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## Influence of body position, PEEP and intra-abdominal pressure on the catheter positioning for neurally adjusted ventilatory assist

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**Abstract Purpose:** Neurally adjusted ventilatory assist (NAVA) relies on the patient's electrical activity of the diaphragm (EAdi) for actuating the ventilator. Thus a reliable positioning of the oesophageal EAdi catheter is mandatory. We aimed to evaluate the effects of body position (BP), positive end-expiratory pressure (PEEP) and intra-abdominal pressure (IAP) on catheter positioning. **Methods:** Twenty-one patients were enrolled in this study. In six different situations [supine or 45° head of bed elevation (HBE) at PEEP 5 and 15 cmH<sub>2</sub>O; left lateral anti-decubitus at PEEP 5 cmH<sub>2</sub>O; supine at PEEP 5 cmH<sub>2</sub>O with abdominal surgical belt (ASB)] the catheter position was evaluated for the stability of the EAdi signal and information provided by a catheter positioning tool (highlighted electrical activity in central leads, absence of p waves in the distal lead). **Results:** With an optimal catheter position EAdi signals were stable for all tested

situations. During “45° PEEP 15” and “supine PEEP 15” absence of p waves in the distal lead revealed a difference compared with “supine PEEP 5” ( $p = 0.03$ ), suggesting a caudal shift of the diaphragm relative to the oesophagus. The analysis of the highlighted electrical activity in the central leads supports this finding, revealing an influence of PEEP, BP and IAP on EAdi catheter position ( $p < 0.01$ ). **Conclusion:** PEEP, BP and IAP may affect the EAdi catheter position, although not compromising a stable signal. Additional information as provided by the catheter positioning tool is needed to ensure an optimal EAdi catheter position.

**Keywords** Neurally adjusted ventilatory assist (NAVA) · Body position · PEEP · Intra-abdominal pressure · Electrical activation of the diaphragm (EAdi)

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### Introduction

During neurally adjusted ventilatory assist (NAVA) the ventilator is triggered by the electrical activity of the diaphragm (EAdi), assessed by a special gastric tube (EAdi catheter) [1–5]. Pressure assistance is applied in proportion to the amplitude of the EAdi, which represents the respiratory effort of the patient controlled by his respiratory centre [6, 7]. The EAdi catheter positioning is

crucial because NAVA relies on a representative signal from the diaphragm. Recently we evaluated a method to determine the optimal position of the EAdi catheter based on the quality and amplitude of the EAdi signal and the trans-oesophageal electrocardiogram (ECG) [8]. Positive end-expiratory pressure (PEEP), body position (BP) and intra-abdominal pressure (IAP) were not considered at that time, although these are factors known to influence the position of the diaphragm [9–11]. Therefore we aimed

to determine their effect on the EAdi signal and the optimal EAdi catheter position.

## Methods

After approval from the local ethics committee (University of Goettingen, Germany) NAVA was initiated on the basis of the clinical decision of the consultant in charge of the intensive care unit (ICU) with the intention to facilitate respirator weaning. We used a ventilator capable of NAVA (Servo-i, Maquet Critical Care, Solna, Sweden). EAdi catheter placement (16 Fr diameter, 125 cm long; Maquet Critical Care, Solna, Sweden) was performed by the study group. Patients were supine with the head of the bed elevated at 30° and pressure support ventilation with preset PEEP was used during EAdi catheter positioning. The catheter was inserted nasally to a maximum distance of 80 cm. For EAdi measurement it is mounted with an electrode array of one reference electrode and eight measuring electrode rings on the distal part of the catheter at intervals of 16 mm, starting at 120 mm from the tip.

Catheter positioning was monitored by a special tool implemented in the ventilator that displays four raw leads of electrical activity representing cranial to caudal arranged electrode pairs. The catheter positioning tool identifies the electromyographic (EMG) signal with the highest amplitude and highlights it in blue [12]. The software highlights two adjacent leads unless only the outermost pair of electrodes detects a diaphragmatic EMG signal. In addition the position of the electrodes in relation to the heart can be estimated by evaluating the presence/absence of p wave (if present) and QRS complex in different leads. Further processing of the signal (e.g. low pass filter to remove ECG) results in the EAdi signal in microvolts ( $\mu\text{V}$ , analogue to potential difference between electrodes) used to control the ventilator during NAVA. During the placement procedure the catheter was extracted in steps of 1 cm. At each step data were recorded over 60 s using special software (NAVA tracker, Maquet Critical Care, Solna, Sweden). The maximum EAdi value of each breathing cycle during tidal breathing was taken to calculate the median EAdi<sub>max</sub> for each step. The catheter position was considered optimal (OPT) when the highlighted EAdi appeared in the central leads, the p wave was absent in the distal lead and a stable EAdi<sub>max</sub> was found [8]. For each patient the catheter placement procedure was randomly repeated for the following six situations without completely removing/reinserting it:

