Acta Biomed for Health Professions 2018; Vol. 89, S. 7: 6-18 DOI: 10.23750/abm.v89i7-S.7737

Original article: Technical skills and tools

Patient-ventilator asynchronies: types, outcomes and nursing detection skills

Enrico Bulleri[1], Cristian Fusi[1], Stefano Bambi[2], Luigi Pisani[3]

[1] Department of Intensive Care and Anaesthesia, Fondazione Poliambulanza Hospital, Brescia, Italy; [2] Medical & Surgical Intensive Care Unit, Careggi University Hospital, Florence, Italy; [3] Department of Intensive Care, Academic Medical Center, Amsterdam, The Netherlands & Mahidol Oxford Tropical Medicine Research Unit, Bangkok, Thailand

Abstract. *Background:* Mechanical ventilation is often employed as partial ventilatory support where both the patient and the ventilator work together. The ventilator settings should be adjusted to maintain a harmonious patient–ventilator interaction. However, this balance is often altered by many factors able to generate a patient ventilator asynchrony (PVA). The aims of this review were: to identify PVAs, their typologies and classifications; to describe how and to what extent their occurrence can affect the patients' outcomes; to investigate the levels of nursing skill in detecting PVAs. *Methods:* Literature review performed on Cochrane Library, Medline and CINAHL databases. *Results:* 1610 records were identified; 43 records were included after double blind screening. PVAs have been classified with respect to the phase of the respiratory cycle or based on the circumstance of occurrence. There is agreement on the existence of 7 types of PVAs: ineffective effort, double trigger, premature cycling, delayed cycling, reverse triggering, flow starvation and auto-cycling. PVAs can be identified through the ventilator graphics monitoring of pressure and flow waveforms. The influence on patient outcomes varies greatly among studies but PVAs are mostly associated with poorer outcomes. Adequately trained nurses can learn and retain how to correctly detect PVAs. *Conclusions:* Since its challenging interpretation and the potential advantages of its implementation, ventilator graphics monitoring can be classified as an advanced competence for ICU nurses. The knowledge and skills to adequately manage PVAs should be provided by specific post-graduate university courses.

Key words: review, patient, waveform, ventilator, asynchrony, dyssynchrony, intensive care unit, nurses, skill, knowledge

Introduction

Mechanical ventilation represents the main life supporting treatment in critically ill patients. However, it is however associated with various complications (1), such as ventilator-associated pneumonia (2), ventilator-induced lung injury (VILI) (3), ventilation-induced diaphragm dysfunction (4) and patient ventilator asynchrony (PVA) (5).

Technological evolutions in delivering and monitoring of mechanical ventilation has rapidly expanded, currently offering a wide array of tools. The ventilator graphics monitoring is one of the most important instruments available for doctors and nurses. Waveforms monitoring allows a bedside unique assessment of the interaction between patient and ventilator, allowing the prevention or early detection of asynchronies.

Mechanical ventilation is frequently employed as partial ventilatory support in situations where both the patient and the ventilator work together. Ideally, the ventilator settings should be adjusted to maintain a normal level of respiratory muscle activity and

For the Triggerlab team (https://triggerlab.org)

a harmonious patient–ventilator interaction (6, 7). However, this fragile balance is often altered by many factors able to generate patient ventilator asynchronies (8). PVA can be defined as "a mismatch between patient breaths and ventilator-assisted breaths as well as the ventilator's ability to meet the patient's flow demand" (5). Since this problem is associated with worse outcomes the prompt identification, management and thus reduction of PVAs have been recognized as fundamental actions during both invasive and non-invasive ventilation (NIV) (9, 10).

Nurses can play a key role in the early detection of an improper interaction between patient and ventilator. However, to date there's no clarity about the diffusion of nurses' knowledge and skills related to the ventilator waveforms interpretation and the detection of asynchronies. Moreover, there are a scarce number of handbooks and monographs facing the issue of patient-ventilator interaction from the nurses' point of view. To the best of our knowledge, this kind of issue is rarely included in intensive care nursing educational programs.

Therefore, we have designed a literature review with the following aims: to identify and classify PVAs during invasive and noninvasive ventilation; to describe how and to what extent their occurrence can affect patients' outcomes (such as mortality, duration of mechanical ventilation, work of breathing, VILI occurrence); lastly, to assess the degree of nursing skills in detecting PVAs through ventilator graphics monitoring.

Methods

A literature review was performed through medical and nursing scientific databases: Cochrane Library, PubMed-Medline and CINAHL. The references of the included full text papers were scanned, and the articles considered pertinent were retrieved and analyzed with same criteria. Three research questions were built using the PICO format (patient population, intervention, comparison- intervention, and outcome of interest) and PECO format when applicable (patient population, exposure, comparation, outcome). The research questions and keywords are reported in table 1.

Studies performed on animals pediatric, and neonatal patients, and trauma patients were excluded. The search was limited to Italian and English languages. No restriction to any study design and no restriction in time was applied in the search, but papers without

Table 1 - Research questions based on the PICO/PECO Format

Issue	Aim	PICO/PECO
Asynchrony	To identify the various typologies of patient-ventilator asynchronies and describe their classifications	**P** – ICU adult patients; **E** – invasive or noninvasive mechanical ventilation; **C** - /; **O** – asynchronies with ventilators
Patients' outcome due to ventilator asynchronies	To reveal how and to what extent patients-ventilator asynchronies can affect patients' outcome	**P** – ICU adult patients; **E** – asynchronous mechanical ventilation; **C** – synchronous mechanical ventilation; **O** – mortality rates, ventilation days, VILI, work of breathing levels
Nursing Skills	To investigate the nurses' level of knowledge and skills in the detecting of patient-ventilator asynchronies through the ventilator graphics monitoring	**P** – ICU nurse; **I** – ventilator graphics monitoring knowledge/skills; **C** – /; **O** – detection of ventilator asynchronies and improvement of patients' outcomes
Keywords	Nurse [MeSH Terms]; ventilator waveform [Text Word]; clinical competence [MeSH Terms] OR skill [Text Word]; knowledge [MeSH Terms]; patient ventilator asynchrony [Text Word]; patient ventilator dyssynchrony [Text Word]; nurse knowledge [Text Word]; ventilators, mechanical [Mesh Term] OR ventilator [Text Word]; patient outcome assessment [MeSH Terms] OR outcomes [Text Word]; patient ventilator interaction [Text Word], work of breathing [MeSH Terms], mortality [MeSH Terms], hospital length of stay [Text Word].		

an abstract were excluded. The upper time limit of this search was settled to June 2018.

All abstracts and full texts of the retrieved records were independently reviewed by two reviewers (the authors EB and CF); any discrepancy resolved collegially.

Results

A total of 1610 records were retrieved through database searches, and an additional 15 records were identified from manuscripts references. A total of 43 records were included in the analysis. Figure 1 shows the flow-chart of the literature review and the overview of included studies.

PVAs classification and types of asynchronies

The papers answering to this research question that were included in this review were 37 (11-47).

The need to identify and understand PVAs has led many authors to search and propose different classification methods.

