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The influence of the airway driving pressure on pulsed pressure variation as a predictor of fluid responsiveness

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Abstract *Objective:* Assessing
pulse pressure variation (PPV) to
predict fluid responsiveness in
mechanically ventilated patients with
tidal volume (VT) and the impact of
VT and airway driving pressure
($P_{plat} - PEEP$) on the ability of PPV
for predicting fluid responsiveness.
Design: Prospective interventional
study. *Setting:* ICU of a university
hospital. *Patients:* Fifty-seven
mechanically ventilated and sedated
patients with acute circulatory failure
requiring cardiac output (CO) mea-
surement. *Intervention:* Fluid
challenge was given in patients with
signs of hypoperfusion (oliguria
<0.5 ml kg^{-1} h^{-1}, attempt to
decrease vasopressor infusion rate).
Fluid responsiveness was defined as
an increase in the stroke index (SI)
$\geq 15\%$. Receiver-operating character-
istic (ROC) curves were generated for
PPV and central venous pressure
(CVP). *Results:* The stroke index
was increased $\geq 15\%$ in 41 patients
(71%). At baseline, CVP was lower
and PPV was higher in responders.
The areas under the ROC curves of
PPV and CVP were 0.77 (95% CI
0.65–0.90) and 0.76 (95% CI 0.64–
0.89), respectively ($P = 0.93$).
The best cutoff values of PPV and
CVP were 7% and 9 mmHg, respec-
tively. In 30 out of 41 responders,
PPV was $<13\%$. Using a polytomic
logistic regression ($P_{plat} - PEEP$)
was the sole independent factor
associated with a PPV value $<13\%$ in
responders. In these responders,
($P_{plat} - PEEP$) was ≤ 20 cmH$_2$O.
Conclusion: In patients mechani-
cally ventilated with low VT, PPV
values $<13\%$ do not rule out fluid
responsiveness, especially when
($P_{plat} - PEEP$) is ≤ 20 cmH$_2$O.

Keywords Critical care ·
Fluid challenge

Introduction

Volume expansion remains a cornerstone of the man-
agement of patients with acute circulatory failure [1–3].
However, an excessive fluid loading could induce
peripheral and pulmonary edema, compromising micro-
vascular perfusion and oxygen delivery [4, 5]. Therefore,
predicting fluid responsiveness could be of particular
interest at the patient's bedside. In the last decade,
dynamic variables such as systolic pressure variation,

stroke volume variation (SVV), respiratory variation in aortic blood flow monitored with esophageal Doppler and pulsed pressure variation (PPV) have been shown to be more accurate in predicting fluid responsiveness than classically used static parameters [central venous pressure (CVP) and pulmonary artery occlusion pressure (PAOP)] in mechanically ventilated patients without spontaneous breathing [6–15]. Because PPV is generated by the pressure transmitted from the airways to the pleural and pericardial spaces, it can be theoretically decreased when a low tidal volume (VT) is applied and/or in patients with low pulmonary compliance [16]. In 21 patients with hemodynamic instability, PPV has been shown to increase with the level of VT [17]. In patients with acute respiratory distress syndrome (ARDS), De Backer et al. [18] showed that the ability of PPV to predict fluid responsiveness was decreased when a tidal volume <8 ml kg^{-1} was applied. As the use of low VT (6–8 ml kg^{-1} of ideal body weight) has been shown to improve patient outcome in acute respiratory distress syndrome [19] and is deemed to prevent the occurrence of ARDS in mechanically ventilated patients, the predictive value of PPV in predicting fluid responsiveness could be questioned when low VT is applied [20, 21]. Therefore, the primary goal of the present study was focused on the ability of PPV to predict fluid responsiveness in sedated patients with acute circulatory failure and mechanically ventilated with low VT. Because PPV could theoretically vary according the VT and the lung compliance, the secondary goal was to assess the impact of VT and airway driving pressure on the ability of PPV to predict fluid responsiveness.

Materials and methods

The present study was approved by the Institutional Review Board (number 08/05-01) as it did not alter or delay the patients' management. The patient's closest contacts were informed of the study.