- Supine or 45° head of bed elevation (HBE) at PEEP 5 and 15 cmH<sub>2</sub>O
- Supine, PEEP 5 cmH<sub>2</sub>O, with abdominal surgical belt (ASB)
- Left lateral anti-decubitus, PEEP 5 cmH<sub>2</sub>O

The measures for catheter positioning (highlighted EAdi in the central leads, absent p wave in the distal lead, stable EAdi<sub>max</sub>) were evaluated over a range of  $\pm 5$  cm from OPT.

The intervention-related catheter positions were referenced to OPT. During data analysis atrial activity was taken into account.

Urinary bladder pressure was measured after retrograde filling with 50 mL of normal saline in supine position at PEEP 5, with and without ASB.

Results are displayed as median with 25/75 percent quartiles (Q). Wilcoxon matched pairs and analysis of variance (ANOVA) were used to compare between groups.

## Results

EAdi catheter placement was possible in all 21 patients (see Table 1 for patient characteristics).

Over all six situations we found a stable EAdi<sub>max</sub> from  $-5$  cm to OPT to 5 cm with a trend to weaker signals at  $-5$  cm ( $p = 0.12$ ). The central leads of the catheter positioning tool were highlighted in more than 95% of patients at OPT in all tested situations, but a shift of the highlighted central leads could be detected in all 21 patients (Fig. 1). The tested situations influenced the optimal catheter position ( $p < 0.01$ ).

P waves could be evaluated in 15 patients (six patients with atrial fibrillation). The OPT condition “absence of p wave in distal lead” was fulfilled at OPT during “left lateral PEEP 5” and “supine PEEP 5” in 93%, during “supine PEEP 5 ASB” in 87%, “45° PEEP 5” in 80% and “45° PEEP 15” and “supine PEEP 15” in 53% of the patients ( $p = 0.03$  compared to “supine PEEP 5”). With the EAdi catheter at OPT + 1 cm, p waves were absent in 93% (“45° PEEP 15”) and 87% (“supine PEEP 15”) of patients. Comparing patients with sinus rhythm and atrial fibrillation neither a main effect of heart rhythm ( $p = 0.41$ ) nor an interaction effect with the tested situations ( $p = 0.57$ ) could be found (Fig. 2).

Considering EAdi<sub>max</sub> in patients with atrial fibrillation, we could not determine a difference between catheter positions in the evaluated range ( $\pm 5$  cm to OPT;  $p = 0.44$ ). In patients with sinus rhythm the EAdi<sub>max</sub> changed ( $p = 0.04$ ) with smaller values at  $-5$  cm.

## Discussion

NAVA relies on a stable EAdi signal for respirator control. Therefore correct placement of the EAdi catheter is mandatory. The EAdi catheter derives the signal from the part of the diaphragm close to the oesophagus. The position of the diaphragm depends on the application of PEEP, BP and IAP [9–11]. Six different situations with

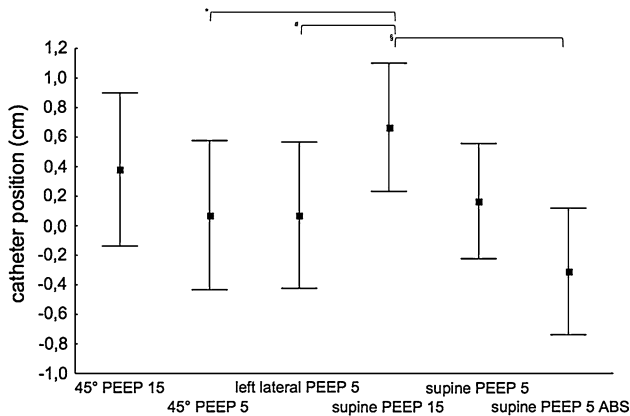
**Table 1** Basic patient characteristics including the catheter position considering data from the positioning tool (OPT), intra-abdominal pressure measured with the patient supine and PEEP set to 5 cmH<sub>2</sub>O (IAP) and intra-abdominal pressure with the abdominal surgical belt in place (IAP ASB)

