Patient-ventilator asynchrony in conventional ventilation modes during short-term mechanical ventilation after cardiac surgery: randomized clinical trial

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Introduction and aim: Studies regarding asynchrony in patients in the cardiac postoperative period are still only a few. The main objective of our study was to compare asynchronies incidence and its index (AI) in 3 different modes of ventilation (volume-controlled ventilation [VCV], pressure-controlled ventilation [PCV] and pressure-support ventilation [PSV]) after ICU admission for postoperative care.

Methods: A prospective parallel randomised trial in the setting of a non-profitable hospital in Brazil. The participants were patients scheduled for cardiac surgery. Patients were randomly allocated to VCV or PCV modes of ventilation and later both groups were transitioned to PSV mode.

Results: All data were recorded for 5 minutes in each of the three different phases: T1) in assisted breath, T2) initial spontaneous breath and T3) final spontaneous breath, a marking point prior to extubation. Asynchronies were detected and counted by visual inspection method by two independent investigators. Reliability, inter-rater agreement of asynchronies, asynchronies incidence, total and specific asynchrony indexes (AIt and AIspecific) and odds of AI ≥10% weighted by total asynchrony were analysed. A total of 17 patients randomly allocated to the VCV (n= 9) or PCV (n=8) group completed the study. High inter-rated agreement for AIt (ICC 0.978; IC95%, 0.963-0.987) and good reliability (r=0.945; p<0.001) were found. Eighty-two % of patients presented asynchronies, although only 7% of their total breathing cycles were asynchronous. Early cycling and double triggering had the highest rates of asynchrony with no difference between groups. The highest odds of AI ≥10% were observed in VCV regardless the phase: OR 2.79 (1.36-5.73) in T1 vs T2, p=0.005; OR 2.61 (1.27-5.37) in T1 vs T3, p=0.009 and OR 4.99 (2.37-10.37) in T2 vs T3, p<0.001.

Conclusions: There was a high incidence of breathing asynchrony in postoperative cardiac patients, especially when initially ventilated in VCV. VCV group had a higher chance of AI ≥10% and this chance remained high in the following PSV phases.

Key words: Ventilator weaning; thoracic surgery; breath triggering; cycle synchrony.

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Contributions: WSL, data curation, investigation, project administration, visualization, formal analysis, roles/writing, original draft; AN, data curation, investigation, roles/writing, original draft; MB, formal analysis, visualization; EOR, MKR, JS, methodology, investigation; AMdS, investigation, roles/writing, original draft; PHdM, methodology, investigation; CCM, CR, visualization, formal analysis; GHdSL, MGdA methodology, investigation, writing, review and editing; NSPM, validation, writing, review and editing; ACEG, methodology, formal analysis; MDaA, methodology, investigation, writing, review and editing; ADDA, supervision, validation, writing, review and editing; DCB, supervision; validation, writing, review and editing; SLC, conceptualization, methodology, validation, writing, review and editing.

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Availability of data and materials: The data that support the findings of this study are available from Wagner Souza Leite but restrictions apply to the availability of these data, which were used under license for the current study, and so are not publicly available. Data are however available from the authors upon reasonable request and with permission of Wagner Souza Leite.

Ethics approval and consent to participate: The study was approved by local clinical research ethics committee (Hospital of Recife, Brazil) by protocol 1,928,293 and registered at ClinicalTrials.gov (NCT03141216). All patients provided written informed consent before surgery.

Consent for publication: All patients provided written informed consent before surgery.

Trial registration: Clinical Trials NCT03141216 (date of registration: February 21, 2017).
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- to evaluate the reliability of the visual inspection method for
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ume;
- to calculate the incidence of patient-ventilator asynchrony and compare the rate of asynchrony in assist-controlled volume or pressure modes and in support pressure mode.

Methods

This parallel clinical trial was carried out in the post-surgical cardiothoracic ICU of a hospital in Recife (Brazil), from March to December 2017. The study received approval by the institutional ethics committee (number 1.928.293) and registered at ClinicalTrials.gov (NCT03141216). All volunteers signed a consent form as a pre-requisite to be included in the study.

Patients

Adult patients were included, aged 18 to 65 years, with BMI

between 18.5 and 29.9 kg/m² in order to avoid heterogeneous pul-
monary mechanics bias imposed by adiposity of patients above that limit, and under mechanical ventilation in the immediate post-

operative care. They were also required to have had a cardiac sur-
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risks, such as prolonged dependence, pneumonia, and asynchrony, and as well as to reverse postoperative complications, namely, atelectasis, pneumonia and respiratory failure [9].