PVAs have been classified with respect to the phase of the respiratory cycle as: asynchronies of the triggering phase or just "trigger asynchronies" (ineffective efforts/delay triggering, auto-triggering, double triggering and reverse triggering); asynchronies during flow delivery phase or "flow asynchronies" (flow starvation in volume controlled ventilation and insufficient pressurization - rise time too slow in pressure support ventilation-); asynchronies during cycling phase or "cycling asynchronies" (late cycling and premature cycling) (11-16). Some authors have identified a fourth category of asynchronies or "expiratory asynchrony" (shortened expiratory time) (12, 13). This classification can facilitate the diagnosis at the bedside using ventilator's waveforms analysis (12).

Subirà et al. have provided another kind of classification, based on the breathing cycle phase (17). Thus PVAs are distinguished in three groups: generated during the inspiratory period (trigger delay, inspiratory flow mismatching, short cycling and reverse triggering); during the transition from inspiration to expiration (double triggering due to short cycling or reverse triggering and expiratory muscle contraction due to prolonged cycling); during the expiratory period (ineffective inspiratory effort, auto-triggering and expiratory muscle contraction).

Lastly, a new classification of PVAs based on the circumstances of occurrence has been introduced (18, 19) to highlight the fact that PVAs occur primarily in the context of either high respiratory drive or low respiratory drive. As explained by Dress et al., in case of high respiratory drive we must discriminate whether the asynchronies (flow starvation, premature cycling, double triggering/breath stacking) are caused by an insufficient level of ventilator assistance and unmatched needs, or whether they are intrinsic to the patient's acute disease and thus best treated with additional sedation (18). At the other extreme, PVAs associated with low respiratory drive (reverse triggering – resulting in double cycling, delayed cycling, ineffective efforts) may be due to distinct mechanisms as sedation or over-assistance (19).

Ineffective effort and trigger delay

Also known as "ineffective triggering", "missed triggering" or "wasted effort", it is the most frequent type of asynchrony (20, 21), both in the early course of the disease, and during prolonged ventilation (22-24). This asynchrony is defined as inspiratory muscle effort not followed by a ventilator breath. The ventilator fails to detect the patient's inspiratory efforts, which are characterized by an increase in trans-diaphragmatic pressure and/or electrical activity of the diaphragm (EAdi) (12, 25, 26).

The inspiratory triggers are affected by delays due to the intrinsic reactivity of ventilators and their functioning characteristics (27). Nonetheless, there are some situations when there is a considerable delay between the time of respiratory muscle activation and the trigger activation, the so-called "trigger delay" (13-16, 28, 29). Ineffective effort and trigger delay are similar asynchronies because they have the same mechanism although yielding a different result. During ineffective efforts the ventilator does not deliver the inspiratory assistance because the trigger is not activated; conversely, with 'trigger delay' the patient manages to activate the trigger after a considerable time.

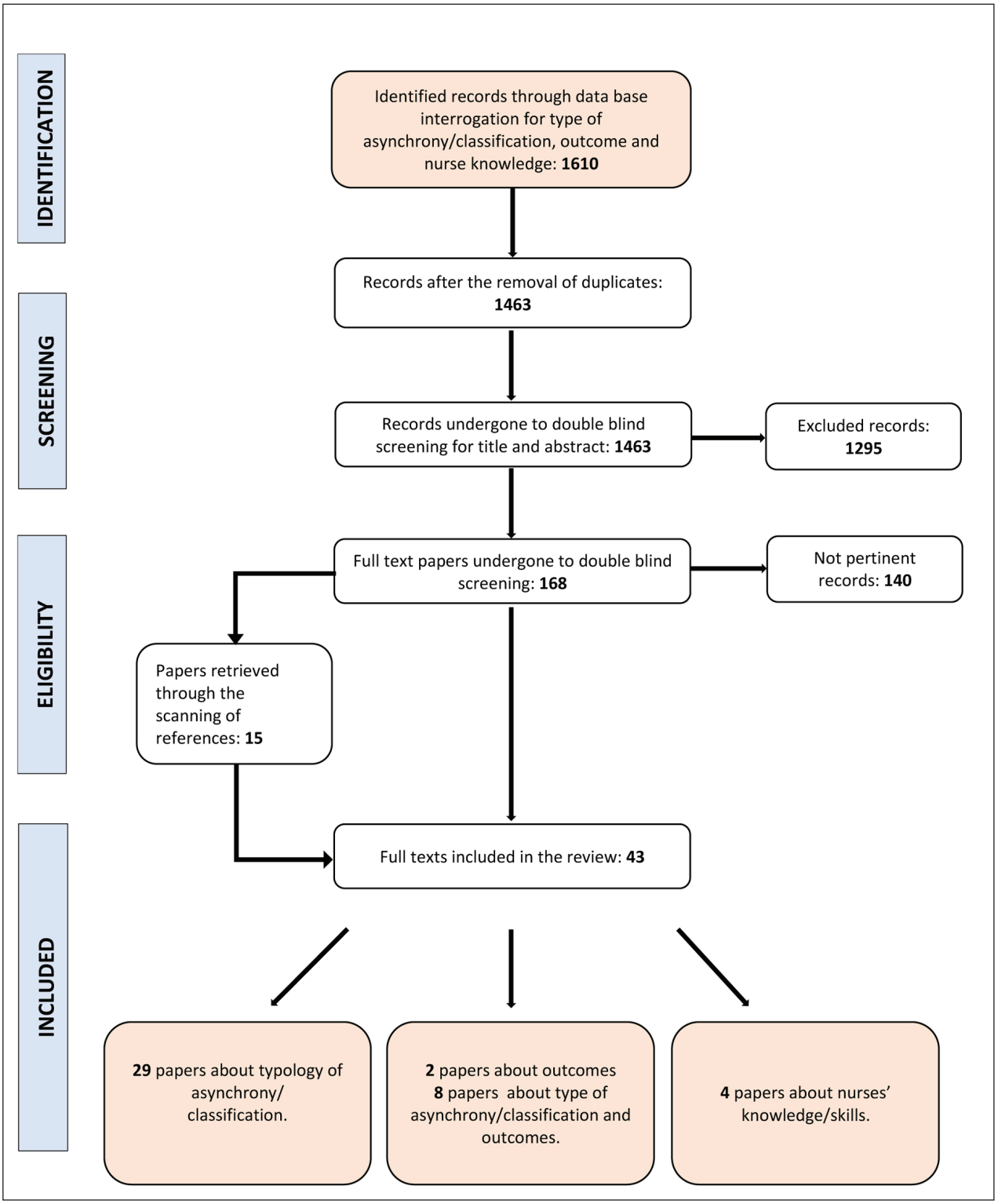

Figure 1. Flow chart of the literature review

Ineffective effort and trigger delay may occur during both the inspiratory or expiratory cycle. It can depend on a variety of mechanisms, such as a weak respiratory drive and/or effort as when these are reduced by ventilator over-assistance (30, 31) and excessive sedation levels (24, 32). They may also occur with a high intrinsic positive end-expiratory pressure (PEEPi), or an excessively low ventilator trigger sensitivity setting (23, 24, 33). The presence of ineffective effort is detected on ventilator graphics by a downward concavity of the flow/time waveform (sign that the expiration is briefly interrupted) with a simultaneous upward concavity of the pressure/time waveform (not apparent in some cases). When a nasogastric tube equipped with electrodes for EAdi recording is inserted, ineffective efforts can be promptly confirmed, i.e. the diaphragmatic depolarization - contraction - is not followed by the trigger activation and the consequent system pressurization (figure 2A).

