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Automated patient-ventilator interaction analysis during neurally adjusted non-invasive ventilation and pressure support ventilation in chronic obstructive pulmonary disease

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CRITICAL CARE

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Introduction

- Poor patient-ventilator interaction may contribute to NIV failure. Delivering synchronous non-invasive assist is challenging with flow or pressure-controlled systems, especially when using excessively leaky or highly compliant interfaces.
- As recommended, patient-ventilator interaction can be evaluated by using the diaphragm electrical activity (EAdi). Besides its monitoring capabilities, EAdi is used during neurally adjusted ventilatory assist (NAVA) as a controller signal for ventilatory assist.
- To our knowledge, there are no studies of patient-ventilator interaction strictly in COPD patients receiving NIV-NAVA, while these patients are more likely to exhibit severe patient ventilator asynchrony . In addition, no study has used the EAdi signal to evaluate patient-ventilator interaction with dedicated NIV ventilators.

Introduction

- This automated analysis allows detection of asynchronies, such as wasted efforts, but also makes it easy to detect the more subtle dyssynchronies, such as trigger delays and cycling-off errors. The present study is the first to use this analysis method to quantify patient-ventilator interaction during non-invasive ventilation.

Study subjects

Adult patients with acute respiratory failure and a medical history of COPD, admitted to the ICU for non-invasive ventilation were eligible for inclusion in the study.

Patients with a known neuromuscular disorder, severe hypoxemic failure ($PaO_2/FiO_2 < 100$ mmHg), or hemodynamic instability requiring high-dose norepinephrine (>0.5 μg/kg/min) were excluded.

Study design

- After enrollment and clinical stabilization, each patient received three 30-minute ventilation protocols in the following order:

1. PSV with the BiPAP Vision with pressure support and positive-end expiratory pressure (PEEP) levels set by the treating physician (NIV-PSVVision).

2. PSV with the Servo-I, an ICU ventilator with NIV algorithm, with similar PEEP and pressure support levels (NIV-PSVServo-I).

3. NAVA with the Servo-I,where NAVA level was adjusted to match peak pressure of NIV-PSV, using manufacturer-supplied software (NIV-NAVA).

Study design

- In order to reduce the amount of leakage on ventilator performance, we chose to use a tightly fitted oronasal mask.
- At the end of each ventilator mode, respiratory discomfort was scored by use of a Visual Analog Scale (from 0 mm (no discomfort) to 100 mm (maximal imaginable discomfort)) and arterial blood gas analysis was performed from an indwelling arterial line.

Data acquisition

Flow

Airway pressure (Paw)

EAdi

Patient-ventilator interaction

(evaluated by comparing airway pressure and EAdi waveforms with automated computer algorithms such as cycling off、trigger delay、wasted efforts)

The NeuroSync index

(calculated as the percentage of timing errors between airway pressure and EAdi)

Data acquisition

1. Study parameters were calculated from a stable 5 minute period at the end of each mode on a breath-by-breath basis using a software routine developed for Matlab (Mathworks, Natick, MA, USA).
2. Neural respiratory rate was calculated as the number of EAdi peaks/min.
3. Trigger and cycle-off error (that is dyssynchrony) were calculated as percentages of neural inspiratory and expiratory time periods, respectively.
4. EAdi and Paw were completely dissociated (that is asynchrony), such as wasted efforts, auto-triggering, multiple assist during EAdi peak (double triggering) and multiple EAdi peaks during assist.

Results

Table 1 Patient characteristics at study inclusion

Number	Age (y)	BMI (kg/m^2)	FEV1 (% pred.)	FVC (% pred.)	FEV1 /FVC	GOLD class.	PF ratio	Reason for admission	Total NIV duration (days)
1	37	25				I	316	Haemoptysis	5
2	74	23				I	308	Exacerbation COPD	3
3	68	38	45	79	42	III	185	Exacerbation COPD	3
4	67	34	69	98	70	II	176	Pneumonia	4
5	67	27	72	100	53	II	180	Exacerbation COPD	5
6	64	26	31	52	43	III	220	Trauma	3
7	58	26				II	143	Exacerbation COPD	6
8	70	28	67	90	55	II	215	Post-op lobectomy	2
9	78	22	77	88	64	II	110	Exacerbation COPD	3
10	75	17	23	61	28	IV	219	Exacerbation COPD	1
11	76	25	62	101	45	II	246	Exacerbation COPD	5

Recent lung function tests for patient 1, 2 and 7 were unavailable in our hospital, but clinical pictures of these patients were consistent with COPD and patient correspondence stated a history of COPD. BMI: body mass index; FVC: forced vital capacity; FEV1: forced expired volume in 1 second; GOLD class: Global Initiative for Chronic Obstructive Lung Disease classification; PF ratio: PaO_2/FiO_2.