Ventilator-associated events and respiratory complications are negative outcomes with potential for morbidity and mortality [9-

22]. Studies concerning the behavior of asynchrony, frequencies

due to asynchrony [19]. Thus, it is noted that the occurrence of

asynchrony may be related to adverse clinical consequences and that it needs important attention in clinical practice.

Asynchronies have been reported to occur in 25% to 100% of

patients regardless of the mode of mechanical ventilation [12,20-

22]. Studies concerning the behavior of asynchrony, frequencies and associated outcomes are important to distinguish whether there is a difference in the patterns of asynchrony depending on the patient’s clinical profile, its degree of incidence and what risks they may represent. The purpose of this study is to explore the presence of asynchrony in post-operative cardiac patients and what impact on outcomes can be observed.

The literature on patient-ventilator asynchrony in patients in the immediate cardiac postoperative period and its clinical impacts is still limited. Understanding the behavior of these events in the population addressed in this study is important for clinical impli-
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topics in an educational institution. Some of the topics discussed were modes of mechanical ventilation, analysis of ventilator graphics and respiratory and hemodynamic monitoring in a critical care unit.

**Sample size**

The dimensioning of the sample size was performed from a pilot study with 9 patients (VCV=5; PCV=4), using GPower v. 3.0 software. For the calculation, α=0.05, β=0.80 were used, and the means and standard deviations of the asynchrony index in the assist-controlled ventilatory phase in VCV (17.20±5.35%) and PCV (9.7±2.34%). As a result, with an effect size of 1.80, 6 participants per group would be needed. As a precautionary measure, a loss rate of 30% was added, thus, it was estimated that in view of a small variability in the results, the sample would be composed of at least 16 patients.

**Statistical analysis**

Some analyses were performed based on the number of individuals (n_individuals = 17) and others on the number of cases, which is equivalent to the pool effect of individuals repeated in three ventilatory phases (n_cases = 51).

Quantitative variables were compared by the Man-Whitney test and categorized by Pearson’s Chi-square test. The analysis of ventilation and oxygenation monitoring parameters and the quantitative data were distributed by phases to each group. Based on the number of individuals, the inter-group and inter-phase analysis were performed using the Anova two-factor test.

**Figure 1.** Definition to identify patient-ventilator asynchrony types. 1) Ineffective effort during expiration - a drop in the pressure curve during expiration and simultaneous increase in the expiratory branch of the flow curve (after 50% of the expiratory curve) insufficient to start a new cycle. 2) Ineffective effort during inspiration - a drop in the inspiratory phase pressure curve simultaneously with a fall in the flow curve also in the inspiratory phase. 3) Double triggering - two consecutive inspiratory efforts without adequate expiratory time. 4) Auto-triggering - start of the flow and pressure waveforms not preceded by a drop at the beginning of the pressure waveform indicating triggering induced by the patient. 5) Late cycling - peak at the end of the pressure waveform plateau (overshoot) before turning to exhalation. 6) Early cycling - a peak in the beginning of the expiratory branch of the flow waveform or occurring in less than 50% of the expiratory curve; 7) Reverse triggering - two consecutive breaths, the first one being ventilator-driven and the following being patient-responsive to the first breath.
The reliability of the visual inspection method and inter-rater agreement were tested respectively by Spearman correlation and intraclass correlation (ICC) of single measures with two-way mixed model and absolute agreement set for the variables of the total number of asynchrony and AIt. We determined an ICC higher than 0.60 as acceptable [30].

The odds of 10% or higher were expressed as odds ratios (OR) by Cochran-Mantel Haenzel test in different scenarios (see Supplementary Material). All tests were two-tailed with \( p < 0.05 \) considered significant and analyzed with SPSS software (ver. 20.0 for Windows, IBM Corp., USA).

**Analysis of results on \( N_{\text{individuals}} \)**

Their mean age was 53±10.9 years (ranging from 21 to 65 years), with over weight (BMI 27.7±2.5 kg/m²) and 60% of them were men. Most patients underwent myocardial revascularization (58.8%), nine of whom were ventilated in VCV and eight, in PCV modes. They presented respiratory and hemodynamic stability and a low mortality risk by EuroScore II classification [31] (Table 1). The dosages of neuromuscular blocking (NMB) drugs, opioids, general and local anesthetics administered to patients during the intraoperative period were similar for both groups. Opioids and sedatives in the postoperative period were seldom administered (Table 1).