No.	Gender	Diagnosis	Rhythm	Age (years)	Height (cm)	BMI	OPT (cm)	IAP (cmH <sub>2</sub> O)	IAP ASB (cmH <sub>2</sub> O)	PEEP (cmH <sub>2</sub> O)	EAdi <sub>max</sub> (μV)
1	M	IAH (CHE)	SR	67	160	25	61	25	MD	8	2.7
2	F	SAH	SR	69	160	16	62	6	10	5	3.3
3	M	Sepsis	Afib	71	178	39	67	14	18	8	8.3
4	M	CHD (ACB)	SR	78	175	29	66	13	16	5	2.1
5	M	Aflut	Afib	70	178	25	68	11	14	6	11.8
6	F	CHD (CAB)	SR	76	152	22	61	8	18	5	3.9
7	M	AS (AVR)	Afib	73	174	27	69	10	18	5	4.4
8	M	CHD (CAB)	SR	57	170	26	70	5	18	5	1.2
9	F	ACS (CAB)	SR	77	164	22	63	9	18	8	7.3
10	F	AS (AVR)	Afib	74	168	27	69	8	18	6	4.2
11	F	Pneumonia	Afib	82	165	37	67	10	14	10	5.6
12	F	TBI	SR	81	170	28	63	13	18	7	7.3
13	F	SAH	SR	39	170	22	57	9	15	6	3.2
14	M	CHD (CAB)	SR	60	178	25	66	9	14	6	13.1
15	M	AS (AVR)	SR	82	165	33	68	14	19	10	3.3
16	M	AS (AVR)	Afib	82	170	22	68	5	18	5	19.8
17	M	CHD (CAB)	SR	66	172	31	67	12	14	8	2.0
18	F	ACS (CAB)	SR	70	160	21	66	7	18	5	1.5
19	M	pneumonia	SR	84	180	25	67	13	19	10	3.7
20	M	ACS (CAB)	SR	69	174	30	69	17	21	5	1.6
21	M	Pneumonia	SR	65	175	27	69	8	18	8	6.7
Median				71	170	26	67	10*	18*	6	3.9
Q25/Q75				67/78	165/175	22/29	63/68	8/13	15/18	5/8	2.7/7.3

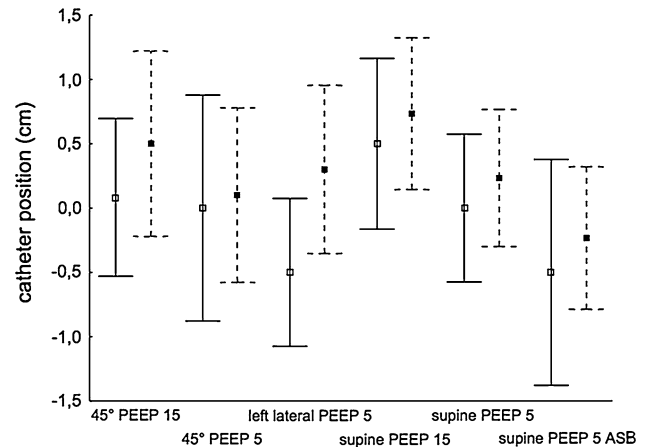
No. number of patient, BMI body mass index,  $NEX_{mod}$  catheter position calculated according to the modified “nose–ear–xiphoid” formula, OPT optimal catheter position, IAP intra-abdominal pressure, ASB abdominal surgical belt, M male, F female, IAH intra-abdominal hypertension, CHE cholecystectomy, SAH subarachnoid haemorrhage, CHD coronary heart disease, CAB

coronary artery bypass, Aflut atrial flutter, AS aortic valve stenosis, AVR aortic valve replacement, ACS acute coronary syndrome, TBI traumatic brain injury, SR sinus rhythm, Afib atrial fibrillation, MD missing data (no ASB applied due to IAH)

\* $p < 0.001$  (IAP compared to IAP ASB)



**Fig. 1** Optimal catheter positions determined by “highlighted central leads” displayed as mean (filled squares) with 95% confidence interval (whiskers) for six different situations; y-axis catheter position in cm from OPT. Significant differences in post hoc paired comparison (Tukey–Kramer) for 45° PEEP 5 vs supine PEEP 15 (\* $p = 0.002$ ), left lateral PEEP 5 vs supine PEEP 15 (# $p = 0.006$ ) and supine PEEP 15 vs supine PEEP 5 ASB (§ $p = 0.0005$ ) ( $n = 21$ )