Premature cycling and double-triggering

Premature or short cycling occurs when the neural time is greater than the ventilator's inspiratory time. The ventilator ends flow delivery, but the patient's inspiratory effort continues (17). Premature cycling describes a condition where the end of the ventilator insufflation anticipates patient's effort termination and it is more frequent in patients with low compliance, such as in Acute Respiratory Distress Syndrome (ARDS), or in case of inspiratory time set too short (34, 35). Moreover, this condition may result in double triggering (36): if the patient's effort exceeds the trigger threshold, it can activate another breath, generating a double-triggering.

The premature cycling occurs at the beginning of expiratory phase. It can be detected by an expiratory flow waveform that start with a peak, but it returns rapidly to a level near to 0 (baseline). The airways pressure waveform (Paw) does not end at the PEEP level but draws a small depression (indicating that inspiratory muscles are still working and depressurizing the system). The patient delays the expiration for few tenths of a second, as the EAdi waveform confirms (figure 2B).

Double-triggering, also named breath-stacking in Assist/Control (A/C) ventilation (37), is characterized by two consecutive ventilator cycles (triggered by the patient) separated by an expiratory time lower than one-half of the mean inspiratory time. The patient's effort is not completed at the end of the first ventilator cycle and triggers a second ventilator cycle (23, 38). On the ventilator's graphic, double triggering is displayed as two breaths very close: as one inspiratory phase has ended, the next one starts immediately. Usually the double triggering is interpreted as a double activation of inspiratory trigger. However, this activation is generated by an only one efforts of respiratory muscles, as confirmed by the EAdi waveform. When the mechanical ventilator cycles to the expiratory phase, an immediate pressure drop occurs, due to the inspiratory muscles that are still in tension and activate the inspiratory trigger, determining a new mechanical insufflation (figure 2C).

Double-triggering and premature cycling can also occur when the patient's ventilatory demand is high and the ventilator inspiratory time is too short (35, 39). These types of asynchrony occur more frequently in patients with severe lung injury and increased respiratory drive (19).

Also, acute respiratory failure patients managed with low tidal volumes (≤6 ml/kg of ideal body weight) can easily develop double triggering. In these patients, the benefits hypothesized by a protective ventilation approach could be vanished when high tidal volumes are delivered due to this asynchrony (40).

Auto-triggering

Auto-triggering also known as "auto-cycling" is defined as a cycle delivered by the ventilator without a prior airway pressure decrease, indicating that the ventilator delivered a breath that was not triggered by the patient (23). The occurrence of auto-triggering can be due to airleaks in the system, or to an excessively high trigger sensitivity. Moreover, changes in airway pressure and/or flow secondary to cardiac oscillations or water accumulation in ventilator tubing can erroneously be sensed as triggering efforts (41, 27, 15).

To detect the activation of inspiratory muscles on the ventilator's graphics, the pressure-time waveform should be observed. A little deflection on the PEEP level immediately before the beginning of the inspira-

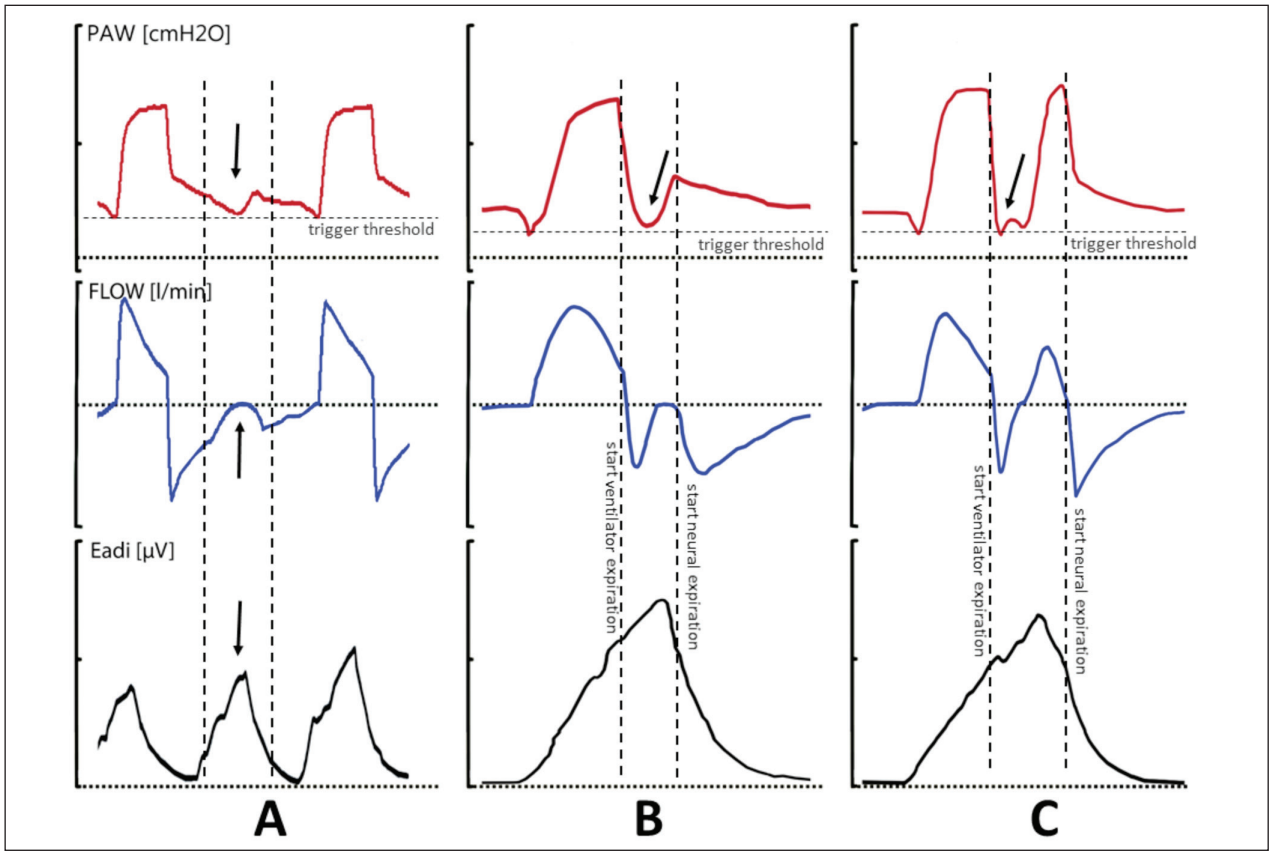

Figure 2. (A) Ineffective effort during pressure support ventilation (PSV). (B) Premature cycling during PSV. (C) Double triggering during PSV

tory phase indicates the presence of trigger activation. Auto-triggering can be spotted on ventilator's graphics by noticing the absence of trigger sign when this is expected (as during pressure support ventilation or assist-control ventilation) and a "passive-like" flow-time waveform. The absence of diaphragmatic depolarization showed by the EAdi waveform confirms the presence of this asynchrony (figure 3A).

