Increased Diaphragmatic Contribution to Inspiratory Effort during Neurally Adjusted Ventilatory Assistance *versus* Pressure Support

An Electromyographic Study

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ABSTRACT

Background: Neurally adjusted ventilatory assist (NAVA), regulated exclusively by the electromyographic activity (EA) of the diaphragm (EAdi), could affect the distribution of neural drive to the various inspiratory muscles. The objective of this study was to compare EAdi, EA of the scalene (EAscal), and EA of the *alae nasi* (EAan), according to the ventilatory mode and assist level in 12 mechanically ventilated patients.

Methods: Seven assist levels of pressure support ventilation (PSV) and NAVA were sequentially applied. EAdi, EAscal, and EAan were quantified and expressed as a percentage of their maximum values. The relative contributions of extradiaphragmatic muscles to inspiratory efforts were assessed by calculating EAscal/EAdi and EAan/EAdi ratios. Three assist levels for each of the two ventilatory modes that resulted in EAdi values of 80 to 100%, 60 to 80%, and 40 to 60% were assigned to three groups (N1, N2, and N3). Results are expressed as median and interquartile range.

Results: EA of inspiratory muscles decreased during PSV and NAVA ($P < 0.0001$). Although EAdi remained constant within groups ($P = 0.9$), EAscal was reduced during NAVA compared with PSV in N1 and N3 (65% [62 to 64] and 27% [18 to 34] in NAVA *vs.* 90% [81 to 100] and 49% [40 to 55] in PSV, $P = 0.007$). Altogether, EAscal/EAdi and EAan/EAdi ratios were lower in NAVA than PSV (0.7 [0.6 to 0.7] and 0.7 [0.6 to 0.8] in NAVA *vs.* 0.9 [0.8 to 1.1] and 0.9 [0.7 to 1.1] in PSV, $P < 0.05$).

Conclusions: NAVA and PSV both reduced extradiaphragmatic inspiratory muscle activity, in proportion to the level of assistance. Compared with PSV, NAVA resulted in a predominant contribution of the diaphragm to inspiratory effort. **(Anesthesiology 2014; 121:1028-36)**

NEURALLY adjusted ventilatory assist (NAVA) is a mode of assisted mechanical ventilation delivering a ventilatory assistance that is exactly synchronous with diaphragmatic contractions and that is proportional to the electromyographic activity (EA) of the diaphragm (EAdi).[1] With NAVA as opposed to pressure support ventilation (PSV), the level of ventilatory assistance provided varies on a breath-by-breath basis[2] according to the intensity of diaphragmatic contractions: the greater the EAdi recorded, the higher the airway pressure delivered. The EAdi–pressure relationship in a given clinical situation is chosen by the clinician in charge of the patient, who adjusts the NAVA "gain" (expressed in cm $H_2O/\mu V$) according to clinical data and blood gases.

What We Already Know about This Topic

- Neurally adjusted ventilatory assist delivers ventilation synchronously with diaphragmatic contractions, and the assistance is proportional to electromyographic activity of the diaphragm. Pressure support ventilation provides a constant pressure during inspiration.

What This Article Tells Us That Is New

- Increasing levels of pressure support ventilation or neurally adjusted ventilatory assist both reduced diaphragmatic electromyographic activity and the inspiratory activity of the scalene and *alae nasi* muscles. Compared with pressure support ventilation, neurally adjusted ventilatory assist led to a larger contribution of the diaphragm to inspiratory efforts.

As the result of a biofeedback loop, increasing the NAVA gain in a given clinical situation results in a reduction of diaphragmatic activity.[2]