The variables of expired tidal volume, respiratory rate, inspiratory time, pH, and partial pressure of carbon dioxide remained within normal range, and oxygenation with PaO\(_2/\text{FiO}_2\) ratio above 200. There were no statistical differences in the comparative analysis between the VCV vs PCV groups for these variables. The inspiratory times in phases T2 and T3 in spontaneous ventilation were

**Results**

Out of 160 patients enrolled and scheduled for cardiac surgery, 17 completed the study (9 in the VCV group and 8 in the PCV group). Figure 2 depicts the participant flowchart.

![Figure 2. Participant flowchart.](image-url)
higher than during assist-controlled ventilation (both, \( p < 0.0001 \)), but this did not influence the analysis of the group-phase interaction (Table 2).

The results of the inter-rater reliability analysis for the total number of asynchronies \( (r = 0.948, p < 0.001) \) and asynchrony indexes \( (r = 0.945, p < 0.001) \) detected by the visual inspection method between two independent evaluators presented a strong correlation. The agreement was also shown to be high for the total number of asynchronies \( 0.98 \) (95% CI 0.965-0.988) and asynchrony index \( 0.978 \) (95% CI 0.963-0.987) between the values estimated by both evaluators. Fourteen patients (82.3%) presented asynchrony at some point in their assisted breathing phases. Every patient was registered at three different phases; which resulted in 51 cases of analysis. These cases made up 255 min of sampling recording, corresponding to 3,813 respiratory cycles, in which 267 (7%) were deemed asynchronous.

