ORIGINAL ARTICLE

Sleep Science

Respiratory polygraphy monitoring of intensive care patients receiving non-invasive ventilation

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ABSTRACT

Introduction: Patients that started on Non-Invasive Ventilation (NIV) need to define several parameters selected on the basis of diurnal arterial blood gas and underlying disease. We hypothesize that respiratory polygraphy (RP) could be useful to monitor NIV. This retrospective work describes RP findings and their impact on the setting of continuous flow ventilators from patients on NIV of Intensive Care Unit (ICU). **Material and Methods:** Patient's data on NIV from at the ICU of Hospital Británico were included in this study. RP recordings were performed in all of them. Respiratory events, such as ventilatory pattern changes, impact on oximetry or tidal volume, were observed to modify the ventilatory mode after RP. **Results:** The RP findings have contributes to change the ventilatory mode for one third of the patients. The mean values of expiratory positive airway pressure (EPAP) and inspiratory positive airway pressure (IPAP) were not significantly different across all the population before or after RP: 8.7±0.3 vs. 8.6±0.4; $p<0.88$ and 18.6±0.6 vs. 17.7±0.7; $p<0.26$ respectively, however, half the patients presented > 2 cmH_2O pressure value changes after RP. **Conclusions:** RP recordings could contribute to broad range of data useful to make decisions about changes in programming and allowed to identify adverse events related to positive pressure.

Keywords: Oximetry; Noninvasive ventilation; Intensive care units; Blood gas analysis.

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INTRODUCTION

Non-Invasive Ventilation (NIV) is a treatment option widely used in patients suffering from hypercapnic respiratory failure, neuromuscular disorders, and sleep-related breathing disorders[1-4].

Usually, when patients are started on NIV, parameters are empirically selected based on diurnal arterial blood gas (ABG), patient tolerance, and underlying disease[5,6]. NIV is most frequently used during sleep when upper airway stability, breathing patterns, the central control of breathing, and respiratory muscle recruitment tend to undergo considerable changes[4-6]. Nevertheless, the increase in minute ventilation and the decrease in CO_2, by the use of NIV may cause emergent events like central apneas or undesirable events such as central ventilatory instability and apnea due to glottic closure[5-7].

In the last years, the characteristics of these events have been described during the analysis of respiratory polygraphy (RP) recordings, giving rise to hypotheses about their origin, in an effort to classify them. The RP could be useful to monitor NIV in some patients, since it can supplement data obtained by other means (oximetry, ventilator software)[5-7]. However, experience and available data are limited with regard to the feasibility of using this monitoring technique in intensive care unit patients[8].

With the aim to describe RP findings and assess their impact on the setting of continuous flow ventilators; we carried out a systematic analysis of data gathered during two years from Intensive Care Unit (ICU) patients on NIV.

MATERIAL AND METHODS

Study Population

Retrospective study of a database of systematic collection in consecutive patients. Between December 2013 and December 2015 we evaluated patients who received some kind of NIV on admission to the ICU of Hospital Británico in Buenos Aires and were candidates to receive NIV after discharge.

Were included in the analysis: 1) adult patients of both sexes with a diagnosis of respiratory failure with or without hypercapnia and/or sleep-related breathing disorders; 2) need of NIV at some point during hospital stay; and 3) RP tracings with more than 240 minutes of valid recording time.

Exclusion criteria: 1) patients with a diagnosis of hypoventilation secondary to drugs (opioids or sedatives); 2) patients who needed invasive mechanical ventilation; and 3) RP tracings with less than 240 minutes of valid recording time[7].

Ethical approval: The protocol was approved by the Ethics and Review Committee at "Hospital Británico de Buenos Aires". All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards in accordance with the ethical standards of the Helsinki Declaration.

Clinical data collected

Anthropometric and demographic data, clinical history, signs of respiratory failure, length of ICU stay (days), arterial blood gas on admission, type and parameters of NIV strategies, choice of interface, and continuous flow ventilation settings, both before and after respiratory polygraphy (RP) analysis were extracted from the medical records.

Respiratory Polygraphy

RP was performed with Alice PDx (Philips-Respironics, USA) *level III* devices[9] with a flow sensor, airway pressure proximal to the mask, thoracic and abdominal effort measured with inductive plethysmography, and finger pulse oximeter.