Reverse triggering

Akoumianaki et al (42) described this type of asynchrony in acutely ill patients undergoing controlled mechanical ventilation. Ventilator insufflations trigger diaphragmatic muscle contractions through activation of the patient's respiratory center in response to passive insufflation of the lungs. If the inspiratory effort is strong enough, a second breath can be delivered by the ventilator, resulting in breath-stacking. As opposed to double-triggering, during reverse triggering the first breath is triggered by the *ventilator* and is followed by a *patient* inspiratory effort (19). The exact causal mechanism is unknown, but this asynchrony was found in heavily sedated ARDS patients (42) and in brain-death (43). Reverse triggering might result in alterations of measured plateau pressures, increased oxygen consumption, and hemodynamic instability. This may also play a role in ventilator induced diaphragmatic dysfunction (11).

A reverse triggering example is showed in figure 3B. A patient is supported with pressure-controlled ventilation. The ventilator starts the insufflation according to the settled time (no sign of triggering, since the breath is mandatory). After some tenths of second the patient activates his/her inspiratory muscles. This activation is detected by the light deflection on the pressure-time waveform, while the flow-time wave-

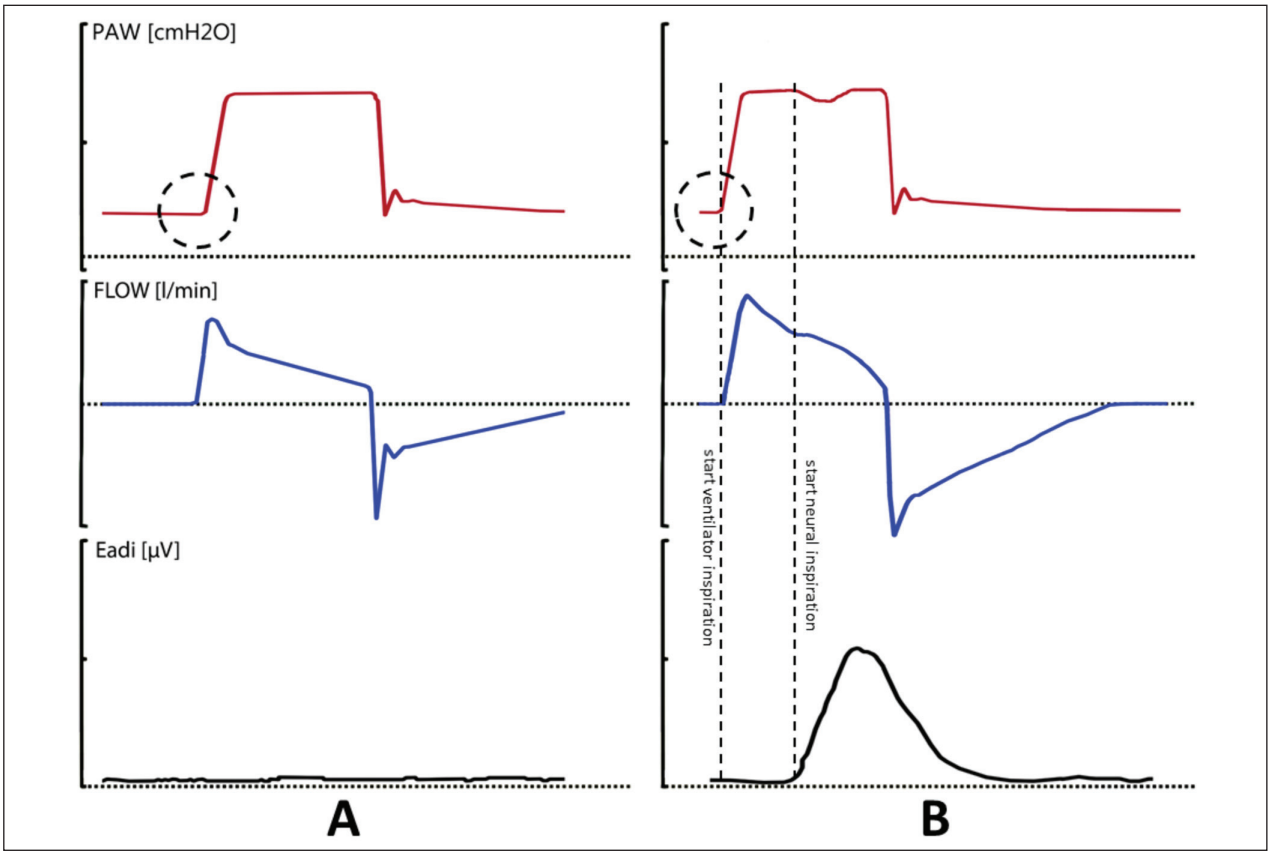

Figure 3. (A) Auto-cycling in PSV. (B) Reverse triggering during pressure-controlled ventilation (PCV)

form shows a light convexity. This kind of assessment on the ventilator's graphics is not easy, and sometimes it's impossible. If an EAdi waveform is available, the diagnosis of reverse triggering is simplified since the discrepancy between ventilator insufflation and the patient neural activation is clearly detectable.

Delayed cycling

When the ventilator inspiratory time exceeds the patients neural inspiratory time, an asynchrony known as late, prolonged or delayed cycling occurs (11). Mechanical insufflation continues after neural inspiration has ceased or even during active expiration. Most frequent causes are an inappropriate timing in cycling setting (17) and airleaks (44, 45). Chronic obstructive pulmonary disease (COPD) and asthma are risk factors for delayed cycling, and the shorter expiratory time contributes to worsening hyperinflation in these patients (46).

An example of delayed cycling due to airleaks caused by a large bronchopleural fistula during PSV is showed in figure 4A. The ventilator displays a delay in the ventilator's cycling as compared to the patient's neural activity. In this case, the flow-time waveform shows a slow decrease and late activation of the expiratory trigger, despite the patient has well began the neural expiration. Simultaneously, the pressure-time waveform records an *increase* in Paw between the end of neural inspiration and the end of the mechanical inspiration. These graphical aspects indicate that the patient truncated the inspiration before the ventilator has ended the inspiratory phase. This is confirmed by the EAdi waveform that displays the mismatch between the diaphragmatic relaxation and the end of mechanical inspiration.

Flow starvation

Gilstrap et al. have defined flow starvation as the PVA that "occurs when gas delivery fails to meet patients' flow demand". Inadequate gas delivery is common when ventilator flow is set inappropriately low, or the combination between V_T and inspiratory time does not result in adequate flow to the injured lung, or when inspiratory flow demands are high and vary from breath to breath (15).

The pressure-time waveform is typically "sucked down" by the patient's inspiratory effort (figure 4B). The delivered flow is markedly lower than patient's demand and excessive muscle loading may occur. When flow starvation is severe, the pressure–time waveform during inspiration can be pulled below the baseline airway pressure by a high patient's flow demands" (15, 16).