### Table 1. Characteristics of the patients at ICU admission.

<table>
<thead>
<tr>
<th></th>
<th>General (n=17)</th>
<th>VCV (n=9)</th>
<th>PCV (n=8)</th>
<th>( p )</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sex</strong> (male, n/%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>10 (58.8)</td>
<td>6 (66.7)</td>
<td>4 (50)</td>
<td>0.49*</td>
</tr>
<tr>
<td>Female</td>
<td>7 (41.2)</td>
<td>3 (33.3)</td>
<td>4 (50)</td>
<td></td>
</tr>
<tr>
<td><strong>Age (years)</strong></td>
<td>52.9 (10.9)</td>
<td>52 (10.9)</td>
<td>54 (15.14)</td>
<td>0.21*</td>
</tr>
<tr>
<td><strong>Body mass index (kg/m²)</strong></td>
<td>27.7 (2.5)</td>
<td>27.1 (2.5)</td>
<td>28.3 (2.6)</td>
<td>0.25*</td>
</tr>
<tr>
<td><strong>EuroScore II (n/%)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0-2 points (low risk)</td>
<td>6 (35.3)</td>
<td>3 (33.3)</td>
<td>3 (37.5)</td>
<td>0.87*</td>
</tr>
<tr>
<td>3-5 points (medium risk)</td>
<td>8 (47.1)</td>
<td>4 (44.4)</td>
<td>4 (50)</td>
<td></td>
</tr>
<tr>
<td>≥6 points (high risk)</td>
<td>3 (17.6)</td>
<td>2 (22.2)</td>
<td>1 (12.5)</td>
<td></td>
</tr>
<tr>
<td><strong>Glasgow Coma Score (points)</strong></td>
<td>8.5 (0.5)</td>
<td>8.2 (0.4)</td>
<td>8.75 (0.5)</td>
<td>0.07*</td>
</tr>
<tr>
<td><strong>Mean arterial pressure (mmHg)</strong></td>
<td>80.1 (13.5)</td>
<td>78.9 (14.3)</td>
<td>81.38 (13.4)</td>
<td>0.77*</td>
</tr>
<tr>
<td><strong>Heart rate (bpm)</strong></td>
<td>91.4 (17.4)</td>
<td>93.7 (15.1)</td>
<td>88.88 (20.5)</td>
<td>0.34*</td>
</tr>
<tr>
<td><strong>SaO₂ (%)</strong></td>
<td>98.8 (1.7)</td>
<td>99.3 (1.3)</td>
<td>98.75 (2.8)</td>
<td>0.91*</td>
</tr>
<tr>
<td><strong>Drainage (ml) pleural</strong></td>
<td>12.5 (28.9)</td>
<td>6.3 (17.7)</td>
<td>18.75 (37.2)</td>
<td>0.49*</td>
</tr>
<tr>
<td><strong>Mediastinal</strong></td>
<td>73.1 (76.1)</td>
<td>59.4 (46.7)</td>
<td>87.5 (99.1)</td>
<td>0.79*</td>
</tr>
<tr>
<td><strong>Surgery type (n/%)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coronary artery bypass grafting</td>
<td>10 (58.8)</td>
<td>5 (55.6)</td>
<td>5 (62.5)</td>
<td>0.28*</td>
</tr>
<tr>
<td>Heart valve replacement</td>
<td>7 (41.2)</td>
<td>4 (44.4)</td>
<td>3 (37.5)</td>
<td></td>
</tr>
<tr>
<td><strong>Surgery duration (min)</strong></td>
<td>199.4 (81.44)</td>
<td>226.88 (69.3)</td>
<td>171.88 (57.6)</td>
<td>0.27*</td>
</tr>
<tr>
<td><strong>CPB duration (min)</strong></td>
<td>81.7 (31.0)</td>
<td>89.3 (29.8)</td>
<td>75 (32.5)</td>
<td>0.11*</td>
</tr>
<tr>
<td><strong>Use of drugs (yes, n/%)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intraop NMBS</td>
<td>13 (76.5)</td>
<td>5 (55.6)</td>
<td>8 (100)</td>
<td>0.20</td>
</tr>
<tr>
<td>Intraop opioids</td>
<td>16 (94.1)</td>
<td>8 (88.9)</td>
<td>8 (100)</td>
<td>1.00</td>
</tr>
<tr>
<td>Intraop general anesthesia</td>
<td>15 (88.2)</td>
<td>8 (88.9)</td>
<td>7 (87.5)</td>
<td>1.00</td>
</tr>
<tr>
<td>Intraop local anesthesia</td>
<td>7 (41.2)</td>
<td>4 (44.4)</td>
<td>3 (37.5)</td>
<td>1.00</td>
</tr>
<tr>
<td>Intraop sedatives</td>
<td>11 (64.7)</td>
<td>5 (55.6)</td>
<td>6 (75)</td>
<td>1.00</td>
</tr>
<tr>
<td>Postop opioids</td>
<td>16 (94.1)</td>
<td>2 (22.2)</td>
<td>2 (25)</td>
<td>1.00</td>
</tr>
<tr>
<td>Postop sedatives</td>
<td>1 (5.9)</td>
<td>1 (11.1)</td>
<td>0 (0)</td>
<td>1.00</td>
</tr>
<tr>
<td><strong>Dosage of drugs (mg/ml)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intraop NMBS</td>
<td>24.69 (13.09)</td>
<td>29.2 (13.16)</td>
<td>21.88 (13.08)</td>
<td>0.23</td>
</tr>
<tr>
<td>Intraop opioids</td>
<td>20.5 (19.38)</td>
<td>18.36 (18.48)</td>
<td>22.38 (21.22)</td>
<td>0.66</td>
</tr>
<tr>
<td>Intraop general anesthesia</td>
<td>23.47 (16.33)</td>
<td>19.64 (11.25)</td>
<td>27.88 (20.79)</td>
<td>0.59</td>
</tr>
<tr>
<td>Intraop local anesthesia</td>
<td>7 (9.41)</td>
<td>9 (9.74)</td>
<td>5 (5.00)</td>
<td>0.46</td>
</tr>
<tr>
<td>Intraop sedatives</td>
<td>5 (0.1)</td>
<td>5 (0.0)</td>
<td>5 (0.1)</td>
<td>1.00</td>
</tr>
<tr>
<td>Mechanical ventilation time (s)</td>
<td>5.88 (2.15)</td>
<td>5.89 (2.47)</td>
<td>5.88 (1.88)</td>
<td>0.69*</td>
</tr>
<tr>
<td>Inspiratory time (s)</td>
<td>1.0 (0.7)</td>
<td>0.98 (0.1)</td>
<td>1.01 (0.07)</td>
<td>0.47</td>
</tr>
<tr>
<td><strong>Comorbidities (n/%)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>None</td>
<td>5 (29.4)</td>
<td>2 (22.2)</td>
<td>3 (37.5)</td>
<td>0.62*</td>
</tr>
<tr>
<td>One to three</td>
<td>12 (70.6)</td>
<td>7 (77.8)</td>
<td>5 (62.5)</td>
<td></td>
</tr>
<tr>
<td>(DM, HBP, Dyslipidemia)</td>
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</tbody>
</table>