During titration, *single circuit continuous positive pressure devices* (Trilogy-Philips and Bipap A40-Philips non-invasive ventilators) were connected to obtain data on leaks (total leak), tidal volume, and point-to-point time pressure curves through a digital communication port (connectivity module). *Only ventilatory pressure modes and interfaces with intentional leaks were used.*

For the adaptation period, the treating team selected the most appropriate settings and interfaces based on the usual protocol findings (morning arterial blood gas without supplemental oxygen; at rest, seated, and awake; clinical and ventilator software data Encore Pro II and Direct View-Philips) and recordings were taken at ICU patients' bedside at night and without supplemental O_2.

Before RP, authors do not contact the patient and did not interfere with the ventilation protocol or ICU effectiveness monitoring (downloaded software data, oximetry, etc.). The RP was performed during the period immediately prior to the discharge of the hospital during the planning of the home use of the NIV, with ambient air to facilitate the identification of respiratory events.

Analysis of respiratory polygraphy under NIV

RP recordings were interpreted according to previously published criteria about RP in patients on NIV[6,7,9]. Respiratory events, such as ventilatory pattern changes that generate instability or discontinuity with a negative impact on oximetry or tidal volume, were counted during RP. According to RP tracings, abnormal respiratory events were classified as oropharyngeal (equivalent to common obstructive apnea) and glottic (apnea with reduced drive in controlled cycles). Apneas and hypopneas were defined according to the drop in air flow or tidal volume: $\geq$ 90% for apnea and $\geq$ 50% for hypopnea for more than 10 seconds associated to $\geq$ 4% oxygen desaturation[9]. Tidal volume was used as efficacy-surrogate for pressure ventilation mode and was interpreted with regard to the leak signal in 1 to 5 minute epochs. The oxygen desaturation index (ODI) was calculated by dividing the total number of desaturation events by valid time of recordings during manual analysis of RP and oxygen saturations below 90% were expressed as a percentage of total recording time (TRT). In addition to this, non-invasive ventilation data were checked after RP analysis and at discharge (device mode and final settings), interface, and use of supplemental oxygen.

Statistical analysis

The information obtained was entered into a spreadsheet. All personally identifiable information was duly managed to preserve patient's privacy and data confidentiality. Demographic variables are described using frequencies, median, and mean values, and their respective dispersion measures. A t-Student test was used to calculate difference and statistical significance. The statistical software used was Prism5 (Graph Pad, La Jolla, CA).

RESULTS

We included fifty patients, 38 of them men (76%) and 12 women. The mean of age was 61.9±14.2 years with a range between 27-86 years of age. We observed that 80% of these patients were older than 50. The mean body mass index (BMI) was 35.6±8.8 kg/m^2. Table 1 shows the clinical and demographic characteristics of study population.

Table 1. Characteristics of study population.

Number of patients	50
Male: n (%)	38 (76)
Age (years)	61.9 ± 14.2*
BMI (kg/m^2)	35.6 ± 8.8*
basal $paCO_2$ (mmHg)	50.1 ± 11.9
$PaCO_2$ > 45 mmHg (%)	66
> 50 years old (%)	80
Coronary disease: n (%)	8 (16)
COPD: n (%)	7 (14)
Cardiac failure: n (%)	4 (8)
Diabetes: n (%)	16 (32)
Arterial Hypertension: n (%)	23 (43)
Chronic kidney failure: n (%)	5 (10)

*Mean and standard deviation. ESS: Epworth sleepness scale.

A 32% of the patients included (16/50) already used some type of NIV before admission, while the rest began adaptation to NIV during their ICU stay due to respiratory complications. A 66% of patients showed hypercapnia and 40% had morning values of > 55 mmHg at baseline. The main reasons for indication of NIV are summarized in Table 2. The flow chart (Figure 1) is shown to illustrate patient selection in the ICU.

RP recordings were taken 5.4±1.0 days (mean) after initiation of NIV. The time elapsed between the decision to use RP and data collection was 1.3±0.8 days.