Flow asynchronies appear to be more common with ventilatory settings that deliver a fixed flow (flow-targeted breaths) rather than with a flow that can vary with effort (pressure-targeted breaths) (47)

Influence of PVAs on patient outcomes

The papers answering to this research question that were included in this review were 10 (21-24, 29, 35, 40, 44, 48, 50).

Chao et al (22) showed that 10.9% of 174 studied patients experienced ineffective breathing efforts. These patients had lower weaning success rates ($p<0.001$). In fact, the mean time of weaning in patients with asynchronies was 72 days versus 33 days in those well adapted to the ventilator ($p=0.013$).

The asynchrony index (AI, number of asynchronous breaths/total number of breaths X 100) >10% has

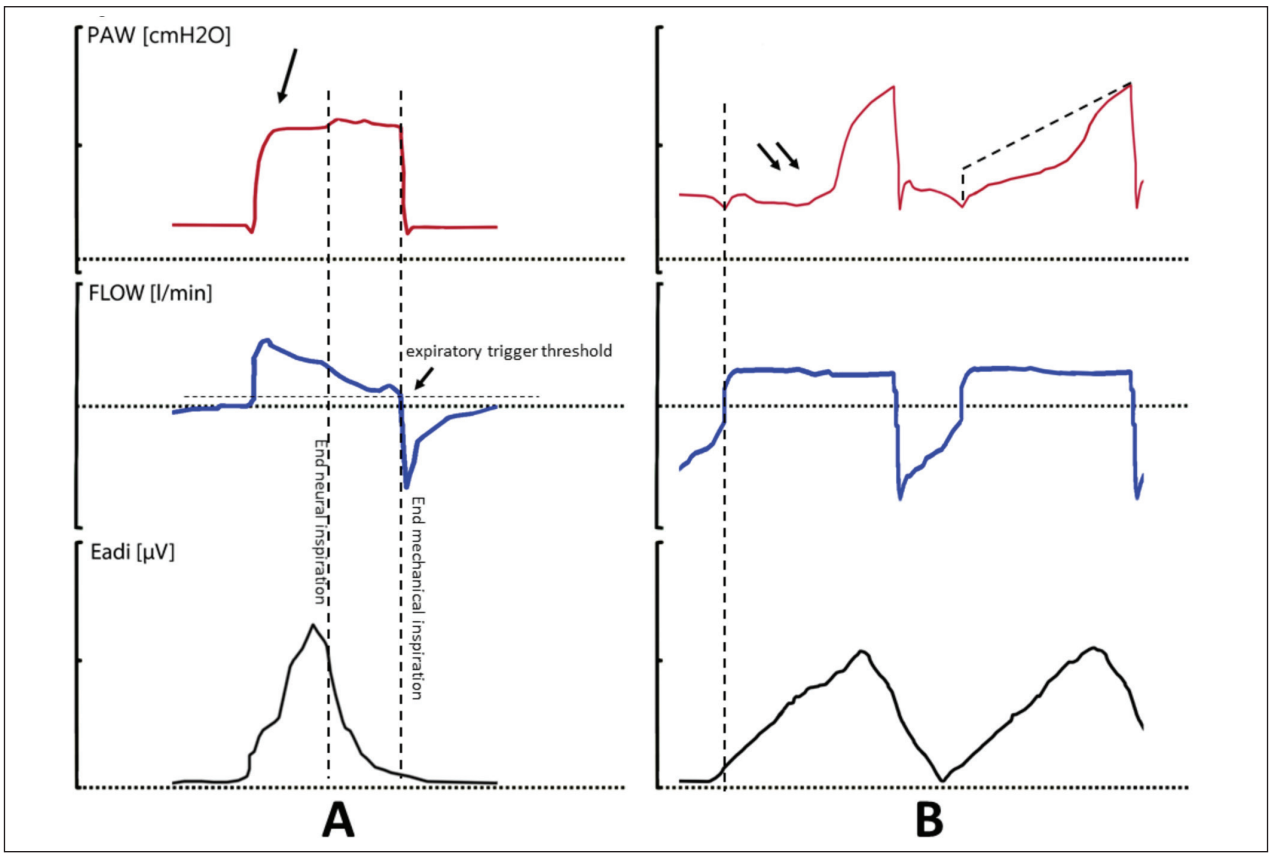

Figure 4. (A) Late cycling during PSV. (B) Flow starvation during volume controlled ventilation. The dot line shows the shape of the waveform in absence of flow starvation

been associated to longer mechanical ventilation duration (p=0.005) and higher incidence of tracheostomy (p=0.007), but not to mortality rates (p=0.36) (23). On the contrary, Blanch et al. found that values of AI>10% were associated to ICU mortality (p=0.011) and hospital mortality (p=0.044), but not to a larger mechanical ventilation duration time (p=0.061) (21).

During NIV the airleaks from the interface can determine a prolonged pressurization of the ventilator, causing an insufficient fall of the flow to reach the expiratory cycling threshold (44). Consequently, the ventilator cycling is considerably delayed, and the work of breathing increases (44), with consecutive decreased patient's compliance to NIV support.

Tokioka et al. (35) evaluated the effects of PSV cycling in patients recovering from acute lung injury, with flow-cycling at 1%, 5%, 20%, 35%, and 45% of peak inspiratory flow. The higher flow-cycling percentages resulted in premature cycling, double-triggering, lower tidal volumes, higher respiratory rate (p<0.001), and higher work of breathing (p<0.001). On the contrary, in patients with COPD higher percentages of expiratory trigger levels seem to decrease the extent of delayed cycling, reduce the intrinsic PEEP level, and the ventilator triggering effort (29).

De Wit et al. (24) found that the increase of ineffective trigger index (ITI, number of ineffective triggers/number of total breaths) was associated to deeper levels of sedation. In fact, lower Richmond Agitation and Sedation Scale scores were associated to higher rates of ineffective breathing efforts (p=0.04). In that study, patients who were awake showed about one-fifth of the total number of ineffective efforts when compared with not-awake patients (p=0.04) (24). The same authors (48) found that ITI ≥10% (if compared to ITI <10%) was an independent predictor for longer mechanical ventilation duration (10 days vs. 4, p=0.0004) and shorter ventilator-free survival (14 days vs. 21, p=0.03). Patients with ITI ≥10% had a longer ICU length of stay (8 days vs. 4, p=0.01) and hospital length of stay (21 days vs. 8, p=0.03). Mortality was similar in the two groups, but patients with ITI ≥10% were less likely to be discharged home (44% vs. 73%, p=0.04) (48).

Vaporidi et al (49) have introduced a new concept of events defined "clusters" of ineffective efforts (IE). These events are defined as more than 30 ineffective efforts in a time period of 3 minutes (about half the number of breaths per minute in a patient with a respiratory rate of 20 breaths per minute). This study showed that the ineffective effort index ≥10% had no correlation with critically ill patient's outcome; the presence of clusters of IE was associated with longer duration of mechanical ventilation (even in presence of IE index <10%) and higher hospital mortality.