*pPearson’s chi square; *Mann-Whitney test; SaO₂, arterial partial oxygen pressure; CPB, cardiopulmonary bypass; DM, diabetes mellitus; HBP, high blood pressure; Intraop, intraoperative; postop, postoperative; NMBS, neuromuscular blocker.

### Analysis of results on Ncases

Out of 51 cases, twenty-three (45.1%) presented asynchrony at some point, occurring in fourteen (51.9%) cases initially ventilated in VCV and nine cases (37.5%) in PCV. The mean number of total asynchronies was 9.04 (7.44%) asynchronous cycles and the AI, was 12.22 (7.99%).

In comparison to PCV, VCV group scored higher indexes in all phases, although not statistically significant. The pattern of AI, between both groups shows large difference in assist-controlled moment and that difference prospectively decreases until extubation, as seen in Figure 3. Out of the cases with asynchrony at some point in their phases \( (n=23) \), 16 presented severe asynchrony (AI of 10% or higher) and 7 had AI less than 10%. There were no statistical differences in EuroScore II \( (p=0.46) \), neither in the respiratory variables (Table 3). The asynchrony severity also showed no
significant associations with the type of mechanical ventilator used (p=1.00) by a binomial test comparing the proportions of patients ventilated in either one of the ventilators available. Out of the cases with AIt of 10% or higher (n=16), thirteen occurred under the use of Savina ventilator and three of them under Engstrom ventilator. Out of the cases with AIt lower than 10% (n=7), six occurred under the use of Savina ventilator and one under the Engstrom ventilator. The odds of AIt of 10% or higher were higher in the VCV group compared to the PCV [VCV 146 (75.6%) vs PCV 47 (24.4%), OR 3.46 (1.97-6.07); p<0.001]. (Figure 4). Regarding the assisted breathing phases, group-independently, the AIt of 10% or higher was more likely to occur during T1 than in T2 (T1: 86 (70.5%) vs T1). T2: 36 (29.5%), OR 3.85 (1.9-7.79); p<0.001. Between the two phases of spontaneous breathing (T2 and T3), the AIt presents a higher chance of severity in phase T3 [T2: 36 (33.6%) vs T3: 71 (66.4%), OR 0.47 (0.24-0.91); p=0.025] (Figure 4). When analyzing the severity of the AIt in both groups and in all phases, we observed that the odds for an AIt of 10% or higher were higher in patients initially ventilated at VCV within all phases [OR 2.79 (1.36-5.73) between T1 and T2; p=0.005, OR 2.61 (1.27-5.37) between T1 and T3; p=0.009 and OR 4.99 (2.37-10.37) between T2 and T3; p<0.001] (Figure 4). In relation to the AIt by types of asynchronies, double triggering and early cycling were the most frequent and with greater magnitude in the groups, whereas auto-triggering and late cycling were not detected. Both in inter-group and in intra-phases analysis, there were no significant differences for the specific AI (Table 4).

Discussion

The main findings in this study were: i) the visual inspection method proved to be reliable for the detection of patient-ventilator asynchrony with strong correlation and high inter-rater agreement; ii) There was a high number of patients who presented asynchrony.

Table 2. Monitoring parameters of ventilation and oxygenation.

