective shot | It can be perceived by the patient's inspiratory effort. | Respiratory muscle weakness. Depression of neural control. hyperinflation (auto-PEEP). | Improper adjustment or problems with the sensitivity mechanism. Prolonged inspiratory time. |
| Double shot | The problem is that the ventilatory effort persists after cycling. Therefore, two consecutive cycles without a break can be observed. | X | Inspiratory time is very short compared to neural time. Low tidal volume in VCV mode. |
| Reverse firing | It may go unnoticed in the clinic, requiring monitoring of esophageal pressure, since the muscle effort does not originate in the patient's respiratory center, but rather in a cycle provided by the ventilator. | X | Muscle strain resulting from mechanical inflation. |

**Continued**

| | | | |
|---|---|---|---|
| Self-firing | This can be verified when the patient experiences a respiratory rate higher than the set rate without exertion. | Transmission of pressure and/or flow oscillations through heartbeats. | "Excessive" sensitivity. Leak in the system. Condensate in the fan circuit. |
| Cycling | | Patient | Fan |
| Premature cycling | Increased peak pressure, respiratory rate, and patient discomfort. | Restrictive respiratory mechanics pattern in PSV mode, as in pulmonary fibrosis. | Inspiratory time is very short compared to that of the patient. |
| Late cycling | Respiratory effort occurs when the ventilator flow ceases. The patient will produce force opposing the ventilator by recruiting accessory muscles. This will result in increased airway pressure. | Obstructive respiratory mechanics in PSV mode, as in COPD. | Inspiratory time is much longer than that of the patient. |
| Flow | | Patient | Fan |
| Insufficient flow | The airflow provided will be less than the ventilatory demand. As a result, the patient will use accessory muscles, experiencing respiratory discomfort. | Excessive ventilatory demand, heightened neural drive. | In VCV, the flow setting is too low. In PCV and PSV systems, the applied pressure is too low, resulting in a long rise time. |
| Excessive flow | In volume-controlled mode, the rise time will be faster, meaning it will reach peak pressure sooner. In pressure-controlled or support mode, the pressure will exceed the set level, favoring the occurrence of a phenomenon called overshoot. | X | In VCV, the flow setting is too high. In PCV and PSV systems, very high applied pressure results in a very short rise time (overshoot). |

Adapted from HOLANDA *et al.* 2018 and ROCHA *et al.* 2018.

In a prospective observational study [4], the most prevalent type of APV in patients with acute brain injury undergoing MV, for example, was ineffective triggering. Although the classification of brain injuries is not a factor related to asynchrony, ventilatory modes, respiratory drive, and analgesia/sedation strategies are associated with APV, suggesting the need to adjust treatment for this specific population.

High-pressure ventilators (HPVs) cause several undesirable clinical effects such as discomfort, dyspnea with symptoms of "air hunger" or "excessive inspiratory effort," worsening of gas exchange, increased respiratory work, diaphragmatic muscle injury, interference with sleep quantity and quality, increased need for sedation, increased need for neuromuscular blockade, among others. Excessive or insufficient ventilatory support can cause respiratory muscle damage, potentially leading to atrophy and/or apoptosis of muscle fibers, or excessive respiratory work and muscle fatigue, respectively [5].

Detecting the type of asynchrony and how to correct it is of paramount importance in the management of critically ill patients on mechanical ventilation. The team's knowledge, updates, and training should be encouraged to provide better care and, in this way, avoid the deleterious effects of prolonged invasive ventilation and reduce the length of hospital stay.

## 2. Methods

This was a cross-sectional observational study conducted in the intensive care units of São Lucas Copacabana Hospital, Rio de Janeiro, Brazil. Adult patients (≥18 years) receiving invasive mechanical ventilation for more than 24 hours were consecutively included between July to September 2024. Exclusion criteria were severe neurological or metabolic disorders affecting respiratory drive, known diaphragmatic dysfunction, palliative care status, or inadequate waveform recordings. Each patient contributed a single two-minute waveform recording, which was used as the unit of analysis. Data collected included demographic variables, duration of mechanical ventilation, and level of sedation assessed using the Richmond Agitation-Sedation Scale (RASS). Ventilatory parameters (mode, PEEP, pressure support or tidal volume, and trigger/cycling settings) were recorded at the time of waveform acquisition. PVA was identified by visual inspection of pressure-time, flow-time, and volume-time waveforms. The asynchrony index (AI) was calculated as the number of asynchronous events divided by the total number of respiratory cycles × 100. AI < 10% was considered mild and ≥10% clinically significant. The study was submitted to and approved by the hospital's research ethics committee under reasoned opinion number 7.998.880 e CAAE 79054824.0.0000.5249. Waveform analysis was independently performed by three trained physiotherapists. Inter-rater reliability was assessed using Cohen's kappa coefficient in a subset of recordings ($\kappa = 0.53$ to 0.74) (**Table 2**).