The diaphragm is not the only muscle active during inspiration in humans, because extradiaphragmatic inspiratory muscles, including upper airway dilator muscles and pump muscles (*e.g.*, the scalenes), all receive inspiratory drive from the central nervous system. This inspiratory drive is not uniform, but is "distributed," both spatially and temporally.[3] The distribution of inspiratory drive is altered by inspiratory loading that differentially modifies the degree of neuromechanical coupling of the various inspiratory muscles. Extradiaphragmatic inspiratory muscles contract earlier and more strongly in the presence of a mechanical load and in response to chemostimulation in healthy subjects[4–7] or in patients during clinical respiratory distress[8] or when patient–ventilator interactions are inadequate.[9–11] The contribution of extradiaphragmatic inspiratory muscles to the inspiratory effort can become greater than the contribution of the diaphragm,[12] suggesting a steeper load–activity relationship for these muscles. Of note, a consistent relationship has been demonstrated between extradiaphragmatic inspiratory muscle activity and dyspneic sensations, in both experimental[4,13] and clinical conditions.[11] For all of these reasons, unloading extradiaphragmatic inspiratory muscles and thereby reducing their EA is a relevant objective of ventilatory assistance.[9–11] PSV achieves this goal, [9,11] but whether or not NAVA also achieves this goal and to what extent is unknown. The present study was therefore designed to address this question, as it has been observed that, for comparable assist levels, tidal volume (V_T) was higher during PSV than during NAVA, despite a lower EAdi.[14,15] These observations are compatible with different effects of the two ventilatory modes on extradiaphragmatic inspiratory muscles.

Materials and Methods

Study Population
The study was conducted in a 16-bed intensive care unit within a 1,600-bed university hospital (Pitié-Salpêtrière Hospital, Paris, France) during a 5-month period (from April to August 2012). Adult patients intubated and mechanically ventilated for acute respiratory failure were eligible for inclusion in the study if (1) they were able to trigger the ventilator in PSV in order to produce a V_T of 6 to 8 ml/kg with pressure support less than 20 cm H_2O; (2) the physician in charge of the patient decided to switch the mode of mechanical ventilation from PSV to NAVA. Exclusion criteria included contraindications to nasogastric tube insertion, known or suspected phrenic nerve dysfunction, neuromuscular disease, and hemodynamic or respiratory instability, *i.e.*, need to increase doses of vasoactive drugs, increase positive end-expiratory pressure, or increase fractional concentration of oxygen (F_{IO_2}) at the time of inclusion. This study was conducted in accordance with the French law on biomedical research and was approved by the appropriate external review board ("Comité de Protection des Personnes Ile-de-France 6 Pitié-Salpêtrière," decision #101–12) of Pitié-Salpêtrière Hospital, Assistance Publique—Hôpitaux de Paris, Paris, France in April 2012. Informed consent was obtained from all patients.

Ventilatory Protocol
Patients were ventilated using a Servo-i ventilator (Maquet Critical Care, Solna, Sweden). Positive end-expiratory pressure and F_{IO_2} were set by the physician in charge of the patient and were not altered during the study. Seven PSV levels (from 7 to 20 cm H_2O) were applied in a stepwise manner, followed by seven corresponding NAVA levels determined using a built-in function ("*NAVA preview*") that calculates what NAVA gain is required to produce equi-PSV assistance (fig. 1).[14–16]

Measurements
Diaphragmatic electromyography was recorded using a 16-French nasogastric tube (Edi catheter; Maquet Critical Care). Airway pressure (P_{aw}), flow, and diaphragmatic electromyogram were acquired from the ventilator *via* an RS232 interface at a sampling rate of 100 Hz, recorded, and analyzed with dedicated software (Servo-i RCR, version 3.7; Maquet Critical Care).

End-tidal partial pressure of carbon dioxide (P_{ETCO_2}) was determined at the end of each condition, using a carbon dioxide Capnostat III sensor kit connected to the carbon dioxide analyzer module of the Servo-i ventilator (Maquet Critical Care).

Electromyographic signals of extradiaphragmatic inspiratory muscles were recorded using surface electrodes.[11] Scalene-targeted recordings were obtained in the posterior triangle of the neck at the level of the cricoid cartilage, and *alae nasi*–targeted recordings were obtained by placing one electrode on each nostril. Signals were preamplified (gain of 0.5), prefiltered below 10 Hz and above 1,000 Hz (Electronique du Mazet, Le Mazet Saint Voy, France), then sampled at 2,000 Hz (PowerLab, AD Instruments, Hastings, United Kingdom), and stored on file for subsequent analysis.