In 2000 the ARDS network clearly showed that a lung-protective ventilation strategy can reduce mortality in patients with acute respiratory distress syndrome (ARDS) (50). Moreover, in ARDS patients ventilated in assist-control-volume (ACV) mode, tidal volumes of 4-6 mL/kg of IBW have been recommended to reduce VILI. However, Pohlman et al demonstrated that tidal volumes settled in ml/kg IBW had a strong association with the occurrence of breath-stacking (p=0.007) (40). Therefore, the beneficial effects of lower tidal volume ventilation may be decreased when this asynchrony is present.

Nursing detection skills

The papers answering to this research question that were included in this review were 4 (51-54).

Published studies about nurses' knowledge and/or skills in ventilator's graphics monitoring are scarce. Chacòn et al. in 2012 (51) investigated the level of nurses skills in detecting patients' ineffective breathing efforts through the monitoring of ventilators' graphics. 2 ICU nurses underwent to ad hoc education for monitoring ventilator's graphics, before undergoing a test about ineffective efforts. The answers of nurses were compared to those of 5 expert physicians (reference standard). The results indicate that nurses, if adequately skilled with specific courses, can detect patients' ineffective efforts with the same accuracy of expert clinicians (k=0.92 for the first nurse, and k=0.74 for the second one) (51).

The ability of nurses in detecting patient-ventilator asynchronies through graphics monitoring was confirmed by the before-after study performed by Fusi et al. (52). The authors have assessed the nurses' knowledge before a specific course on ventilator's graphics and after 6 months from its end. They record-

ed a significant increase in knowledge at the end of the training ($p<0.001$) which was retained after 6 months ($p<0.001$) (52).

Lynch-Smith et al. in 2016 (53), evaluated the influence on the mean duration of mechanical ventilation exerted by the education on patient-ventilator interaction performed on nurses and respiratory therapists. The study showed an increase of knowledge in nurses and respiratory therapists ($p<0.001$), but failed to demonstrate a relevant reduction in duration of mechanical ventilation (53). During the same year, Ramirez et al. (54) performed a survey on 25 hospitals in Chile that was administered to different professional roles in the ICUs with the aim to understand the factors affecting the ability to detect patient-ventilator asynchronies. The authors found that the only significant factor associated with an increased detection of PVAs was to have received previous training in ventilator waveform analysis ($p<0.001$). The professional role and the experience of the ICU team members did not influence the correctness in detecting the patient-ventilator asynchronies.

Discussion and conclusion

Salient findings of this review are: *1)* PVAs have been classified with respect to the phase of the respiratory cycle or based on the circumstance of occurrence but there is agreement on the existence of 7 types of PVAs: ineffective effort, double trigger, premature cycling, delayed cycling, reverse triggering, flow starvation and auto-cycling; *2)* the influence on patient outcomes varies greatly among studies but PVAs are mostly associated with poorer outcomes; *3)* adequately trained nurses can learn and retain how correctly detect PVAs.

The PVAs classification according to the phases of breathing cycle, has been made with the intent to ease the healthcare professional comprehension and detection through the ventilator waveforms. The classification offered by Dress et al. (18) and Pham et al. (19), based on the circumstances of PVAs occurrence, could simplify the treatment approach to the PVAs. However, there are no published studies showing that the use of PVAs classification methods could improve the detection and fixing of the PVAs. Beyond the diverse classifications, there is agreement on the existence of 7 types of PVAs, even if some incongruencies still persist among the definitions of the single typologies of PVA. This element could generate confusion in the understanding and approaching of PVAs, especially among the less trained professionals. Since the last 20 years, modern ventilators are equipped with continuous respiratory waveform monitoring on their displays useful in the detecting of asynchronies. Pressure and flow waveforms are available in all the modern ventilators, being a fundamental tool to understand patient-ventilators interactions (12). However, they have some limitations: visual inspection of waveforms in search of patient-ventilator asynchronies is objectively difficult (55). Moreover, the healthcare professionals' ability to recognize PVAs can be very low and affected by training in ventilator waveform analysis (54). In addition, some PVA are hardly recognizable if only the pressure-time and flow-time waveforms are used (18). In fact, sometimes the ventilator's waveforms could appear "normal" also when an asynchrony is occurring (56).

Some additional tools to face these limitations are available on the market: esophageal pressure monitoring and EAdi monitoring. The esophageal pressure is a surrogate of pleural pressure, providing useful data for the respiratory mechanics and pulmonary stress evaluation (57). This parameter allows an accurate interpretation of patient-ventilator interactions and asynchronies (6), but the esophageal pressure measurement is often underused in clinical settings due to lack of knowledge (58). EAdi signal allows to measure the size of diaphragmatic depolarization, expressed in μV. The nasogastric tube for EAdi records directly the respiratory drive and it's very accurate in revealing the beginning and the duration of neural inspiration and expiration (32). Its widespread use is limited by the need to have available a specific mechanical ventilator equipped with a patented technology and software.

PVAs are associated to poor outcomes, but it's not still clear if the occurrence of asynchronies is a factor directly affecting these outcomes or if it's an indicator of illness severity. In fact, the predisposing factors for PVAs are often related to the patients' severe clinical conditions, the presence of COPD, the ventilation modes and the changes of ventilator settings (22, 23).

Incidence of PVAs is affected by large variability in case definition, patients' conditions, ventilator modes, time and methods of observation, with studies reporting AI >10% rates ranging from 12 to 43% (21, 38). Among the occurrence of asynchronies, ineffective efforts are those with the highest percentages (20, 49). One of the main and frequent limits in the studies on incidence of PVAs and their effects on patients' outcomes is the short times of observations. In order to overcome this limitation, some researchers have studied the occurrence of asynchronies using adequate software for the continuous recording of the patient-ventilator interaction (21, 49).

The nurse could potentially play a crucial role in the early detection of PVA, since he/she is the professional figure spending the most part of the working time at the bedside. The detection of auto-cycling during brain death assessment is one enlightening example. In fact, the lack of detection of this asynchrony can potentially delay the brain death diagnosis (59) with consequences as longer ICU management times, and increased risk of losing potentially transplantable organs (60). The correct interpretation of ventilator waveforms could improve the multidisciplinary workflow in ICU and the therapeutic interventions (61). The effective early identification of double triggering, cluster of ineffective efforts and asynchronies between neural times and ventilator times could decrease the risk of complications. However, to date only few nurse researchers have faced the complex area of patient-ventilator interaction. In particular there is a lack of studies on the effectiveness of ventilator graphics monitoring performed by nurses.

The few available studies indicate that nurse-led ventilator waveform analysis is a practice rarely performed (13, 20, 54, 61, 62). Potential reasons for this can be found in the complexity of this kind of monitoring, the lack of specific educational courses and shortage of resources and didactic tools (61-63). These findings hint to a wide knowledge-gap in the patient-ventilator interaction domain that should be tackled by the clinical and academic community.