**Fig. 2** Optimal catheter positions determined by “highlighted central leads” for patients with sinus rhythm (filled squares and dashed lines;  $n = 15$ ) and atrial fibrillation (open squares and solid lines;  $n = 6$ ) displayed as mean (squares) with 95% confidence interval (whiskers) for six different situations; y-axis catheter position in cm from OPT

regard to PEEP, BP and IAP were evaluated and their effects on the catheter position relative to the diaphragm via the information provided by the catheter positioning tool (highlighted central leads and absence of p waves in the distal lead) were found. The changes of the EAdi signal were not significant comparing catheter positions from  $-5$  to OPT to  $+5$  cm and would not have impaired running the NAVA mode. The electrode array on the EAdi catheter is 14.4 cm wide and the ventilator software always uses the diaphragmatic EMG with the highest amplitude found for calculating the EAdi signal used for NAVA. Thus even with a catheter that is displaced  $\pm 5$  cm from OPT there are still electrodes close to the diaphragm, thereby ensuring a constant signal quality. This result is in accordance with our previous study and demonstrates the limits of safety implemented in the EAdi signal acquisition [8]. EAdi<sub>max</sub> therefore is only suitable to detect large changes in the EAdi catheter position relative to the diaphragm.

Further limitations have to be considered when looking at our results. Our measurement technique relies on the detection of the electromyographic activity of the diaphragmatic tunnel covering 2–3 cm of the oesophagus [13] and the assumption that the signal originates from its centre [12]. The accuracy of measurement is limited by the electrode distance of 16 mm. Nevertheless we were able to demonstrate changes.

The evaluation of the p waves revealed a difference between “supine PEEP 5” and “45° PEEP 15” and “supine PEEP 15”. The fact that the distal lead still had proximity to the right atrium in both PEEP 15 situations may be explained by the fact that the increase in PEEP displaces the diaphragm and thoracic content, including the heart, to a more caudal position. Froese and Byran [10] reported that a PEEP level of 10 cmH<sub>2</sub>O results in a 2-cm caudal shift of the middle part of the diaphragm compared with zero PEEP. Comparing patients with and without p waves we did not find a statistically significant difference although Fig. 2 suggests a shift to deeper catheter positions in patients with sinus rhythm. Figure 2 considers the highlighted central leads only and not the additional information provided by the p waves. Therefore the figure allows the interpretation that OPT was determined at a more cranial position in patients with sinus rhythm compared with patients with atrial fibrillation. This observation is confirmed by the

smaller EAdi<sub>max</sub> at  $-5$  cm from OPT in patients with sinus rhythm but not in patients with atrial fibrillation. A possible explanation lies in the catheter positioning procedure that defined OPT (pulling the catheter out stepwise) and the different prioritization of the variables (first, EAdi highlighted in central leads; second, p waves absent in the distal lead; third, stable EAdi<sub>max</sub>). Although we consider only a small collective it might be assumed by the evaluation of the EAdi<sub>max</sub> data that catheter positioning was more accurate in patients in whom p waves were unavailable.

The analysis of the highlighted central leads reveals effects of PEEP, BP and IAP on the diaphragm, with a high PEEP displacing it caudally and an increased IAP displacing it to a more cranial position (Fig. 1). The changes are consistent over all tested situations and similar to the results described above regarding p waves. A 30° HBE increases IAP by 3.7 mmHg [14] and a 45° HBE increases IAP by 9 mmHg [15]. This might explain why the caudal shift in “supine PEEP 15” seems to be more pronounced than in “45° PEEP 15”. Furthermore it explains a caudal shift in “supine PEEP 5” as OPT was established at 30° HBE at a median PEEP of 6 cmH<sub>2</sub>O.

## Conclusion

PEEP, BP and IAP affect the optimal EAdi catheter position. NAVA ventilation is not affected due to the wide electrode array compensating for the small diaphragmatic shift seen with such changes. However this only holds true if an optimal catheter position is ensured in advance.

A verification of the optimal catheter position should be performed after major changes in ventilator settings, patient positioning or clinical condition e.g. increases of abdominal pressure. Catheter positioning is not impaired by the lack of p waves.

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