Data Analysis
Ventilatory and Diaphragmatic Electromyogram Data Analysis. These data were analyzed on a breath-by-breath basis. Flow-derived variables included V_T, minute ventilation, and mean inspiratory flow. Diaphragmatic electromyogram-derived variables included duration of neural inspiration, total neuroventilatory cycle, inspiratory duty cycle, and respiratory rate. The area under the curve of the diaphragmatic electromyogram signal, as provided by the in-house Maquet software, was used to quantify the corresponding electromyogram activity (EAdi) and was expressed as a percentage of its maximal value as observed under a given condition.
Surface Electromyogram Signal Processing and Data Analysis. For each condition, surface electromyogram
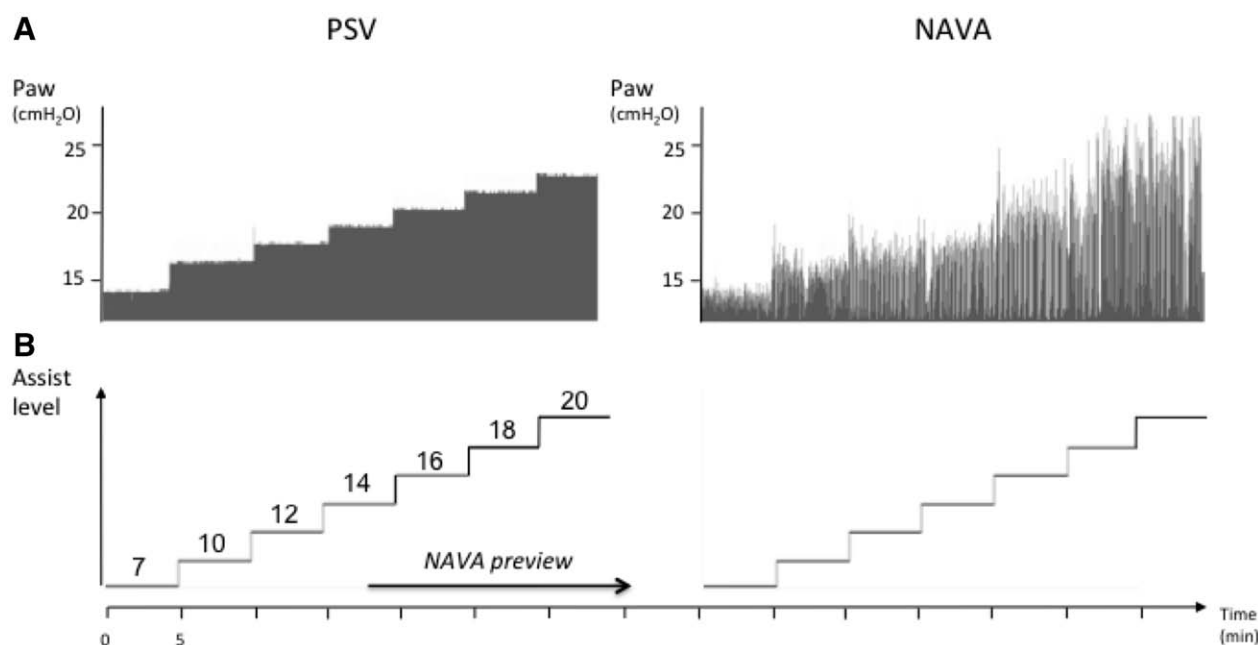
Fig. 1. Representation of the ventilatory protocol sequence using increasing assist levels in pressure support ventilation (PSV) (from 7 to 20 cm H_2O), then in neurally adjusted ventilatory assist (NAVA). (*A*) An example of airway pressure (P_{aw}) tracings obtained in a patient. The NAVA levels were determined at each step during the procedure in PSV, using the *NAVA preview* function (*B*).

signals were averaged according to Hug *et al.*[11,17]: raw electromyogram data were root-mean-squared over a 2-ms fixed window; the continuous root-mean-squared signal was split into as many epochs of mechanical inspiration determined from the airway pressure signal, and then averaged over 3 min; and the averaged root-mean-squared signal was smoothed (triangular Bartlett window width 3,001 points) in order to obtain an electromyogram root-mean-squared envelope. The area under the curve of this envelope was measured and used to quantify the EA (EAscal and EAan for scalene and *alae nasi*, respectively). EAscal and EAan, as well as EAdi, were expressed as a percentage of their maximal value as observed under a given condition. EAscal/EAdi and EAan/EAdi were calculated for each condition.