<table>
<thead>
<tr>
<th>Initial mode</th>
<th>Ventilatory phases</th>
<th>Vc/kg (ml/kg)</th>
<th>FR (rpm)</th>
<th>Tinsp (s)</th>
<th>pH</th>
<th>PaCO2 (mmHg)</th>
<th>PaO2/FiO2</th>
</tr>
</thead>
<tbody>
<tr>
<td>VCV</td>
<td>T1 (n=9)</td>
<td>8.9 (2.5)</td>
<td>17.5 (4.4)</td>
<td>0.99 (0.07)</td>
<td>7.38 (0.1)</td>
<td>38.3 (7.2)</td>
<td>356.5 (91.7)</td>
</tr>
<tr>
<td></td>
<td>T2 (n=9)</td>
<td>10.2 (2.7)</td>
<td>14.8 (2.7)</td>
<td>1.29 (0.14)</td>
<td>7.36 (0.1)</td>
<td>38.3 (3.0)</td>
<td>398.9 (87.3)</td>
</tr>
<tr>
<td></td>
<td>T3 (n=9)</td>
<td>9.3 (3.3)</td>
<td>15.7 (3.0)</td>
<td>1.33 (0.17)</td>
<td>7.33 (0.6)</td>
<td>39.0 (6.0)</td>
<td>381.6 (73.8)</td>
</tr>
<tr>
<td>PCV</td>
<td>T1 (n=8)</td>
<td>8.7 (1.3)</td>
<td>16.6 (2.1)</td>
<td>1.01 (0.07)</td>
<td>7.30 (0.1)</td>
<td>40.6 (6.0)</td>
<td>375.6 (91.4)</td>
</tr>
<tr>
<td></td>
<td>T2 (n=8)</td>
<td>8.7 (1.3)</td>
<td>15.8 (2.5)</td>
<td>1.14 (0.14)</td>
<td>7.33 (0.1)</td>
<td>39.3 (3.7)</td>
<td>346.7 (45.3)</td>
</tr>
<tr>
<td></td>
<td>T3 (n=8)</td>
<td>8.9 (2)</td>
<td>16.8 (4.0)</td>
<td>1.2 (0.13)</td>
<td>7.36 (0.1)</td>
<td>36.8 (2.8)</td>
<td>360.2 (63.6)</td>
</tr>
</tbody>
</table>

Intergroup: VCV x PCV

- T1 x T2: 0.20
- T1 x T3: 0.57
- T2 x T3: 0.46
- Interaction group-phase: 0.89

- Student t-test; two-factor ANOVA test; Paw, airway pressure; Ppeak, peak pressure; Vte/kg, tidal volume/predicted body weight; PaCO2, arterial partial pressure of carbon dioxide; PaO2, arterial partial oxygen pressure; FiO2, inspired oxygen fraction.

Table 3. Comparison of severity scores and respiratory variables between AI cut-off points.

<table>
<thead>
<tr>
<th>Variables</th>
<th>AI &lt;10% (n=7)</th>
<th>AI ≥10% (n=16)</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>EuroScore I</td>
<td>1.5 (2.12)</td>
<td>2.71 (1.8)</td>
<td>0.46</td>
</tr>
<tr>
<td>V (ml/PBW)</td>
<td>10.52 (3.27)</td>
<td>9.25 (2.12)</td>
<td>0.29</td>
</tr>
<tr>
<td>RR (ipm)</td>
<td>16.57 (2.15)</td>
<td>15.06 (2.11)</td>
<td>0.20</td>
</tr>
<tr>
<td>Tins (s)</td>
<td>1.13 (0.17)</td>
<td>1.18 (0.2)</td>
<td>0.63</td>
</tr>
<tr>
<td>pH</td>
<td>7.34 (0.04)</td>
<td>7.37 (0.07)</td>
<td>0.34</td>
</tr>
<tr>
<td>PaCO2 (mmHg)</td>
<td>39.4 (4.44)</td>
<td>41.16 (5.9)</td>
<td>0.48</td>
</tr>
<tr>
<td>PaO2/FiO2</td>
<td>357.28 (48.3)</td>
<td>371.16 (86.3)</td>
<td>0.46</td>
</tr>
</tbody>
</table>

- Mann-Whitney test.
with the ventilator at some point during the immediate postoperative period, although compared to the total number of ventilatory cycles their percentage of asynchronous cycles was low; iii) The presence of asynchrony and AI ≥10% was not influenced by clinical severity and did not lead to alterations in oxygenation and ventilation, and there were no cases of weaning failure; iv) The chance of AI ≥10% was higher in VCV ventilation than in PCV, and it maintains in the following PSV phases; and v) double triggering and early cycling were the most common and with the highest indexes with short-term mechanical ventilation.

**Offline asynchrony detection method application**

The most advanced asynchrony detection methods include automatic detection software [13,29-31] and semi-invasive methods [14,32-36], which allow more accurate monitoring of the interaction between mechanical ventilators and patients by capturing signals of diaphragmatic activity during the inspiratory effort. Even so, the advanced methods have their limitations for use in clinical practice.