The sedated (midazolam or propofol with sufentanil or remifentanil with a targeted goal of sedation; Ramsay score [22] = 4–6) and mechanically ventilated ICU patients without spontaneous breathing [no spontaneous breath on the screen of the ventilator (Drager Evita 2 Dura, Germany), six patients with a Ramsay score = 6 were given neuromuscular blockade] with acute circulatory failure were eligible to participate in the study. Acute circulatory failure was defined as systolic blood pressure <90 mmHg or the need for vasopressors (dopamine >5 μg kg^{-1} min^{-1} or epinephrine or norepinephrine >0.1 μg kg^{-1} min^{-1}) to maintain a systolic blood pressure >90 mmHg [7]. The association of a clinical infection, the presence of systemic inflammatory

response syndrome and acute circulatory failure defined septic shock [23].

Inclusion and exclusion criteria

In mechanically ventilated and sedated ICU patients with acute circulatory failure, the following inclusion criteria were required:

- The cardiac output or index (CO or CI) was monitored (pulmonary artery catheter Swan-Ganz CCOmbo CCO/SvO2, Edwards Lifesciences LLL, Irvine, CA, or PiCCO, Pulsion Medical Systems AG, Munchen, Germany).
- A fluid challenge was indicated because of signs of hypoperfusion (oliguria <0.5 ml kg^{-1} h^{-1}, CI inadequate for tissue needs, attempt to decrease vasopressor infusion rate).

Patients with cardiac arrhythmias, with known tricuspid insufficiency, with obvious impaired ventricular dysfunction (radiological evidence of cardiogenic pulmonary edema, PAOP >18 mmHg) were excluded. Moribund patients, parturient and patients <18 years of age were also excluded.

Fluid challenge procedure and fluid challenge responsiveness

The fluid challenge was given intravenously via a specific venous line at a constant rate (999 ml h^{-1}, Fresenius Vial®, France, using an infusion pump with 250 or 500 ml isotonic saline or hydroxy-ethyl–starch solution 6% 130/0.4) according to the assessment of the attending physician [7]. The fluid responsiveness was defined as an increase in the stoke index (SI, ratio of CI and heart rate) ≥15%, separating the studied population into responders (R) and non-responders (NR) [7].

Measured variables and time of measurement

- Patients characteristics: age, sex, height, weight and APACHE II score [24] at admission were recorded. The cause of acute circulatory failure, the inotropic and/or vasopressive support [epinephrine, norepinephrine, dobutamine, dopamine (μg kg^{-1} min^{-1})] and the number of organ dysfunctions using the ODIN score [25] were recorded.
- Mechanical ventilation parameters: tidal volume (ml kg^{-1} of ideal body weight), respiratory rate (RR,

cycle min^{-1}), inspiratory oxygen fraction ($\mathrm{F_iO_2}$), the level of positive end expiratory pressure (PEEP) and plateau pressures ($\mathrm{cmH_2O}$) were recorded. The ideal body weight was defined as follows: IBW = X + 0.91 [height (cm) -152.4] ($X = 50$ for male and $X = 45.5$ for female).

- Hemodynamic parameters: heart rate (HR, bpm), mean arterial pressure (MAP, mmHg), central venous pressure (CVP, mmHg), PPV (%), CI (l min^{-1} m^{-2}) and SI (ml m^{-2}) were measured or calculated before fluid challenge (baseline = T_0) and within 10 min after the end of fluid challenge (T_1). The ratio HR/RR was calculated as De Backer recently showed that this ratio could impact the reliability of PPV to predict fluid responsiveness in hypovolemic patients [26]. The CO was calculated by the mean of three measurements using transpulmonary thermodilution in patients with PiCCO (injection of 15 ml of cold saline with an adequate thermodilution curve on the monitor screen) or by continuous thermodilution in patients with a pulmonary artery catheter. The CVP and MAP were measured invasively with a zero referenced to the middle axillary line. The CVP was measured at end-expiration. The PPV value was calculated as initially reported by Michard et al. [7], using the recording of invasive arterial pressure on the monitor screen (Intellivue MP 160, Philips, Eindhoven, The Netherlands). Maximal ($\mathrm{PP_{max}}$) and minimal pulse pressures ($\mathrm{PP_{min}}$) were calculated as described by Michard et al. [7]. The pulse pressure variation (PPV %) was calculated as follows: $\mathrm{PPV} = 100 \times 2[(\mathrm{PP_{max}} - \mathrm{PP_{min}})/(\mathrm{PP_{max}} + \mathrm{PP_{min}})]$. PPV was evaluated in triplicate over each of three consecutive respiratory cycles. The mean values of the three determinations were used for statistical analysis.