Groups of EAdi-based Assist Levels. To allow pertinent comparison between the two ventilatory modes, three assist levels from the seven levels tested for each of the two ventilatory modes that resulted in EAdi values of 80 to 100%, 60 to 80%, and 40 to 60% were identified and assigned to three groups (N1, N2, and N3), respectively.

Statistical Analysis

Statistical analysis was performed using Minitab® Statistical Software version 16 (Minitab Inc., State College, PA). Results are expressed as median and interquartile range [25 to 75]. A Friedman analysis of variance for each variable was performed to compare the seven assist levels during both PSV and NAVA procedures, followed, when appropriate, by pairwise comparisons using the Bonferroni method to account for the effects of multiplicity. The within-group and between-group changes of the variables were analyzed using the Scheirer–Ray–Hare test, a nonparametric two-way (ventilatory-mode effect and assist-level effect) ANOVA for repeated measures. Pairwise comparisons of significant effects were also performed, using the Bonferroni method. EAscal/EAdi and EAan/EAdi comparisons between PSV and NAVA were performed using the Wilcoxon test. The relationship between EAdi and EAscal or EAan was examined using the Spearman rank correlation coefficient. The level of significance for all statistical tests was set at P value less than 0.05.

Results

Based on previous experience with similar studies, a convenience sample of 12 patients was studied. Patient characteristics and ventilator settings are provided in table 1. The assist levels sets for groups N1, N2, and N3 were 7 [7 to 7], 12 [12 to 14], and 16.0 [14 to 19] cm H_2O for PSV and 0.5 [0.2 to 1.0], 0.8 [0.6 to 1.6], and 1.8 [1.5 to 3.1] cm $H_2O/\mu V$ for NAVA, respectively. Within each group, ventilatory assist assessed by mean P_{aw} was not significantly different between PSV and NAVA (P = 0.5) (table 2).

Alae nasi electromyograms were successfully recorded in all patients, whereas scalene electromyograms could be correctly recorded in only 9 of 12 patients.

Changes in breathing pattern and EA throughout PSV and NAVA procedures are detailed in figure 1 and table 1 in Supplemental Digital Content 1, http://links.lww.com/ALN/B89.

Breathing Pattern

Neither ventilatory mode nor assist level significantly influenced breathing pattern. However, P_{ETCO_2} decreased from N1 to N3 (without within-group changes), suggesting that

Table 1. Characteristics of the Patients, Ventilator Settings, and Arterial Blood Gases at Inclusion

| | Clinical Characteristics | | | | | | | Mechanical Ventilation | | | | | Arterial Blood Gases | | | |
Patient (No.)	Age (yr)	BMI (kg/m²)	Comorbidities	Diagnostic	SAPS II	Sedative Drugs	RASS	Duration (days)	V_T (ml/kg)	FiO_2	PS (cm H_2O)	PEEP (cm H_2O)	pH	Pao_2/Fio_2 (mmHg)	$Paco_2$ (mmHg)	HCO_3^- (mM)
1	59	26	COPD	Pneumonia*	22	No	0	7	6.9	0.3	—	5	7.41	263	39	24
2	64	22	RLD	Pneumonia	41	Propofol	-1	3	7.5	0.4	—	5	7.47	185	32	23
3	72	23	COPD	Pneumonia	43	Propofol	0	5	5.8	0.5	20	5	7.36	142	68	38
4	85	28	No	ARDS	56	Propofol	-3	6	8.5	0.4	16	5	7.38	206	45	25
5	68	33	COPD	CRA, ARDS	106	No	-4	10	6.8	0.3	—	5	7.45	237	37	27
6	71	25	CHF	Pneumonia, ARDS*	47	No	-3	25	5.4	0.5	10	6	7.36	190	57	31
7	63	47	CHF	Pulmonary edema	39	No	-4	2	6.8	0.4	20	4	7.40	246	50	30
8	78	46	No	Septic shock, ARDS	70	No	0	11	9.2	0.4	16	4	7.34	223	40	21
9	69	36	No	Pneumonia	47	No	0	4	8.1	0.4	16	5	7.57	163	37	34
10	61	35	No	Pneumonia	67	Midazolam	-4	2	8.6	0.5	10	4	7.27	140	41	18
11	58	27	No	Cardiogenic shock	41	No	0	4	6.3	0.4	—	5	7.49	220	34	26
12	74	21	COPD	Pneumonia	65	No	-5	6	6.1	0.4	14	5	7.40	195	30	18
Median	68	28			47		-2	6	6.9	0.4	16	5.0	7.40	200	40	26
IQR	[63–73]	[25–36]			[41–66]		[-4–0]	[4–8]	[6,3–8,3]	[0.4–0.5]	[13–17]	[4.8–5.0]	[7.36–7.46]	[179–221]	[36–48]	[23–31]