The most frequent residual respiratory events identified were apnea and hypopnea (obstructive or oropharyngeal): median and percentile values 25-75%, 4 ev/hour (1-22); and apnea or hypopnea with reduced drive (glottic or with involvement of the respiratory center): 28 events/patient (6.5-63.7). Table 3 summarizes RP findings.

The typical periodic breathing pattern (15% of recordings) was a frequent finding in our population. Long asynchrony events (>20% of TRT) associated with O_2 desaturation were identified in 6 patients (12%), and were frequently related to leaks beyond the compensatory capabilities of the ventilator. These cases were addressed by making changes in trigger sensitivity or program (3 patients), and by changing the mask (3 patients).

Table 2. Diagnosis related with indication of NIV

Diagnosis	n = 50*
Duchenne disease	2% (1)
Restrictive chest wall disorders	6% (3)
Motor neuron disease	8% (4)
Obesity-Hypoventilation syndrome	30% (15)
COPD	6% (3)
Overlapping síndrome (OSA-COPD)	8% (4)
Polyneuropathies	6% (3)
Central apneas y CSR	12% (6)
Complex OSA	8% (4)
Other	14% (7)

*Percentage and number of cases. CRS Cheyne Stokes Respiration. OSA: Obstructive Sleep Apnea

The mean values of expiratory positive airway pressure (EPAP) and inspiratory positive airway pressure (IPAP) were not significantly different across the population (Figure 2C and D) before or after RP: p<0.88 and p<0.26, respectively. However, half the patients presented > 2 cmH_2O pressure value changes (Figure 3A and B). Most frequent adjustments were due to EPAP insufficient titration with oropharyngeal residual events or reduced support pressure with excessively low tidal volume. Occasionally, it was also possible to reduce inspiratory pressure values.

The RP findings have contribute to change the ventilatory mode for one third of the patients; nevertheless, the averages of EPAP or IPAP were not different in all population (Figure 2C and D), although in individual patients the setting changes could be significant (Figure 2A and B).

Findings of this study have showed that 32.35% of patients without previous NIV, and 37.5% with previous NIV, changed mode (Figure 4A and B respectively). Moreover, we analyzed each range of adjustment by illness. We observed that the EPAP changes were more frequent in patients with some kind of sleep apnea or hypoventilation syndrome, while IPAP was modified in all groups (Figure 5).

Silicone nasobuccal masks with exhalation port were predominantly used (88%). After RP, 8% of the masks were changed (4 patients) and supplemental oxygen was indicated for 40% of the remaining patients. Finally, 49 patients were discharged with an indication of NIV with continuous flow devices suitable for home care settings.

DISCUSSION

Using NIV does not mean that the patient´s ventilation needs will be adequately satisfied. Physical examination, which is usually performed during the day, is considered the best way to monitor these patients. However, the most significant respiratory

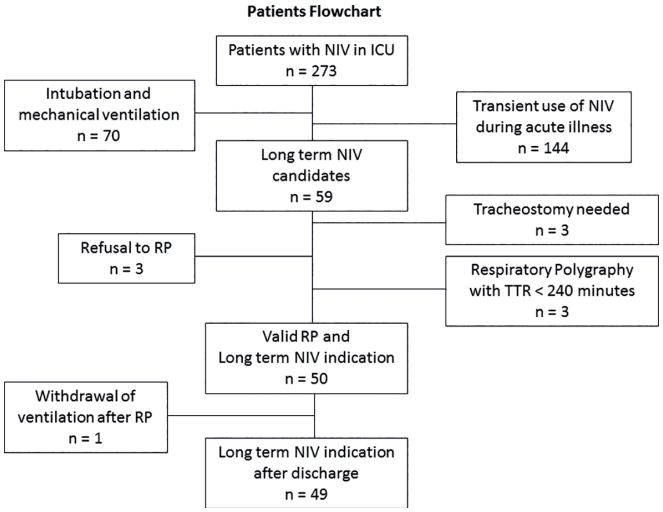


Figure 1. Flow Chart.