**Table 2.** Inter-rater reliability for patient-ventilator asynchrony detection.

| Comparison | Kappa ($\kappa$) | Interpretation |
|---|---|---|
| Evaluator 1 vs Evaluator 2 | 0.74 | Good agreement |
| Evaluator 1 vs Evaluator 3 | 0.68 | Good agreement |
| Evaluator 2 vs Evaluator 3 | 0.53 | Moderate agreement |

Kappa ($\kappa$): Cohen's kappa coefficient. Agreement was interpreted as follows: <0.20 poor, 0.21 - 0.40 fair, 0.41 - 0.60 moderate, 0.61-0.80 good, and >0.80 excellent.

### 2.1. Assessment

Assessments were conducted daily for fifteen consecutive days, in the morning or afternoon, on patients receiving mechanical ventilation (MV) who were not under the care of other professionals at the time of assessment. Asynchrony analysis was performed by observing two-minute videos of pressure-time, flowtime, and volume-time graphs recorded on a mobile phone and subsequently stored in a folder accessible to all independent evaluators. The videos were recorded by ICU physiotherapists to create a database. During filming, asynchrony corrections and ventilation management were performed as necessary, according to the routine care of the responsible department. Subsequently, this data was analyzed by a group of three physiotherapists specializing in intensive care with more than five years of professional experience in the field, who had been previously trained in the identification and correction of asynchronies. In case of discrepancies in the three classifications, a fourth specialist physiotherapist was consulted.

### 2.2. Statistical Analysis

Continuous variables were expressed as median (IQR) and compared using the Mann-Whitney test. Categorical variables were analyzed using Fisher's exact test. Binary logistic regression was performed to identify variables associated with PVA and AI ≥ 10%. Variables with $p < 0.20$ or clinical relevance were included in multivariate models. Results were expressed as odds ratios (OR) with 95% confidence intervals (CI). Model discrimination was assessed using receiver operating characteristic (ROC) curves and area under the curve (AUC). A p-value < 0.05 was considered statistically significant.

## 3. Results

Eighty-three patients on invasive mechanical ventilation were included. The median age was 65 years (IQR 55 - 76), with a predominance of males (73%). The sedation score had a median RASS of 0 (IQR −1 to 0). The presence of APV was identified in 18 patients (21.7%), and 12 patients (14.5%) presented an asynchrony index (AI) greater than 10%.

The comparison between patients with and without asynchrony demonstrated a significant association between the presence of asynchronies and longer mechanical ventilation time (18.5 vs 8.0 days; $p < 0.01$), as well as higher RASS levels in the asynchrony group (0 [0 - 2] vs 0 [−1 - 0]; $p = 0.04$). No relevant differences were observed in demographic characteristics, including age, sex, weight, and height ($p > 0.05$) (**Table 3**).

**Table 3.** Characteristics of patients according to the presence of asynchronies.

| Variable | No asynchrony (n = 65) | With asynchrony (n = 18) | p |
|---|---|---|---|
| Age (years) | 65 [55 - 76] | 60 [56 - 68] | 0.50 |
| Height (cm) | 167 [158 - 176] | 166 [162 - 173] | 0.87 |
| Weight (kg) | 67 [56 - 78] | 74 [67 - 82] | 0.14 |
| VM in days | 8 [6 - 11] | 18.5 [16 - 21] | <0.01 |

**Continued**

| | | | |
|---|---|---|---|
| RASS sedation | 0 [−1 - 0] | 0 [−1 - 2] | 0.04 |
| Male (%) | 73.8% | 72.2% | 1.00 |

VM: mechanical ventilation; RASS: Richmond agitation sedation scale; cm: centimeters; Kg: kilograms.

Stratified analysis based on the severity of asynchronies (absence of asynchrony or mild asynchronies) and relevant asynchronies demonstrated significant differences in clinical outcomes. A progressive increase in mechanical ventilation time was observed between the groups (9 and 20.5 days, respectively; p < 0.01), highlighting an association between greater severity of asynchrony and longer duration of ventilatory support.

Similarly, RASS values were significantly higher in the group with relevant asynchronies (2 vs 0 in the other groups; p = 0.07), suggesting a higher level of alertness in these patients. No statistically significant differences were observed between the groups for demographic variables, including age, sex, weight, and height (p > 0.05) (**Table 4**).