* Postoperative.

ARDS = acute respiratory distress syndrome; BMI = body mass index; CHF = chronic heart failure; COPD = chronic obstructive pulmonary disease; CRA = cardiorespiratory arrest; FiO_2 = fraction of inspired oxygen; IQR = interquartile range; PEEP = positive end-expiratory pressure; PS = pressure support; RASS = Richmond Agitation Sedation Scale; RLD = restrictive lung disease; SAPS II = simplified acute physiology score; V_T = tidal volume.

Table 2. Effects of Ventilatory Mode and Assist Level on Breathing Pattern

	N1		N2		N3		Scheirer–Ray–Hare P Value	
	PSV	NAVA	PSV	NAVA	PSV	NAVA	Mode Effect	Assist-level Effect
P_{aw} mean (cm H_2O)	10 [10–12]	10 [9–12]	15 [14–17]*	14 [13–15]*	18 [17–20]*†	18 [15–19]*†	0.5	<0.0001
P_{aw} peak (cm H_2O)	14 [13–15]	17 [14–21]	19 [18–20]*	23 [20–26]*	22 [20–25]*†	30 [23–33]*†‡	0.002	<0.0001
V_T/kg (ml/kg)	6.2 [4.5–7.1]	6.2 [5.2–7.0]	7.1 [6.0–8.2]	6.8 [5.3–9.2]	7.5 [6.9–7.9]	6.9 [5.7–7.2]	0.5	0.08
RR (/min)	32 [28–42]	30 [27–41]	28 [26–39]	28 [26–40]	31 [27–33]	33 [31–37]	1.0	0.5
T_I (s)	0.60 [0.50–0.84]	0.62 [0.54–0.77]	0.68 [0.47–0.85]	0.59 [0.44–0.84]	0.63 [0.50–0.78]	0.56 [0.45–0.71]	0.6	0.7
T_T (s)	2.03 [1.45–2.21]	2.17 [1.51–2.27]	2.16 [1.58–2.40]	2.16 [1.53–2.35]	2.14 [1.90–2.35]	2.02 [1.70–2.09]	0.9	0.7
T_I/T_T (%)	34.0 [29.5–39.5]	33.0 [28.0–37.5]	31.0 [28.0–37.5]	29.0 [24.5–36.5]	31.0 [26.0–34.5]	29.5 [24.5–34.5]	0.4	0.2
V_E (l/min)	10.6 [8.6–13.1]	11.3 [9.5–13.2]	11.2 [10.2–12.9]	11.6 [9.7–14.8]	11.2 [9.8–11.6]	12.3 [10.0–13.0]	0.4	0.5
V_T/T_I (ml/s)	518 [446–701]	504 [433–539]	489 [448–674]	577 [513–622]	513 [430–556]	560 [542–585]	0.5	0.5
P_{ETCO_2} (mm Hg)	40 [39–43]	39 [36–45]	36 [25–42]*	38 [26–42]	32 [25–39]*	33 [26–40]*	0.8	0.05

Values indicate median [interquartile range].

* $P < 0.05$ vs. N1 within the same mode. † $P < 0.05$ vs. N2 within the same mode. ‡ $P < 0.05$ vs. PSV within the same assist-level group.