In conclusion, PVA are variously defined and classified, but the achievement of a unique and widely shared definition of the typologies of asynchronies should be desirable. Asynchronies have been associated to ICU and in-hospital mortality, and have the potential to compromise important clinical objectives. However, it's not clear if PVAs represent the root cause or are simply proxies of patients' illness severity level. Monitoring system to detect PVAs are currently available and effective, but scarcely implemented for the lack of skills, shortage of resources and education. Since its difficult interpretation and the potential implication of its implementation, the ventilator graphics monitoring can be classified as an advanced competence for nurses. The knowledge and training to manage adequately this issue should be provided by specific post-graduate university courses.

References

1. Klompas M. Complications of mechanical ventilation, the CDC's new surveillance paradigm. N Engl J Med 2013; 368 (16): 1472-5.
2. Kalanuria AA, Zai W, Mirski M. Ventilator-associated pneumonia in the ICU. Crit Care 2014; 18 (2): 208.
3. Slutsky AS, Ranieri VM. Ventilator-induced lung injury. N Engl J Med 2013; 369 (22): 2126-36.
4. Vassilakopoulos T, Petrof BJ. ventilator-induced diaphragmatic dysfunction. Am J Respir Crit Care Med 2004; 169: 336-41.
5. Sasson CS, Foster GT. Patient-ventilator asynchrony. Curr Opin Crit Care 2001; 7 (1): 28-33.
6. Wrigge H, Reske AW. Patient-ventilator asynchrony: adapt the ventilator, not the patient! Crit Care Med 2013; 41 (9): 2240-1.
7. Mauri T, Yoshida T, Bellani G, et al. Esophageal and transpulmonary pressure in the clinical setting: meaning, usefulness and perspectives. Intensive Care Med 2016; 42 (9): 1360-73.
8. Kondili E, Prinianakis G, Georgopoulos D. Patient-ventilator interaction. Br J Anaesth 2003; 91 (1): 106-19.
9. Garofalo E, Bruni A, Pelaia C, Liparota L, Lombardo N, Longhini F, et al. Recognizing, quantifying and managing patient-ventilator asynchrony in invasive and noninvasive ventilation. Expert Rev Respir Med 2018; 12 (7): 557-67.
10. Piquilloud L, Vignaux L, Bialais E, Roeseler J, Sottiaux T, Laterre PF, et al. Neurally adjusted ventilatory assist improves patient-ventilator interaction. Intensive Care Med 2011; 37 (2): 263-71.
11. Branson RD, Blakeman TC, Robinson BR. Asynchrony and Dyspnea. Respir Care 2013; 58 (6): 973-89.
12. Georgopoulos D, Prinianakis G, Kondili E. Bedside waveforms interpretation as a tool to identify patient-ventilator asynchronies. Intensive Care Med 2006; 32 (1): 34-47.
13. Nilsestuen JO, Hargett KD. Using ventilator graphics to

identify patient-ventilator asynchrony. Respir Care 2005; 50 (2): 202-34.
14. Epstein SK. How often does patient-ventilator asynchrony occur and what are the consequences? Respir Care 2011; 56 (1): 25-38.
15. Gilstrap D, MacIntyre N. Patient-ventilator interactions. Implications for clinical management. Am J Respir Crit Care Med 2013; 188 (9): 1058-68.
16. de Wit M. Monitoring of patient-ventilator interaction at the bedside. Respir Care 2011; 56 (1): 61-72.
17. Subirà C, de Haro C, Magrans R, Fernández R, Blanch L. Minimizing Asynchronies in Mechanical Ventilation: Current and Future Trends. Respir Care 2018; 63 (4): 464-78.
18. Dres M, Rittayamai N, Brochard L. Monitoring patient-ventilator asynchrony. Curr Opin Crit Care 2016; 22 (3): 246-53.
19. Pham T, Telias I, Piraino T, Yoshida T, Brochard L. Asynchrony Consequences and Management. Crit Care Clin 2018; 34 (3): 325-41.
20. Mellott KG, Grap MJ, Munro CL, Sessler CN, Wetzel PA, Nilsestuen JO, et al. Patient ventilator asynchrony in critically ill adults: frequency and types. Heart Lung 2014; 43 (3): 231-43.
21. Blanch L, Villagra A, Sales B, Montanya J, Lucangelo U, Luján M, et al. Asynchronies during mechanical ventilation are associated with mortality. Intensive Care Med 2015; 41 (4): 633-41.
22. Chao DC, Scheinhorn DJ, Stearn-Hassenpflug M. Patient-ventilator trigger asynchrony in prolonged mechanical ventilation. Chest 1997; 112 (6): 1592-9.
23. Thille AW, Rodriguez P, Cabello B, Lellouche F, Brochard L. Patient-ventilator asynchrony during assisted mechanical ventilation. Intensive Care Med 2006; 32 (10): 1515-22.
24. de Wit M, Pedram S, Best AM, Epstein SK. Observational study of patient-ventilator asynchrony and relationship to sedation level. J Crit Care 2009; 24 (1): 74-80.
25. Chen CW, Lin WC, Hsu CH, Cheng KS, Lo CS. Detecting ineffective triggering in the expiratory phase in mechanically ventilated patients based on airway flow and pressure deflection: feasibility of using a computer algorithm. Crit Care Med 2008; 36 (2): 455-61.
26. Blanch L, Sales B, Montanya J, Lucangelo U, Garcia-Esquirol O, Villagra A, et al. Validation of the Better Care® system to detect ineffective efforts during expiration in mechanically ventilated patients: a pilot study. Intensive Care Med 2012; 38 (5): 772-80.
27. Racca F, Squadrone V, Ranieri M. Patient-ventilator interaction during the triggering phase. Respir Care Clin N Am 2005; 11 (2): 225-45.
28. Costa R, Navalesi P, Spinazzola G, Rossi M, Cavaliere M, Antonelli M. Comparative evaluation of different helmets on patient–ventilator interaction during noninvasive ventilation. Int Care Med 2008; 34 (6): 1102-8.
29. Tassaux D, Gainnier M, Battisti A, Jolliet P. Impact of expiratory trigger setting on delayed cycling and inspiratory muscle workload. Am J Respir Crit Care Med 2005; 172 (10): 1283-9.
30. Thille AW, Cabello B, Galia F, Lyazidi A, Brochard L. Reduction of patient-ventilator asynchrony by reducing tidal volume during pressure-support ventilation. Intensive Care Med 2008; 34 (8): 1477-86.
31. Leung P, Jubran A, Tobin MJ. Comparison of assisted ventilator modes on triggering, patient effort, and dyspnea. Am J Respir Crit Care Med 1997; 155 (6): 1940-8.
32. Parthasarathy S, Jubran A, Tobin MJ. Cycling of inspiratory and expiratory muscle groups with the ventilator in airflow limitation. Am J Respir Crit Care Med 1998; 158 (5 Pt 1): 1471-8.
33. Vaschetto R, Cammarota G, Colombo D, Longhini F, GrossI F, Giovanniello A, et al. Effects of propofol on patient-ventilator synchrony and interaction during pressure support ventilation and neurally adjusted ventilatory assist. Crit Care Med 2014; 42 (1): 74-82.
34. Tassaux D, Michotte JB, Gainnier M, Gratadour P, Fonseca S, Jolliet P. Expiratory trigger setting in pressure support ventilation: from mathematical model to bedside. Crit Care Med 2004; 32 (9): 1844-50.
35. Tokioka H, Tanaka T, Ishizu T, Fukushima T, Iwaki T, Nakamura Y, et al. The effect of breath termination criterion on breathing patterns and the work of breathing during pressure support ventilation. Anesth Analg 2001; 92 (1): 161-65.
36. Mauri T, Bellani G, Grasselli G, Confalonieri A, Rona R, Patroniti N, et al. Patient-ventilator interaction in ARDS patients with extremely low compliance undergoing ECMO: a novel approach based on diaphragm electrical activity. Intensive Care Med 2013; 39 (2): 282-91.
37. Chanques G, Kress JP, Pohlman A, Patel S, Poston J, Jaber S, et al. Impact of ventilator adjustment and sedation analgesia practices on severe asynchrony in patients ventilated in assist-control mode. Crit Care Med 2013; 41 (9): 2177-87.
38. Vignaux L, Vargas F, Roeseler J, Tassaux D, Thille AW, Kossowsky MP, et al. Patient-ventilator asynchrony during non invasive ventilation for acute respiratory failure: a multicenter study. Intensive Care Med 2009; 35 (5): 840-46.
39. Thille AW, Brochard L. Promoting patient-ventilator synchrony. Clin Pulm Med 2007; 14 (6): 350-9.
40. Pohlman MC, McCallister KE, Schweickert WD, Pohlman AS, Nigos CP, Krishnan JA, et al. Excessive tidal volume from breath stacking during lung-protective ventilation for acute lung injury. Crit Care Med 2008; 36 (11): 3019-23.
41. Imanaka H, Nishimura M, Takeuchi M, Kimball WR, Yahagi N, Kumon K. Autotriggering caused by cardiogenic oscillation during flow-triggered mechanical ventilation. Crit Care Med 2000; 28 (2): 402-7.
42. Akoumianaki E, Lyazidi A, Rey N, Matamis D, Perez-Martinez N, Giraud R, et al. Mechanical ventilation-induced reverse triggered breaths: a frequently unrecognized form of neuromechanical coupling. Chest 2013; 143 (4): 927-38.
43. Delisle S, Charbonney E, Albert M, Ouellet P, Marsolais P, Rigollot M, et al. Patient-ventilator asynchrony due to