Statistical analysis: data are expressed as the median with 5th and 95th percentiles. Comparison of two medians was performed using the Mann–Whitney test and comparison of two proportions using the Fisher exact method. Receiver-operator characteristic (ROC) curves were constructed to evaluate the capacity of PPV and CVP to predict fluid responsiveness. When the ROC curve area was greater than 0.5, the best cutoff value was defined by the Youden index. The comparison between the ROC curve of PPV and CVP was performed using the Hanley test [27]. Considering that the areas under the ROC curves (AUC) reported by Michard et al. [7] (0.98 ± 0.03), Vieillard Baron et al. [11] (0.940 ± 0.038) and Kramer et al. [10] [0.99 (0.96–100)], we assumed an area under the ROC curve of PPV should be >0.87 (the lowest value previously observed) to be clinically relevant. To observe an AUC equal to 0.92 ± 0.05, 55 patients had to be included in the study. Analysis was performed using SAS version 8.1, SAS Institute, Cary, NC, and a P value <0.05 was considered statistically significant.

Results

Eighty-three patients (57 men) were eligible for the study. Twenty-six were excluded because of cardiac arrhythmia ($n = 16$), moribund patients ($n = 5$), violation of the study protocol ($n = 3$), right-to-left shunt ($n = 1$) or risk of pulmonary edema (PAOP = 25 mmHg) ($n = 1$). Therefore, 57 patients [18 women (32%); septic shock = 39 patients (68%), hemorrhagic shock = 9 patients (16%), vasoplegic shock with systemic inflammatory response syndrome = 9 patients (16%)] (Table 1) were included. A VT <8 ml kg^{-1} IBW was applied in 54 out of 57 included patients [95% of studied population; median value = 5.5 ml kg^{-1} IBW (3.5–7.7)]. Fluid challenge induced an SI increase $\geq$15% in 41 patients (72%) (R). Table 2 shows the comparison between R and NR. At baseline, MAP, CVP and SI were significantly lower and PPV was significantly higher in R than in NR (Table 2). For the other studied parameters, there was no statistical difference. Baseline individual values of CVP and PPV of R and NR are shown in Fig. 1. The areas under the ROC curves of PPV and CVP were 0.77 (95% CI 0.65–0.90) and 0.76 (95% CI 0.64–0.89), respectively ($P = 0.93$) (Fig. 2). The best cutoff values of PPV and CVP were 7% [sensitivity = 61% (48–74), specificity = 94% (70–99), positive predictive value = 96% (91–100), negative predictive value = 52% (39–65), accuracy = 77%] and 9 mmHg [sensitivity = 68% (52–82), specificity = 81% (54–96), positive predictive value = 90% (82–98), negative predictive value = 50% (37–63), accuracy 74%], respectively.

Figure 1 shows that 17 Rs were associated with low PPV values (<7%, the best cutoff value). Thus, a post-hoc analysis was performed to compare Rs with PPV values

Table 1 Causes of acute circulatory failure

Underlying diseases	Responders (%) $n = 41$	Non-responders (%) $n = 16$
Septic shock	26 (63)	13 (81)
Peritonitis	12 (29)	7 (44)
Pneumonia	12 (29)	5 (31)
Bacteremia	1 (2)	–
Pyelonephritis	1 (2)	1 (6)
Hemorrhagic shock	9 (22)	0
Aortic aneurism	2 (5)	–
Esophageal varicose bleeding	2 (5)	–
Trauma	3 (7)	–
Retroperitoneal hemorrhage	1 (2)	–
Vasoplegic shock/SIRS	6 (15)	3 (19)
Postoperative	3 (7)	2 (13)
Multi-trauma	2 (5)	1 (6)