NAVA = neurally adjusted ventilatory assist; P_{aw} = airway pressure; P_{ETCO_2} = end-tidal partial pressure of carbon dioxide; PSV = pressure support ventilation; RR = respiratory rate; T_I = inspiratory time; T_T = total neuroventilatory cycle; T_I/T_T = inspiratory duty cycle; V_E = minute ventilation; V_T = tidal volume; V_T/T_I = mean inspiratory flow.

increased ventilation hence increased assistance (table 2 and Supplemental Digital Content 1, fig. 2, http://links.lww.com/ALN/B89).

Electromyographic Activities of Inspiratory Muscles

The EA of scalene and *alae nasi* decreased from N1 to N3, with no significant difference between PSV and NAVA: EA was decreased by 46% [29 to 56%] and 60% [31 to 73%] for EAscal ($P = 0.08$) and by 53% [46 to 78%] and 76% [60 to 82%] for EAan ($P = 0.3$), respectively (see Supplemental Digital Content 1, fig. 3, http://links.lww.com/ALN/B89). Within each of the three assist levels tested, EAdi was not significantly different between the two ventilatory modes, whereas EAscal was reduced during NAVA compared with PSV in N1 ($P = 0.006$) and N3 ($P = 0.03$) (table 3). Furthermore, EAscal/EAdi was lower in NAVA (0.7 [0.6 to 0.7]) than in PSV (0.9 [0.8 to 1.1]). This was also the case for EAan/Eadi (0.9 [0.7 to 1.1] in PSV *vs.* 0.7 [0.6 to 0.8] in NAVA, $P = 0.009$; fig. 2). While not reaching statistical significance, assist level tended to decrease EAan/EAdi ($P = 0.06$) and EAscal/EAdi ($P = 0.06$).

Overall, EAan and EAscal were correlated with EAdi (ρ = 0.61, 95% CI, 0.51 to 0.70, $P < 0.0001$ for *alae nasi*; and ρ = 0.60, 95% CI, 0.47 to 0.71), both during PSV and NAVA. Individual correlations were observed in only one half of patients (see Supplemental Digital Content 1, fig. 4 and table 2, http://links.lww.com/ALN/B89).

Discussion

In this study conducted in critically ill and mechanically ventilated patients, increasing levels of PSV and NAVA reduced diaphragmatic EA and the inspiratory activity of the scalene and *alae nasi* muscles. These results suggest a global effect on inspiratory drive. PSV and NAVA had comparable effects on EAan and EAscal in absolute terms (table 3). However, EAan/EAdi and EAscal/EAdi ratios were significantly lower during NAVA than during PSV (fig. 2).

Methodological Considerations

First, this is a physiological study of limited size. We acknowledge that this could explain some discrepancies in the significance of the results. Second, to limit the risk that differences between PSV and NAVA could be due to comparisons of nonsimilar assist levels, assist levels were paired in such a way as to obtain similar values of EAdi that correlate with the inspiratory effort produced by the patients.[18,19] As a result, mean airway pressures, *i.e.*, the assist level delivered by the ventilator,[20] were similar between PSV and NAVA in each of the three assist level groups. Third, we also did not measure the relative contributions of the various inspiratory muscles to inspiratory effort according to the classical approach described by Gilbert *et al.*,[21] which requires measurement of esophageal pressure and gastric pressure. This constitutes a limitation to the interpretation of our results, but electromyogram-based and pressure-based indices of the

Table 3. Effects of Ventilatory Mode and Assist Level on Electromyographic Activity of Inspiratory Muscles

	N1		N2		N3		Scheirer–Ray–Hare P Value	
	PSV	NAVA	PSV	NAVA	PSV	NAVA	Mode Effect	Assist-level Effect
EAdi (%)	95 [81–100]	95 [89–100]	72 [65–81]*	72 [66–76]*	55 [52–59]*†	52 [45–59]*†	0.9	<0.0001
EAan (%)	91 [83–100]	84 [76–95]	68 [32–79]*	50 [38–62]*	47 [24–61]*	23 [17–33]*†	0.08	<0.0001
EAscal (%)	90 [81–100]	65 [62–74]‡	65 [48–83]	55 [47–69]	49 [40–55]*	27 [18–34]*†‡	0.007	<0.0001
EAan/Eadi	1.00 [0.74–1.18]	0.88 [0.79–1.0]	0.88 [0.47–1.14]	0.72 [0.53–0.87]	0.92 [0.36–1.26]	0.45 [0.29–0.70]‡	0.03	0.06
EAscal/EAdi	1.00 [0.82–1.00]	0.70 [0.64–0.81]‡	0.81 [0.73–1.21]	0.78 [0.67–0.96]	0.84 [0.67–1.05]	0.56 [0.50–0.61]‡	0.003	0.06