Table 3. Results of RP under NIV

Total time of valid recordings (minutes)	442.2
Residual AHI	15.1 ± 10.6*
ODI	38.8 ± 8.3*
T < 90 (minutes)	70.28 ± 20.23**
Number of central apneas	12 ± 31.8
Number of apneas and oropharyngeal hypoapneas (ev/hour)	4 (1-22)&
Number of apneas and hypopneas with reduced drive	28 (6.5-63.7)&
Breathing pattern (> 30 minutes of TRT)	15 %
Asynchronies > 20% TRT	12%
Mean leak (l/min)	35.1 ± 13.7

AHI: Apnea Hypopnea Index per recording time. ODI: O2 desaturation index≥ 4%; T< 90:Time under SaO_2<90%; TRT: total recording time. *Values expressed as mean and standard deviation. ** Values expressed in minutes of TRT & Values expressed as median and P25-75

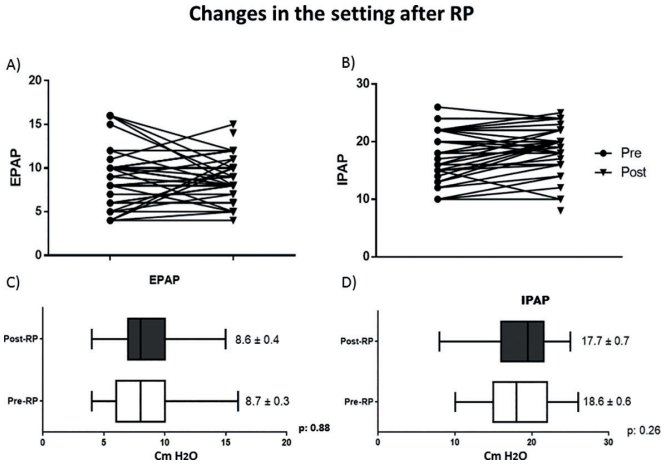


Figure 2. Changes in the pressure ventilator setting after RP. A and B; individual patients. C and D; all population.

events that require monitoring occur during sleep[5-7,10].

RP is not designed to detect neurophysiological signals and, therefore, cannot tell if patients are awake or asleep[9]. In addition to this, the quality of sleep of ICU patients as well as

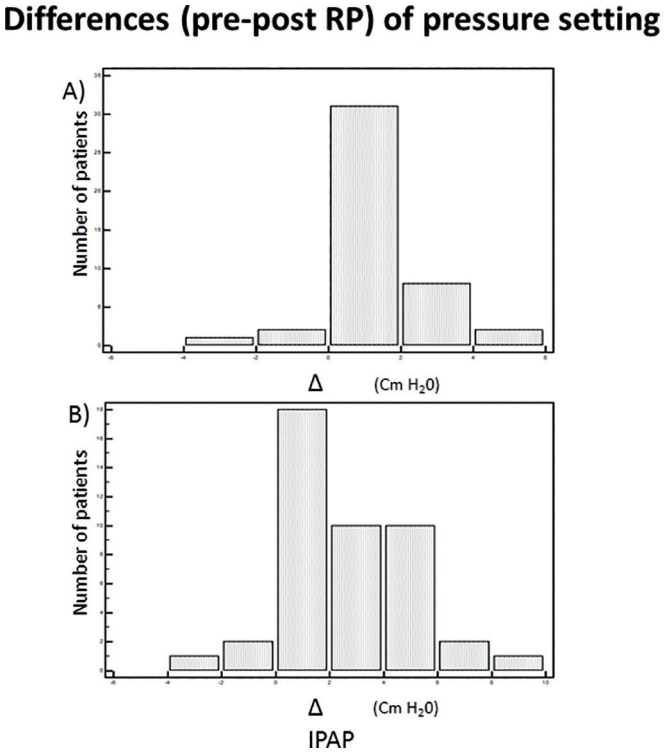


Figure 3. Changes in the ventilator setting expressed as differences (delta) pre and post respiratory polygraphy.