Percentages are rounded, so total could be different from 100%

Table 2 Comparison between responders and non-responders

|	Responders $n = 41$	Non-responders $n = 16$	P value
Day of the study during ICU stay	1 [0–6]	2 [0–8]	0.19
Males, n (%)	30 (73)	9 (56)	0.22
Age	70 [41–86]	71 [25–83]	0.91
Height (cm)	171 [152–180]	169 [140–184]	0.97
Weight (kg)	75 [59–100]	78 [37–106]	0.41
APACHE II score	24 [14–38]	20 [14–43]	0.27
Number of organ dysfunctions (ODIN score [23])	2 [1–3]	2 [1–5]	0.98
Use of adrenergic support (n) (doses)	–	–	
Norepinephrine, n (%)	33 (80)	15 (94)	0.42
Norepinephrine, ($\mu g\ kg^{-1}\ min^{-1}$)	0.5 [0.1–5.4]	0.6 [0.3–2.8]	0.59
Dobutamine, n (%)	2 (5)	2 (13)	ND
Epinephrine, n (%)	2 (5)	0 (0)	ND
Respiratory rate (cycles min^{-1})	22 [16–30]	22 [10–33]	0.65
PEEP (cmH_2O)	4 [0–10]	6 [0–17]	0.34
Tidal volume (ml)	450 [380–600]	450 [330–550]	0.29
Ideal body weight per kg (ml kg^{-1})	6.0 [4.8–7.8]	5.6 [3.7–9.7]	0.19
F_iO_2 (%)	50 [40–100]	50 [30–100]	0.47
Plateau pressure (cmH_2O)	21 [12–29]	20 [12–29]	0.85
Heart rate, T_0 (bpm)	99 [61–133]	90 [60–170]	0.27
Heart rate, T_1 (bpm)	94 [58–129]	86 [50–159]	0.42
Ratio HR/RR	4.17 [2.44–7.69]	4.00 [2.00–8.33]	0.97
Mean arterial pressure (mmHg)			
T_0	69 [56–100]	86[49–109]	0.004
T_1	83 [63–111]	93 [44–119]	0.08
Cardiac index (l $min^{-1}\ m^{-2}$)			
T_0	2.8 [1.8–4.3]	3.2 [1.1–5.3]	0.08
T_1	4.0 [2.5–5.9]	3.6 [1.0–5.0]	0.17
Stroke index (ml m^{-2})			
T_0	28 [17–46]	41 [9–61]	0.03
T_1	41 [26–63]	44 [8–62]	0.95
Central venous pressure (mmHg)			
T_0	7 [2–20]	13 [7–20]	0.004
T_1	10 [4–19]	15 [8–26]	0.001
Pulse pressure variation (%)			
T_0	8 [0–31]	3 [1–8]	0.002
T_1	3 [0–16]	3 [−1 to 8]	0.63
Fluid challenge			
Hydroxy-ethyl starch, n (%)	39 (95)	14 (88)	0.31
Volume infused (ml)	500 [250–500]	500 [250–500]	0.07
Death, n (%)	19 (46)	5 (31)	0.38

<7%, with PPV values between 7 and 12% and with PPV values $\geq 13\%$. The tidal volume (in ml and in ml kg^{-1} of IBW), the baseline heart rate, the ratio RR/HR and the airway driving pressure ($P_{plat} - PEEP$) were higher in Rs with PPV $\geq 13\%$, whereas SIs were lower in Rs $\geq 13\%$ (Table 3). Using a polytomic logistic regression (stepwise), the airway driving pressure ($P_{plat} - PEEP$) was the sole independent factor associated with a PPV value $<13\%$ in Rs [PPV $\geq 13\%$ reference; $13 < PPV \leq 7\%$, odds ratio (OR) = 0.61 (0.44–0.85); PPV <7%, OR = 0.67 (0.50–0.90)]. Figure 3 shows that the driving pressure was $\leq 20\ cmH_2O$ in responders with PPV <13%. In responders with PPV >13%, HR/RR was statistically higher than in other responders [5.88 vs. 4.35 (PPV between 7 and 13%) and 3.57 (PPV < 7%), $P < 0.001$].