Results

Table 2 Ventilator settings

Patient	PS level (cmH2O)	PS rise time (s)	PS cycle off (% peak flow)	NAVA level (cmH2O/μV)	NAVA trigger (μV)	PEEP (cmH2O)	FiO_2 (%)
1	6	0.20	30	0.1	0.5	6	70
2	10	0.20	50	0.8	0.5	8	50
3	8	0.20	70	0.4	0.5	8	50
4	5	0.20	50	0.1	1.0	7	60
5	6	0.20	50	0.1	0.5	4	40
6	5	0.05	50	5.0	0.5	5	30
7	10	0.00	50	0.2	0.5	6	55
8	6	0.20	50	0.2	0.5	6	45
9	6	0.20	50	0.2	0.5	6	70
10	8	0.00	60	0.1	0.5	5	35
11	6	0.20	50	0.2	0.5	6	40

Pressure support (PS) levels and rise time hold for both ventilators, whereas cycle-off criteria is only set for $NIV\text{-}PSV_{Servo\text{-}I}$. The BiPAP Vision uses the Auto-Trak Sensitivity algorithm to trigger and cycle off the ventilator and cannot be set individually. PEEP and FiO2 were similar for all three ventilatory modes. FiO_2: inspired oxygen fraction; NAVA: neurally adjusted ventilatory assist; PEEP: positive end-expiratory pressure.

Results

Table 3 Breathing pattern and respiratory drive

	NIV-PSV_{Vision}	NIV-$PSV_{Servo-I}$	NIV-NAVA
Peak EAdi (μV)	25.6 (18.6 - 43.5)*	34.7 (18.8 - 49.0)	23.8 (17.1 - 48.0)
Peak airway pressure (cmH_2O)	15.3 (13.0 - 18.5)*#	12.5 (10.4 - 15.2)	12.9 (11.7 - 16.0)
Inspiratory peak flow (L/min)	92.5 (72.1 - 110.0)*#	54.1 (46.8 - 63.2)	45.6 (38.7 - 61.1)
Neural resp. rate (breaths/min)	22.7 (17.6 - 27.0)	25.2 (18.5 - 28.2)	25.1 (18.3 - 31.7)

*NIV-PSV_{Vision} vs. NIV-$PSV_{Servo-I}$ (*P* <0.05), #NIV-PSV_{Vision} vs. NIV-NAVA (*P* <0.05). EAdi, electrical activity of the diaphragm; NAVA: neurally adjusted ventilatory assist; NIV: non-invasive ventilation; PSV: pressure support ventilation.