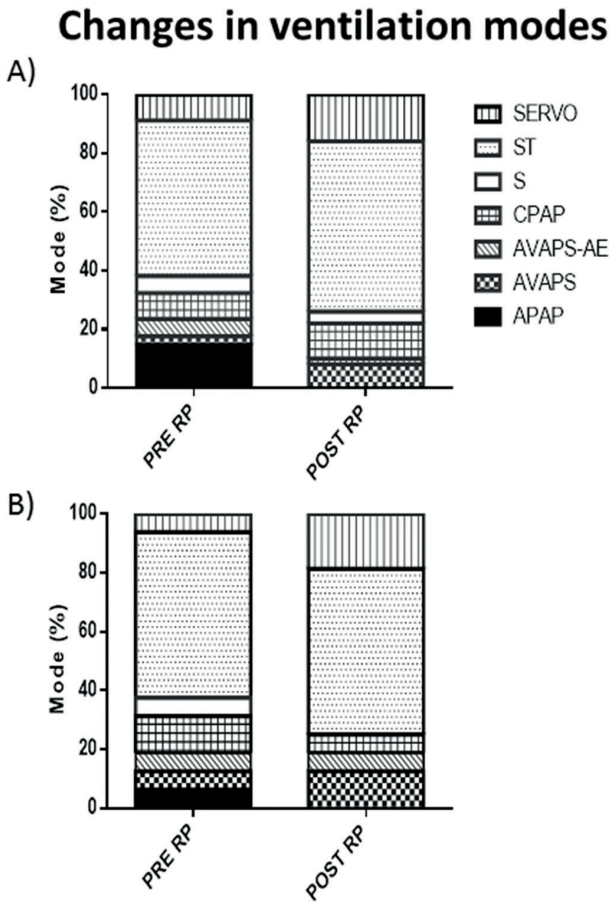
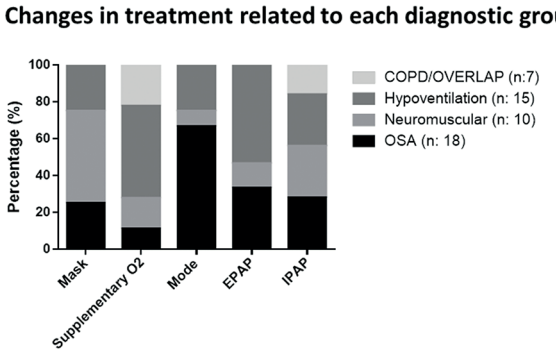


Figure 4. Changes in ventilator modes after respiratory polygraphy analysis.



	OSA	Neuromuscular	Hypoventilation	COPD/OVERLAP
Mask	25	50	25	0
Supplementary O2	11.1	16.7	50	22.2
Mode	66.7	8.3	25	0
EPAP	33.33	13.33	53.34	0
IPAP	28	28	28	16

Figure 5. Changes in ventilator programming and additional adjustments in treatment for main diagnostic groups.

their wake-sleep cycle is severely affected[11,12]. These two factors can contribute to the underestimation of nocturnal NIV-related respiratory events and affect the accuracy of the methodology.

In this study, authors did not take part in the indication of NIV or the choice of ventilatory modes, parameters or interfaces before RP. The NIV protocol was in charge of intensive care physicians and pulmonologists specialized in sleep medicine and home care ventilation and was based on titration platforms that consisted of central oximetry monitoring and electrocardiography, arterial blood gas, clinical parameters, and ventilator software data used to monitor basic ventilation efficacy.

The intensive care team determined the timing and frequency of data analyses. RP was performed during the process of preparation for discharge, when it was assumed that parameters did not need major adjustments and after an average adaptation period of >5 days. This is the typical protocol used for NIV initiation in our hospital and most ICUs and respiratory care units. RP recordings were obtained by qualified sleep medicine technicians through a systematic technique using standardized assemblies. Likewise, tracings were read and interpreted by trained pulmonologists, which is one of the strengths of this study. It is worth mentioning that this system did not provide real time information, since information was obtained the following morning after the manual count of events and recordings analysis.

Notably, ventilatory modes were modified in one third of the patients after analysis and discussion of RP results. In this group, there were both patients who used NIV before admission to the hospital and first-time users. Ventilation had to be adapted to meet patients' needs due to acute interoccurrences (respiratory disease, postoperative period, etc.), which was reflected by the change from auto-adjusting CPAP to spontaneous/timed (S/T) in non-hypercapnic patients. The most frequently selected mode was bilevel S/T or variants with assured target volume, with or without auto-EPAP.