Discussion

The present study including 57 patients with acute circulatory failure challenges the ability of PPV to predict the fluid responsiveness. Whereas a PPV value $\geq 13\%$ accurately predicts a fluid responsiveness, an increase in SI $\geq 15\%$ could be observed in 13/14 patients with PPVs between 7 and 12% and in 17 patients with a PPV value <7%, especially when an airway driving pressure $\leq 20\ cmH_2O$ was applied.

This study involved patients with all types of shock for whom fluid administration remains one of the main therapeutic treatments for hypotension. The inclusion of nine patients with hemorrhagic shock (all responders) could explain 72% of responders, which is in the high

Fig. 1 Individual values of *PPV* and *CVP* according to the fluid responsiveness with the best cutoff values of PPV and CVP (*line*)
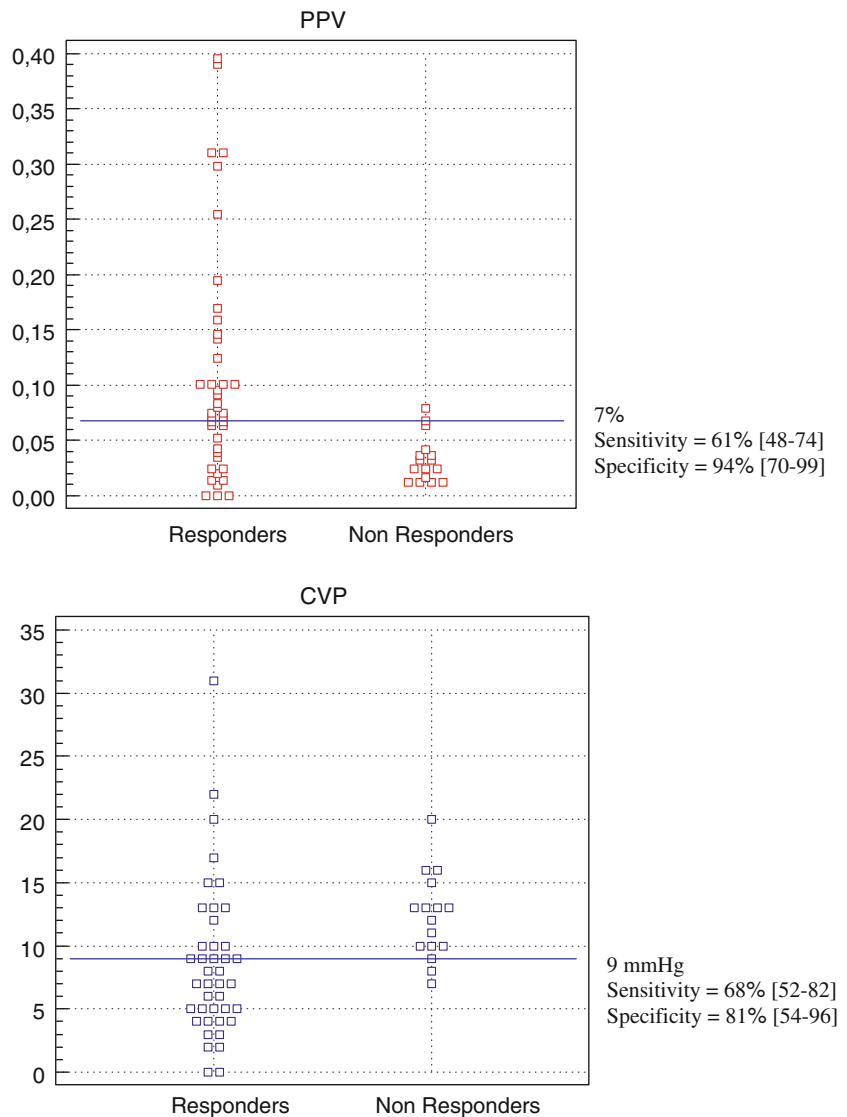
range of what has been previously reported (40–72%), and the high value of the AUC of CVP [8].