Results

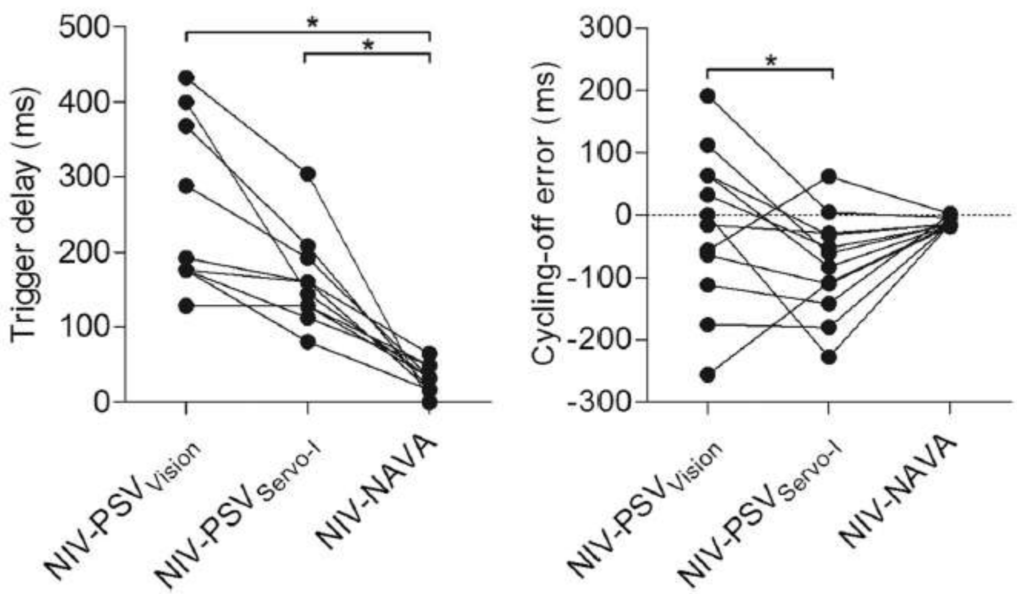

Figure 1 Trigger delay (left) and cycling-off error (right) for the different ventilator modes. Y-axis for cycle-off error: positive values indicate late cycling off, and negative values indicate early cycling off. *P <0.05. NAVA: neurally adjusted ventilatory assist; NIV: non-invasive ventilation; PSV: pressure support ventilation.