Values indicate median [interquartile range].

* $P < 0.05$ vs. N1 within the same assist-level group. † $P < 0.05$ vs. PSV within the same assist-level group. ‡ $P < 0.05$ vs. N1 within the same mode. ‡ $P < 0.05$ vs. N2 within the same mode.

EAan = electromyographic activity of alae nasi; EAdi = electromyographic activity of diaphragm; EAscal = electromyographic activity of scalene; NAVA = neurally adjusted ventilatory assist; PSV = pressure support ventilation.

relative contributions of inspiratory muscles to inspiratory effort would appear to vary in the same direction.[22]

General Effects on Extradiaphragmatic Inspiratory Activity

EAan and EAscal decreased in response to increased assistance in PSV and NAVA. In line with previous observations,[8,11] this occurred rapidly. This suggests that despite the fact that EAdi is the source of the NAVA feedback loop, NAVA and PSV may have a nonspecific inhibitory effect on central inspiratory drive. This is attested to by the fact that a NAVA-related reduction in EAan was observed in our patients despite bypass of the upper airway by the endotracheal tube. Similar findings have already been reported with PSV by our group.[11] The origin of the NAVA-related and PSV-related decrease in inspiratory drive may be either chemical or nonchemical. As expected, P_{ETCO_2} decreased with increasing ventilatory assistance (table 2). This was however not true on an individual basis, while the reduction in EAdi when NAVA gain was increased. This supports a NAVA-related nonchemical inhibition of ventilatory drive, as previously described with PSV.[23] This feedback could be mediated by airway or musculoskeletal mechanoreceptor afferents.[24–26]

Differential Effects of NAVA and PSV on Extradiaphragmatic Muscle Activity

We were surprised to find that EAscal/EAdi and EAan/EAdi were significantly lower during NAVA than during PSV, despite similar assist levels. We had indeed postulated that, because NAVA is regulated exclusively by EAdi, it would have less inhibitory effect on EAscal and EAan than PSV. PSV may have failed to reduce EAscal and EAan to the same extent as NAVA because of factors other than the simple level of assistance. PSV is known to be associated with delayed cycling[27] that prevents complete expiration[28] and therefore promotes dynamic hyperinflation.[27] This may place the diaphragm on an unfavorable part of its force–length relationship,[29] resulting in ineffective inspiratory efforts.[27,30] Both mechanisms have been associated with the recruitment of inspiratory extradiaphragmatic muscles.[10,13] There is a lack of ineffective triggering efforts during NAVA,[14,31,32] and it can be postulated that NAVA may prevent dynamic hyperinflation. This would improve diaphragmatic efficiency and decrease the need to recruit extradiaphragmatic inspiratory muscles. In this regard, we did not formally quantify patient–ventilator asynchronies in our study, and we did not compare the airway pressure time product or the time from electromyographic onset to pressurization onset between PSV and NAVA. These approaches would have helped detect subtle differences in the actual assistance provided, beyond the comparison of mean airway pressures that we performed. Nevertheless, we did observe many ineffective efforts during PSV, suggestive of intrinsic positive end-expiratory pressure, and none during NAVA. It is therefore possible that some degree of hyperinflation under PSV could have contributed
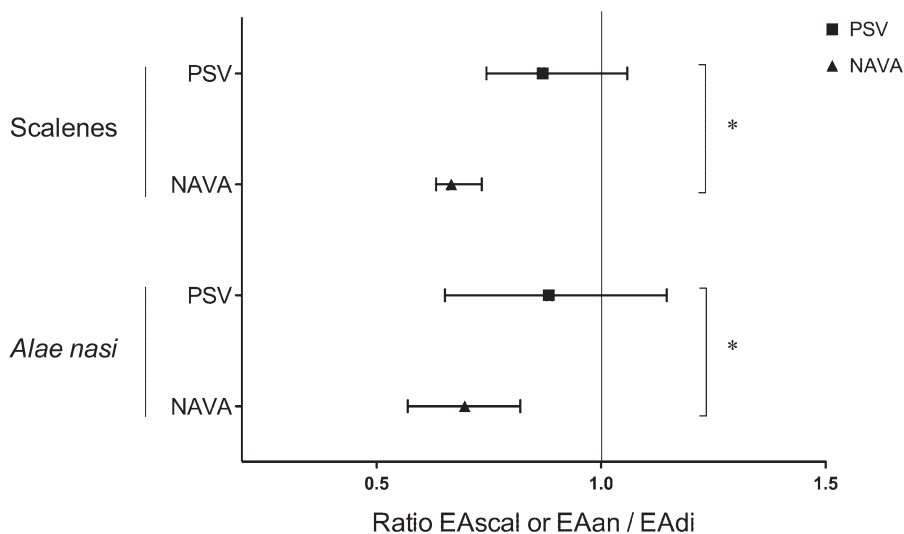
Fig. 2. Contribution of scalene and *alae nasi* to inspiratory effort relative to the diaphragm in pressure support ventilation (PSV) (*squares*) and neurally adjusted ventilatory assist (NAVA) (*triangles*). Data are expressed as median (interquartile range). *P < 0.05. EAan = electromyographic activity of *alae nasi*; EAdi = electromyographic activity of diaphragm; EAscal = electromyographic activity of scalene.