**Table 4.** Characteristics according to an asynchrony index (AI) greater than 10%.

| Variable | Mild or absent asynchrony (n = 71) | IA > 10% (n = 12) | p |
|---|---|---|---|
| Age (years) | 65.0 [55.0 - 73.5] | 63.0 [56.8 - 74.5] | 0.91 |
| Height (cm) | 167.0 [160.0 - 175.0] | 166.5 [160.8 - 169.2] | 0.54 |
| Weight (kg) | 67.0 [58.0 - 78.0] | 74.0 [61.2 - 81.2] | 0.63 |
| VM in days | 9.0 [7.0 - 11.0] | 20.5 [17.8 - 21.5] | <0.01 |
| RASS sedation | 0.0 [−1.0 - 0.0] | 1.0 [−0.2 - 2.0] | <0.07 |
| Male (%) | 76.1% | 58.3% | 0.29 |

VM: mechanical ventilation; RASS: Richmond agitation sedation scale; IA: asynchrony index; CM: centimeters; KG: kilogram.

Univariate analysis by logistic regression demonstrated that the duration of mechanical ventilation was significantly associated with the presence of APV (OR 1.32; 95% CI 1.18 - 1.49; p < 0.01).

The RASS score also showed a significant association with the presence of asynchrony (OR 1.41; 95% CI 1.02 - 1.96; p = 0.04), suggesting that higher levels of alertness are related to a greater occurrence of mismatch between patient and ventilator. On the other hand, demographic variables, including age (OR 0.98; p = 0.41) and weight (OR 1.03; p = 0.12), did not show a statistically significant association with the outcome (**Table 5**).

**Table 5.** Univariate analysis by logistic regression in the presence of asynchronies.

| Variable | OR | 95% CI | p |
|---|---|---|---|
| VM in days | 1.32 | (1.18 - 1.49) | <0.01 |

**Continued**

| | | | |
|---|---|---|---|
| RASS sedation | 1.41 | (1.02 - 1.96) | 0.04 |
| Weight | 1.03 | (0.99 - 1.07) | 0.12 |
| Age | 0.98 | (0.95 - 1.02) | 0.41 |

VM: mechanical ventilation; RASS: Richmond agitation sedation scale; OR: odds ratio; CI: confidence interval.

In multivariate logistic regression analysis, MV time remained independently associated with the presence of asynchrony (OR 1.29; 95% CI 1.15 - 1.46; p < 0.01) and IA > 10% (OR 1.31; 95% CI 1.16 - 1.49; p < 0.01). The RASS score also remained an independent factor associated with asynchrony (OR 1.36; 95% CI 1.01 - 1.92; p = 0.04) and IA > 10% (OR 1.55; 95% CI 1.10 - 2.20; p = 0.01) (**Table 6** and **Table 7**).

**Table 6.** Multivariate analysis by logistic regression in the presence of asynchronies.

| Variable | OR adjusted | 95% CI | p |
|---|---|---|---|
| VM in days | 1.29 | (1.15 - 1.46) | <0.01 |
| RASS sedation | 1.36 | (1.01 - 1.92) | 0.04 |

VM: mechanical ventilation; RASS: Richmond agitation sedation scale; OR: odds ratio; CI: confidence interval.

**Table 7.** Multivariate analysis by logistic regression with IA > 10%.

| Variable | OR adjusted | 95% CI | p |
|---|---|---|---|
| VM in days | 1.31 | (1.16 - 1.49) | <0.01 |
| RASS sedation | 1.55 | (1.10 - 2.20) | 0.01 |

VM: mechanical ventilation; RASS: Richmond agitation sedation scale; OR: odds ratio; CI: confidence interval.

Univariate analysis by logistic regression demonstrated that the duration of mechanical ventilation was significantly associated with the occurrence of clinically relevant asynchrony (IA ≥ 10%) (OR 1.35; 95% CI 1.20 - 1.55; p < 0.01), indicating a progressive increase in the risk of asynchrony as the duration of ventilatory support increases.

The RASS score did not show a significant association with the outcome (OR 1.62; 95% CI 1.15 - 2.28; p = 0.06). Demographic variables, such as age (OR 1.00; p = 0.91) and weight (OR 1.02; p = 0.28), did not show a statistically significant association with the occurrence of IA ≥ 10% (**Table 8**).

ROC curve analysis showed that the duration of mechanical ventilation had high discriminatory capacity for identifying PVA (AUC 0.91; 95% CI 0.83 - 0.98) and AI ≥ 10% (AUC 0.97; 95% CI 0.94 - 1.00), as shown in **Figure 1**. However, these findings should be interpreted with caution, as MV duration may represent both a marker and a consequence of asynchrony.