Software limitations are usually research-purpose-only application and also dependent on determined mechanical ventilators models. Meanwhile, the semi-invasive methods require professional expertise for adequate catheter positioning in order to ensure accurate functioning and reliability on the graphics capture. Another problem is the high-price of both set of methods, which makes them unfeasible for daily clinical practice [20,29,31].

![Figure 4. Total asynchronies and Odds ratio weighted by AI with their respective confidence intervals. Situation analysis: 1, VCV x PCV modes; 2, T1 x T2 phases; 3, T1 x T3 phases; 4, T2 x T3 phases; 5, VCV x PCV in T1-T2 strata; 6, VCV x PCV in T1-T3 strata; 7, VCV x PCV in T2-T3 strata.](image1)

**Table 4. Specific asynchrony indexes by modes and phases.**

<table>
<thead>
<tr>
<th>Initial mode</th>
<th>Phase</th>
<th>AI</th>
<th>IIE</th>
<th>DT</th>
<th>EC</th>
<th>IEE</th>
</tr>
</thead>
<tbody>
<tr>
<td>VCV</td>
<td>T1 (n=5)</td>
<td>17.20 (5.35)</td>
<td>-</td>
<td>10.75 (5.37)</td>
<td>6</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>T2 (n=3)</td>
<td>14.7 (4.8)</td>
<td>3</td>
<td>4 (1.41)</td>
<td>2.67 (1.15)</td>
<td>1.5 (0.71)</td>
</tr>
<tr>
<td></td>
<td>T3 (n=6)</td>
<td>14.39 (8.5)</td>
<td>1.25 (0.5)</td>
<td>8.83 (12.35)</td>
<td>3.75 (3.1)</td>
<td>-</td>
</tr>
<tr>
<td>PCV</td>
<td>T1 (n=4)</td>
<td>9.75 (2.34)</td>
<td>1</td>
<td>4.5 (4.95)</td>
<td>2.5 (0.71)</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>T2 (n=3)</td>
<td>10.86 (7.36)</td>
<td>-</td>
<td>2.3 (1.53)</td>
<td>2 (1.41)</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>T3 (n=2)</td>
<td>12.16 (5.15)</td>
<td>1</td>
<td>3.5 (0.71)</td>
<td>-</td>
<td>4 (1.4)</td>
</tr>
<tr>
<td>p</td>
<td>Inter-group VCV x PCV</td>
<td>0.37</td>
<td>0.67</td>
<td>0.46</td>
<td>0.53</td>
<td>0.06</td>
</tr>
<tr>
<td></td>
<td>Inter-phases</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>T1 x T2</td>
<td>0.96</td>
<td>1.00</td>
<td>0.56</td>
<td>0.33</td>
<td>0.15</td>
</tr>
<tr>
<td></td>
<td>T1 x T3</td>
<td>0.22</td>
<td>-</td>
<td>0.68</td>
<td>0.70</td>
<td>0.50</td>
</tr>
<tr>
<td></td>
<td>T2 x T3</td>
<td>0.26</td>
<td>-</td>
<td>0.97</td>
<td>0.29</td>
<td>0.10</td>
</tr>
<tr>
<td></td>
<td>Interaction group-phase</td>
<td>0.64</td>
<td>0.87</td>
<td>0.74</td>
<td>0.24</td>
<td>0.24</td>
</tr>
</tbody>
</table>

All: total asynchrony index; IIE, ineffective inspiratory effort; DT, double-triggering; EC, early cycling; IEE, ineffective expiratory effort; RT, reverse triggering; ANOVA two-way.
The method of visual inspection is acceptable for asynchrony diagnosis and thus helps to take the measures of correcting it. The results of Thille et al. [20] on evaluating this method by two assessors showed good reproducibility due to the strong and significant correlation (n=62, ρ=0.94, p<0.01) and high agreement (κ value 0.96, p<0.01) in long-term patients under mechanical ventilation. These results were similar to ours.

According to Kottner et al., despite varying according to aim, diagnoses and estimated margin of error for decision-making, values of at least 0.60 for intra-class coefficient are an acceptable level of reliability for a method of evaluation [30]. Thus, we consider that the method of visual inspection adopted for this study is reliable for the detection of asynchrony. However, we recognize that the analysis may be underestimated in relation to semi-invasive methods [37].