The present study shows an area under the ROC curve of PPV = 0.77 (95% CI 0.65–0.90), which is far from those reported by Michard [7], Vieillard-Baron and Kramer (AUC of ROC curve 0.98, 0.94 and 0.99, respectively) [7, 10, 11]. However, our findings are closer to those reported by Hofer [12], De Backer [18] and Huang [28] (0.808, 0.76 and 0.768, respectively). The best cutoff value was 7% with a sensitivity and specificity, positive and negative predictive values, and accuracy of 61, 94, 88, 96 and 50%, respectively. This finding means that a positive fluid responsiveness could be associated with low value of PPV. As shown in the Fig. 1, the findings of the present study mean that a PPV value ≥13% and even ≥7% is highly predictive of fluid

responsiveness, but fluid responsiveness could not be ruled out in patients with lower PPV values.

The use of a low VT (<8 ml kg^{-1} IBW in 54 out of 57 patients) is probably the main explanation of the discrepancy between the findings of the present study and those of the previous ones. Pulsed pressure variation is caused by the transmission of airway pressure to the pleural and pericardial spaces, which induces changes in venous return and cardiac preload. Therefore, PPV could be theoretically limited when the part of transmitted airway pressure to the pleural and pericardial spaces is low. This could be due to the use of low VT in normal lungs with high compliance and in ARDS patients with lungs that have low compliance and are stiff. In these conditions, the probability of transmitting a sufficient pressure variation to the pleural and pericardial spaces to induce large PPV is low [16, 29, 30].
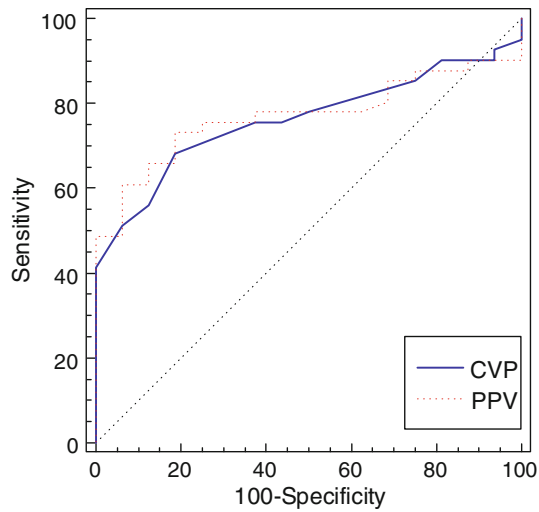
Fig. 2 Receiver-operating characteristic (ROC) curves of *PPV* and *CVP*

Fig. 3 Driving pressure according the range of *PPV* values in responders (*closed circle*) and non-responders (*open circle*)

In anesthetized pigs, Reuter et al. [31] and Kim et al. [32] have shown that the higher the tidal volume is, the higher variation of stroke volume or PPV, respectively. In 21 critically ill patients, Charron et al. [17] showed that PPV increases with the increase in VT. In septic patients with ARDS/ALI mechanically ventilated patients with VT <8 ml kg^{-1} IBW, De Backer et al. [18] reported a lower ability of PPV (area of the ROC curve of PPV $= 0.71 \pm 0.09$) to predict fluid responsiveness. This finding was recently confirmed by Vallée et al. [33], who reported that PPV failed to accurately predict fluid responsiveness in patients ventilated with VT <8 ml kg^{-1} [ROC curve area $= 0.62$ (0.45–0.80)]. Huang et al. [28]
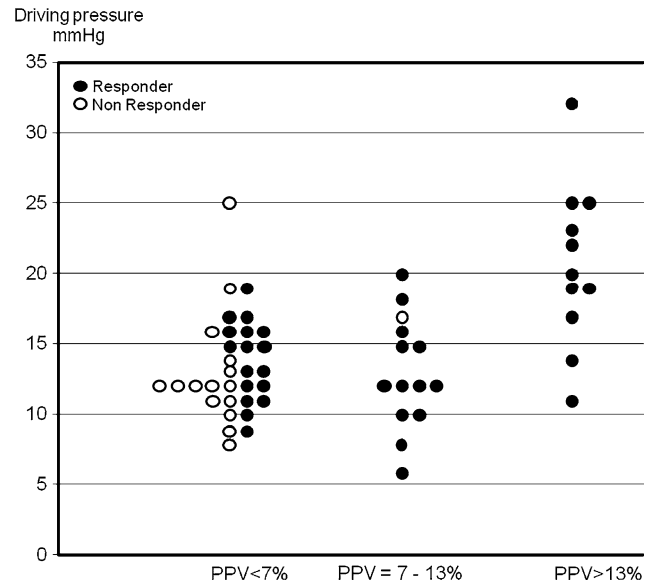
also reported an AUC for the ROC curve of PPV $= 0.768$ in early ARDS patients who were ventilated with VT $= 6.4 \pm 0.7$ ml kg^{-1} IBW. The present study reporting patients in acute circulatory failure and mechanically ventilated with low VT shows a similar value of AUC of the ROC curve [0.77 (95% CI 0.65–0.90)]. In the studies reported by Michard et al. [7], Vieillard Baron et al. [11] and Kramer et al. [10], respectively, greater VT was used (8–12 ml kg^{-1}; 8 ± 2 ml kg^{-1} with a respiratory rate 15 breaths/min^{-1}; 8–10 ml kg^{-1}, respectively). When a low tidal volume is applied in a patient with normal lung,