Results

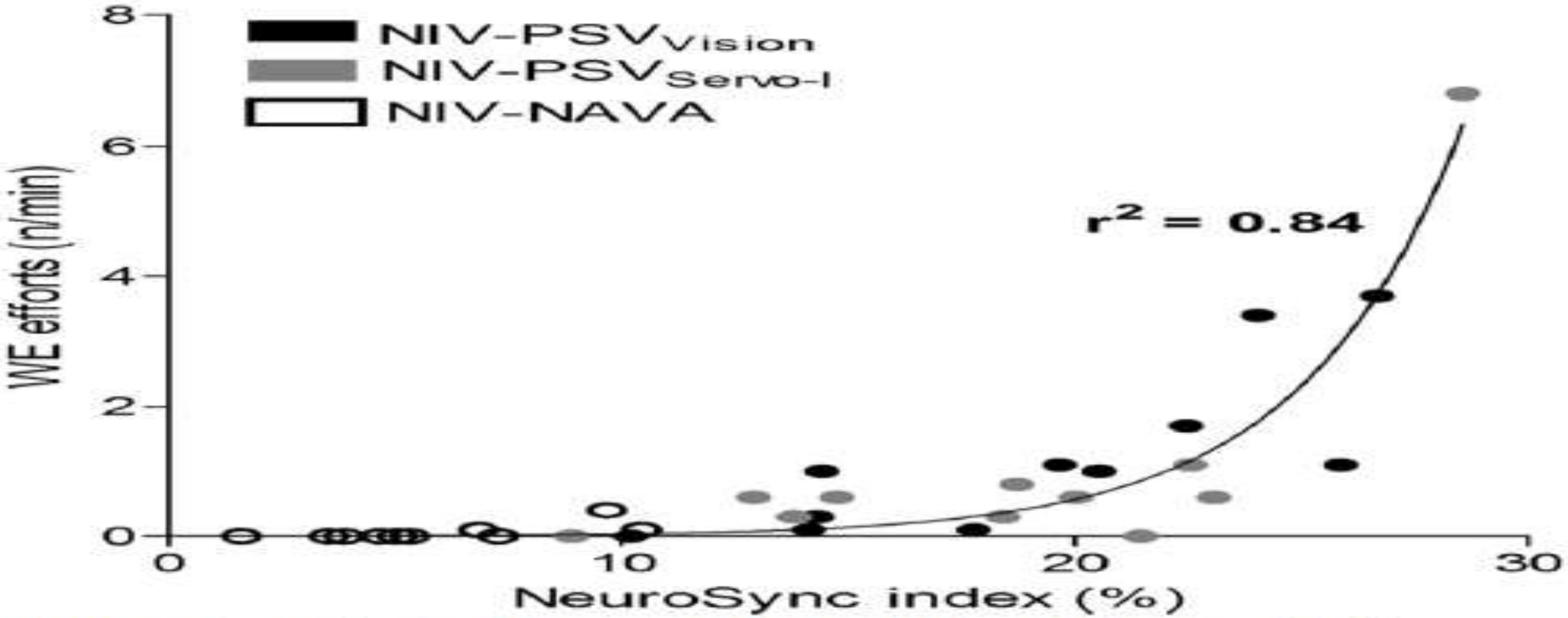

Figure 2 Correlation between the number of wasted efforts and the NeuroSync index. Note that for this regression analysis, the NeuroSync index was recalculated without wasted efforts to avoid mathematically coupled variables, and is thus consequently primarily a measure of dyssynchrony (trigger and cycle-off errors). Accordingly this correlation shows that progressive dyssynchrony, increases the number of wasted efforts. NAVA: neurally adjusted ventilatory assist; NIV: non-invasive ventilation; PSV: pressure support ventilation.

Results

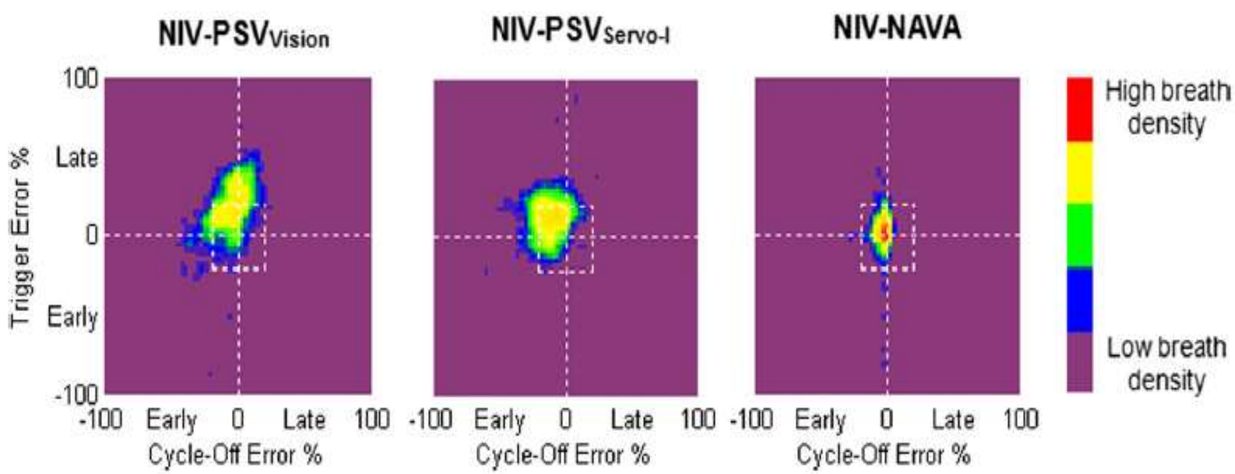

Figure 3 Breath density graph for relative trigger (Y-axis) and cycling-off (X-axis) errors, for all breaths in all patients, during each ventilator mode. The small white 'box' in the center of each graph indicates the limit between synchrony (neural efforts matched to assist delivery with less than 20% error - inside the box) and dyssynchrony (neural efforts poorly related to assist delivery, >20% error - outside the box). These breath-density graphs show for NIV-NAVA a concentrated breath density in the center, which should be anticipated since it is driven by EAdi. With NIV-PSV_{Vision} and NIV-$PSV_{Servo\text{-}I}$ breaths are more spread out and have considerable proportions of dyssynchronous breaths compared to NIV-NAVA. NAVA: neurally adjusted ventilatory assist; NIV: non-invasive ventilation; PSV: pressure support ventilation.