Asynchronies incidence and impact in clinical outcomes

In our findings around 80% of the patients presented some type of asynchrony, and this was similar to other studies, although their patients were non-surgical. Kuo et al. [37] reported an incidence of asynchrony of 87% and Fabry et al. [38] detected 81%, both with the majority of patients having COPD. De Wit et al. [39] detected 85% in patients with ARF mainly due to pneumonia [38-40]. In these studies, they appeared as factors associated with the incidence of asynchrony to the hyperinflated lung condition of some patients and deep sedation. Our incidence rate was lower compared to other studies such as Chao et al. [41], who detected 10.9% in chronically ill patients in prolonged mechanical ventilation weaning. Robinson et al. It is noteworthy that, although the incidence was high, it had a small magnitude with only 7% of asynchrony cycles, and no repercussions were observed for oxygenation and ventilation. Some studies report associations of asynchronies cycles with the worst prognosis in clinical outcomes, such as longer mechanical ventilation [34], higher incidence of tracheostomy [35], longer ICU stay, and hospital mortality [44-47]. Others suggested associations between the high prevalence of asynchrony and changes in physiological variables, such as ventilation and oxygenation, described in the literature as influencing the severity of the asynchrony index. The study by Thille et al. [20] analyzed 62 patients with no specific profile with duration of mechanical ventilation of around 10 days, who were able to trigger assisted ventilation of around 10 days, who were able to trigger assisted ventilation. Two mechanical ventilators from different manufacturers were used, with operating characteristics with small differences. We believe that this did not influence the results since the asynchrony indices did not differ in the analysis stratified by the manufacturer of the mechanical ventilator.

Methodological limitations

Some limitations to be considered are that our results are based on a selected population profile, less than 65 years of age, not obese, with low risk for the severity score, who had undergone elective surgeries, and had no history of pulmonary disease. We did not evaluate respiratory function and muscular strength in the pre-surgical period, which are factors associated to the presence of
asynchrony. In future studies, it would be interesting to verify whether the implications observed in this study apply to obese cardiac post-operative patients, who were older, had been on mechanical ventilation for a longer period, or had postoperative complications, since we noticed a larger number of these patients, who ended up being excluded from our study because they were not covered by our criteria.

There is a high presence of asynchrony, and in most cases with critical asynchrony index in surgical patients, although we cannot extrapolate the results to more severe clinical conditions. The method of visual inspection, although reliable and reproducible, is done offline, allowing reanalysis, which in clinical practice is not possible. This offline method is time-consuming, requiring expertise not only to recognize and classify changes in curves but also to handle the files to be analyzed later.

**Clinical implications**

In view of this high presence of asynchrony and a significant incidence of asynchrony index of 10% or greater, it is necessary to reinforce that the ICU healthcare professionals involved in the management of mechanical ventilation be better aware of monitoring these events and minimizing them for improved clinical prognosis. In these patients, PCV ventilation seems to be better because it had a lower chance of a critical asynchrony index, besides the additional advantage of preventing pulmonary complications due to unregulated pressure. We concluded that there is a high incidence of patients with asynchrony at some time during the short period of mechanical ventilation in the postoperative period although with a low incidence of asynchronous cycles, with emphasis on early cycling and double firing. The VCV mode presented a higher chance of the occurrence of critical asynchrony index remaining during the prospective phases towards weaning.

**List of abbreviations**

- Aspecific: asynchrony index specific
- Alt: asynchrony index total
- CPB: cardiopulmonary bypass
- DC: delayed cycling
- DM: diabetes mellitus
- DT: double triggering
- EC: early cycling
- EIT: electrical impedance tomography
- FiO2: inspired fraction of oxygen
- HBP: high blood pressure
- HR: heart rate
- ICU: intensive care unit
- IEE: expiratory ineffective effort
- IIE: inspiratory ineffective effort
- NMB: neuromuscular blocking
- PaCO2: arterial partial pressure of carbon dioxide
- PaO2: arterial partial pressure of oxygen
- Paw: airway pressure
- PCV: pressure-controlled ventilation
- PEEP: positive end-expiratory pressure
- PSV: pressure support ventilation
- PVA: patient-ventilator asynchrony
- RR: respiratory rate
- RT: reverse triggering
- SaO2: arterial partial pressure of oxygen
- SpO2: peripheral oxygen saturation
- Tins: inspiratory time
- VCV: volume-controlled ventilation
- Vte: expired tidal volume

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