Table 8. Univariate analysis by logistic regression with IA > 10%.

| Variable | OR | 95% CI | p |
|---|---|---|---|
| VM in days | 1.35 | (1.20 - 1.55) | <0.01 |
| RASS sedation | 1.62 | (1.15 - 2.28) | 0.06 |
| Weight | 1.02 | (0.98 - 1.06) | 0.28 |
| Age | 1.00 | (0.96 - 1.04) | 0.91 |

VM: mechanical ventilation; RASS: Richmond agitation sedation scale; OR: odds ratio; CI: confidence interval.

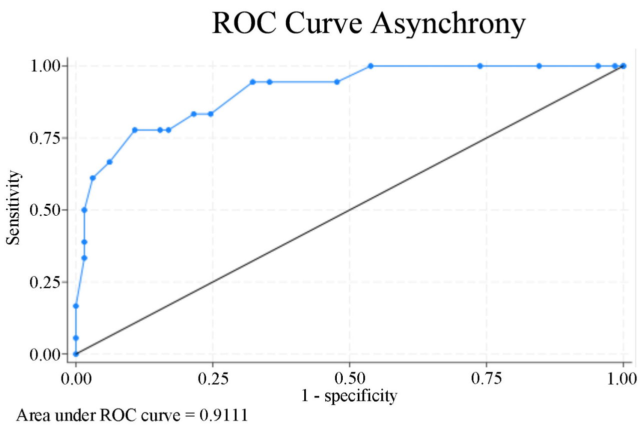


Figure 1. ROC curves of mechanical ventilation time for predicting asynchrony (AUC 0.91; 95% CI 0.83 - 0.98) and IA ≥ 10% (AUC 0.97; 95% CI 0.94 - 1.00).

## 4. Discussion

The results of the present study demonstrate that APVs are frequent events in clinical practice, with a prevalence like that described in contemporary studies. Recent evidence indicates that asynchronies remain highly prevalent in patients on mechanical ventilation, although they are frequently underdiagnosed in clinical practice [6] [7].

The association between asynchrony and longer MV duration observed in this study is consistent with recent data from the literature. More recent studies demonstrate that patients with IA greater than 10% have longer MV duration, as well as worse clinical outcomes, including increased ICU stay [7] [8]. Recent clinical trials have also demonstrated that systematized strategies for identifying and correcting asynchronies can significantly reduce MV duration [9].

Furthermore, MV duration demonstrated excellent discriminatory capacity for predicting asynchrony, corroborating the hypothesis that simple clinical variables can act as risk markers. However, this association should be interpreted with caution, since the relationship between asynchrony and MV is likely bidirectional [5].

Although duration of mechanical ventilation was strongly associated with PVA, this variable should not be interpreted as a causal predictor. The relationship is likely bidirectional, as prolonged ventilation may increase the risk of asynchrony, while asynchrony itself may contribute to longer ventilation duration.

Another relevant point is the association with the level of sedation (RASS). Recent studies reinforce that the balance between sedation and respiratory drive is fundamental for adequate patient-ventilator interaction, with inadequate sedation being one of the main factors associated with the development of asynchronies [8] [10].

Recent advances in the literature highlight the role of new technologies in detecting these asynchronies. Methods based on artificial intelligence and automated analysis of ventilatory curves have demonstrated greater sensitivity and capacity for continuous monitoring compared to traditional visual analysis [11] [12]. Furthermore, recent reviews indicate that the integration of multiple physiological signals may represent the future of monitoring the patient-ventilator interaction [13] [14].

A recent Delphi study also reinforced that certain types of asynchronies, such as ineffective firing and double firing, are the most clinically relevant and associated with worse outcomes [15].

From a clinical standpoint, the results of this study reinforce the need for systematic and continuous monitoring of asynchronies, as well as the training of the multidisciplinary team for their identification and appropriate management.

## 5. Limitations of the Study

This study has some important limitations. Firstly, the observational design prevents the inference of causality between asynchrony and mechanical ventilation time. Furthermore, specific types of asynchronies were not evaluated, which could provide more detailed information about their clinical impact. The absence of detailed ventilatory variables, such as ventilatory mode and adjusted parameters, also limits the understanding of associated factors. The use of a convenience sample limits the generalizability of the findings, since patients were included according to availability during the data collection period, which may introduce selection bias. The absence of repeated measurements and the use of a single short recording per patient may underestimate the true prevalence of asynchrony.

## 6. Conclusion

Asynchronies are frequent events in critically ill patients and are independently associated with longer mechanical ventilation time and higher levels of alertness. Mechanical ventilation time has demonstrated predictive capacity for identifying asynchronies, especially when combined with sedation level. These findings reinforce the importance of continuous monitoring of patient-ventilator interaction and optimization of ventilatory parameters as strategies to improve clinical outcomes in mechanically ventilated patients.

## Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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