Results

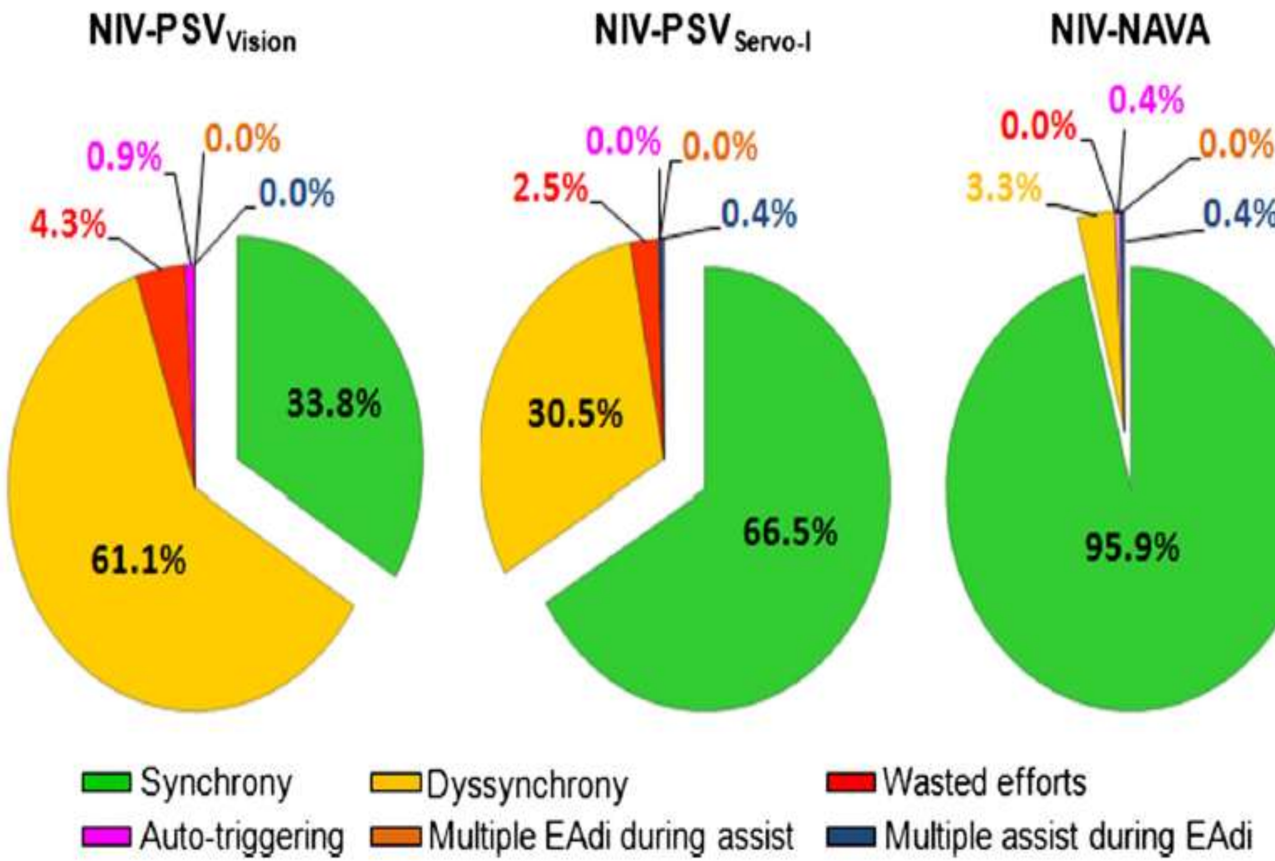

Figure 4 Percentage of synchronous, dyssynchronous and asynchronous (wasted efforts, auto-triggering, multiple EAdi during assist, and multiple assist during EAdi) breaths for the different ventilator modes. NAVA: neurally adjusted ventilatory assist; NIV: non-invasive ventilation; PSV: pressure support ventilation.

Discussion

- First, we show that neurally adjusted noninvasive ventilation synchronizes assist to inspiratory effort in patients with COPD, whereas dedicated NIV ventilator or ICU ventilator pressure support modes do not ensure acceptable patient-ventilator interaction in individual patients.
- Second, wasted efforts increase drastically after timing errors between EAdi and airway pressure reach 20%.
- Third, automated analysis of patient-ventilator interaction using computer algorithms allows objective detection of patient-ventilator interaction during NIV.

Discussion

- Our results are consistent with previous studies that showed improved patient-ventilator interaction with neurally compared to pneumatically controlled mechanical ventilation
- First, we included only patients with COPD, which are more likely to exhibit poor patientventilator interaction .
- Second, dedicated NIV-NAVA and NIV-PSV software was used instead of software for invasive ventilation in the previous studies .
- Lastly, an automated analysis method for quantifying patient-ventilator asynchronies and the more subtle dyssynchronies was used [20],

Conclusions

- non-invasive NAVA improves patient-ventilator interaction compared to PSV in COPD patients.
- progressive mismatch between neural effort and pneumatic timing is strongly associated with the number of wasted efforts.


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