to our results. The differences observed might also have been due to the different nature of the trigger between PSV (flow) and NAVA (EAdi). However, previous data comparing the effects of flow triggered NAVA and EAdi triggered NAVA suggest that the beneficial effects of NAVA on patient–ventilator synchrony relate more to the proportional character of the assistance than to the triggering method.[15] Preliminary data from our group suggest that NAVA and proportional assist ventilation have similar effects on patient–ventilator synchrony in spite of the different nature of their triggering method.[33] Of note, the lower EAan/EAdi and EAscal/EAdi ratios observed in NAVA could also have been partly due to facilitated EAdi. An excitatory reflex facilitating EAdi has been described in healthy subjects in response to an increase in peak inspiratory flow.[34] In our patients, flow-related parameters such as peak P_{aw} were higher in NAVA than in PSV, which could have increased EAdi for a given level of assistance. Finally on this, an electromyographic recruitment pattern showing a greater diaphragm contribution to inspiratory effort in NAVA than in PSV can be considered to be a negative finding, suggesting failure of NAVA to "spare" the diaphragm relative to PSV. It may also mean that NAVA was more efficient than PSV to restore a closer to normal breathing pattern, with a decrease in neuromechanical coupling greater in extradiaphragmatic inspiratory muscles than in the diaphragm.

Implications for Future Studies

In view of the strong relationship between dyspnea and extradiaphragmatic inspiratory muscle activation in mechanically ventilated patients,[4,11] our results provide a rationale to specifically design a study evaluating differential dyspnea relief during NAVA and PSV. Of note, our observations with PSV support the notion that EAan and EAscal could provide

useful signals to adjust ventilatory assistance.[11] Finally, there are clues in the literature to suggest that NAVA could improve gas exchange.[35] This effect could proceed from improved ventilation of the lung bases,[36] in line with the favorable effect of diaphragm pacing on the alveoloarterial gradient in mechanically ventilated quadriplegic patients.[37] The greater contribution of the diaphragm to inspiratory effort in NAVA than in PSV that we observed is consistent with this hypothesis.

In conclusion, NAVA as PSV reduced the activity of extradiaphragmatic inspiratory muscles, in proportion to the level of assistance provided. Compared with PSV, NAVA resulted in a predominant contribution of the diaphragm to inspiratory effort. Further studies are required to determine whether this is a positive or a negative effect.

Acknowledgments

Competing Interests

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