reverse triggering occurring in brain-dead patients: clinical implications and physiological meaning. Am J Respir Crit Care Med 2016; 194 (9): 1166-8.
44. Calderini E, Confalonieri M, Puccio PG, Francavilla N, Stella L, Gregoretti C. Patient-ventilator asynchrony during noninvasive ventilation: the role of expiratory trigger. Intensive Care Med 1999; 25 (7): 662-67.
45. Gentile MA. Cycling of the mechanical ventilator breath. Respir Care 2011; 56 (1): 52-60.
46. Chiumello D, Poli F, Tallarini F, Chierichetti M, Motta G, Azzari S, et al. Effect of different cycling-off criteria and positive end-expiratory pressure during pressure support ventilation in patients with chronic obstructive pulmonary disease. Crit Care Med 2007; 35 (11): 2547-52.
47. Yang LY, Huang YC, Macintyre NR. Patient-ventilator synchrony during pressure-targeted versus flow-targeted small tidal volume assisted ventilation. J Crit Care 2007; 22 (3): 252-7.
48. de Wit M, Miller KB, Green DA, Ostman HE, Gennings C, Epstein SK. Ineffective triggering predicts increased duration of mechanical ventilation. Crit Care Med 2009; 37 (10): 2740-5.
49. Vaporidi K, Babalis D, Chytas A, Lilitsis E, Kondili E, Amargianitakis V, et al. Clusters of ineffective efforts during mechanical ventilation: impact on outcome. Intensive Care Med 2017; 43 (2): 184-91.
50. Acute Respiratory Distress Syndrome Network, Brower RG, Matthay MA, Morris A, Schoenfeld D, Thompson BT, et al. Ventilation with lower tidal volumes as compared with traditional tidal volumes for acute lung injury and the acute respiratory distress syndrome. N Engl J Med 2000; 342 (18): 1301-8.
51. Chacón E, Estruga A, Murias G, Sales B, Montanya J, Lucangelo U, et al. Nurses' detection of ineffective inspiratory efforts during mechanical ventilation. Am J Crit Care 2012; 21 (4): e89-93.
52. Fusi C, Bulleri E, Ricci R. The nurses' knowledge in the evaluation of the breath asynchrony. Scenario. 2014; 31 (4): 26-30.
53. Lynch-Smith D, Thompson CL, Pickering RG, Wan JY. Education on patient-ventilator synchrony, clinicians' knowledge level, and duration of mechanical ventilation. Am J Crit Care 2016; 25 (6): 545-551.
54. Ramirez I, Arellano DH, Adasme RS, Landeros JM, Salinas FA, Vargas AG. Ability of ICU health-care professionals to identify patient-ventilator asynchrony using waveform analysis. Respir Care 2017; 62 (2): 144-49.
55. Longhini F, Colombo D, Pisani L, Idone F, Chun P, Doorduin J, et al. Efficacy of ventilator waveform observation for detection of patient–ventilator asynchrony during NIV: a multicentre study. ERJ Open Res 2017; 3 (4): 00075.
56. Haynes JM. Patient-Ventilator Asynchrony and Standard Waveforms: Looks Can Be Deceiving. Respir Care 2017; 62 (7): 1004.
57. Baedorf Kassis E, Loring SH, Talmor D. Esophageal pressure: research or clinical tool? Med Klin Intensivmed Notfmed 2018; 113: 13-20.
58. Brochard L. Measurement of esophageal pressure at bedside: pros and cons. Curr Opin Crit Care 2014; 20 (1): 39-46.
59. McGee WT, Mailloux P. Ventilator autocycling and delayed recognition of brain death. Neurocrit Care 2011; 14 (2): 267-71.
60. Arbour RB. Confounding factors in brain death: Cardiogenic ventilator autotriggering and implications for organ transplantation. Intensive Crit Care Nurs 2012; 28 (6): 321-8.
61. Mellott KG, Dabbs A. Reported practices of nurse recognition and management of patient ventilator asynchrony. Am J Crit Care 2014; 23 (3): e41-2.
62. Bulleri E. Patient fights the ventilator o curve che tolgono il fiato? Ruolo, conoscenze, formazione e prospettive degli Infermieri nel monitoraggio grafico della ventilazione meccanica. Conference proceeedings. 34° ANIARTI National Congress – 15-10-2015. https://wp.aniarti.it. [Online].; 2015 [cited 2018 Apr 1. Available from: http://wp.aniarti.it/wp-content/uploads/2015/12/bulleri.pdf.
63. Mellott KG, Grap MJ, Munro CL, Sessler CN, Wetzel PA. Patient-ventilator dyssynchrony: clinical significance and implications for practice. Crit Care Nurse 2009; 29 (6): 41-55.

Correspondence:
Enrico Bulleri, RN
Department of Intensive Care and Anaesthesia,
Fondazione Poliambulanza Hospital, Brescia (Italy)
E-mail: ebulleri86@gmail.com