It is worth pointing out that 14% (7/50) of patients used servo-assisted ventilation, even though current indication for patients with periodic breathing, central apnea, and low ejection fraction is currently under discussion[13-15].

The technology used in current ventilators allows physicians to follow up ventilation efficacy variables such as: tidal volume, minute ventilation, breathing rate, and even oximetry coupled to flow or pressure waves. Each built-in software is based on the features defined by the manufacturer for each device. There are scarce descriptions of the clinical use of the graphs offered by these softwares[15]. There is a growing interest in the need to monitor home care[15-17] and intensive care settings[18].

In spite of these basic monitoring variables, physicians changed the ventilatory mode for one third of the patients and made pressure adjustments of at least 2 cmH_2O in half of the patients after RP. This proves that in patients on NIV, variables such as tidal volume, asynchronies, periodic breathing, and apnea should be measured directly, since clinical examinations and gasometric tests could fail to detect them[7,8]. The reduced number of patients and the heterogeneity of the population and NIV indications, however, do not allow comparisons.

At present, the practice of counting respiratory events manually through this technique is under discussion[5,7,19,20]. The conventional criteria used to classify respiratory events in polysomnographies (PSG) is not defined in detail[19,20] (reduced respiratory drive, glottic apnea, and asynchronies) and, therefore, alternative classifications are suggested to interpret these abnormal findings[6,7]. It is interesting to note that the classic definitions are of little use to define events when pressure and flow signals are used from therapy devices. Some groups propose sub-classify hypopneas and apneas events although this is still controversial[5-7,10]. Besides, PSG is not always available in the ICU, it is expensive and EEG data are frequently hard to interpret due to ICU-related interferences and artifacts.

Our ICU ventilated patients presented a mean respiratory disturbance index of 15.1±10.6 ev/hour, which is conventionally defined as non-optimal titration [20] (effective for PSG titration in patients without COPD).

Asynchronies during NIV have been described for up to 50% of the patients[21] and can cause O_2 desaturation[22] and sleep fragmentation, thus reducing sensitivity to hypoxia and hypercapnia[23]. A European study used electromyography to describe severe asynchronies in 25 % of their patients (50% of these cases were due to leaks)[24]. Even though the tolerance threshold has not been defined yet, we found asynchronies that were classified as severe or long in 12% of the patients, as stated by Vignaux et al.[24] and Fanfulla et al[22]. They were frequently related to non-intentional leaks in spite of the fact that patients were monitored.

There was no capnography in our study, an obvious limitation at the time of defining effective ventilation. During NIV with leaks, transcutaneous capnography could be necessary, though it is expensive and the signal drift frequently makes interpretation difficult[16]. In addition, according to

previous descriptions, supplemental O_2 may hide residual hypoventilation[25]. Consequently, RP recordings were obtained with ambient air.

The tidal volume signal is not measured directly; rather it is transmitted from continuous flow ventilators. Therefore, it has a margin of error of ± 20%, depending on the device used[15]. Even though this margin may be clinically significant for the individual patient, some recommendations regard it as a valid measurement[20].

In spite of these limitations, respiratory polygraphs operated by technicians offer important bedside information related to a titration platform applicable to in-patients, and could become a useful resource at centers where there is no polysomnography or for patients that cannot go to hospital[18].

Beyond the descriptions provided, it is necessary to study the use of RP by assessing the clinical effect of recordings and their impact on ventilation efficacy and treatment compliance in the long term by controlled studies.

CONCLUSIONS

To conclude, bedside polygraphy in the ICU may be useful for patients on NIV when clinical data suggests an indication for chronic NIV. RP can be performed easily and rapidly, providing a broad range of data useful to make decisions without moving the patient.

In our experience, RP led to several changes in programming and allowed to identify adverse events related to positive pressure. More studies including higher number of patients are necessary to assess the impact of its use.

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CONFLICT OF INTEREST

All authors certify that they have no affiliations with or involvement in any organization or entity with any financial interest (such as honoraria; educational grants; participation in speakers' bureaus; membership, employment, consultancies, stock ownership, or other equity interest; and expert testimony or patent-licensing arrangements), or non-financial interest (such as personal or professional relationships, affiliations, knowledge or beliefs) in the subject matter or materials discussed in this manuscript.

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