Table 3 Comparison in responders population with PPV value <7, 7–12 and ≥13%

	<7% n = 17	7–12% n = 13	≥13% n = 11	P value
Day of the study during ICU stay	1 [0–11]	1 [0–3]	1 [0–3]	0.22
Males, n (%)	11 (65)	9 (69)	10 (91)	0.36
Age (years)	70 [47–86]	68 [41–86]	68 [19–88]	0.76
Height (cm)	170 [145–180]	174 [152–185]	172 |160–183]	0.32
Weight (kg)	74 [58–111]	75 [58–101]	77 [59–92]	0.49
APACHE II score	22 [13–43]	23 [13–31]	25 [20–43]	0.41
ODIN score	2 [1–4]	2 [1–3]	2 [1–4]	0.53
Respiratory rate, T_0 (cycles min^{-1})	24 [15–32]	20 [16–32]	20 [15–29]	0.17
Tidal volume, T_0 (ml)	420 [320–500]	460 [420–550]	540 [400–720]	0.004
Ideal body weight per kg (ml kg^{-1})	5.5 [3.5–7.0]	5.7 [4.3–7.6]	6.7 [5.0–12.2]	0.06
F_iO_2, T_0 (%)	50 [25–100]	60 [30–100]	50 [40–100]	0.31
Plateau pressure, T_0 (cmH$_2$O)	19 [13–29]	18 [12–26]	25 [11–32]	0.06
PEEP, T_0 (cmH$_2$O)	6 [0–14]	6 [2–12]	4 [0–8]	0.06
Plateau pressure – PEEP, T_0 (cmH$_2$O)	15 [9–19]	12 [6–20]	20 [11–32]	0.001
Heart rate T_0 (bpm)	87 [55–106]	101 [68–133]	122 [91–172]	<0.001
Ratio HR/RR	3.57 [2.00–4.76]	4.35 [3.45–7.14]	5.88 [4.17–8.33]	<0.001
MAP T_0 (mmHg)	67 [49–119]	74 [58–100]	70 [56–102]	0.89
Cardiac index, T_0 (l min^{-1} m^{-2})	2.5 [1.8–5.0]	2.8 [2.0–4.3]	2.9 [1.6–4.3]	0.68
Stroke index, T_0 (ml m^{-2})	38 [17–51]	30 [18–51]	23 [14–32]	0.006
CVP, T_0 (mmHg)	7 [2–31]	5 [0–13]	10 [0–17	0.51

the mechanical ventilation induces a slight alteration in driving pressure. In ARDS patients with a high lung stiffness, the application of low VT leads to higher driving pressures that are transmitted less to the cardiac cavities. In both cases, the impact of mechanical ventilation on venous return and thus on PPV is blunted. The lack of transmission of airway pressure to the intracardiac cavities could also explain the lack of prediction of fluid responsiveness by dynamic preload parameters (PPV and stroke volume variation) in open-chest conditions [34]. Moreover, the use of low VT could lead to using higher respiratory rates and decreasing the HR/RR ratio in order to prevent severe hypercapnia. Recently, De Backer et al. [26] reported that the increase in RR decreased the PPV in 17 hypovolemic patients. In this study, PPV became negligible when HR/RR decreased below 3.6, which is close to the ratio found in responders with PPV <7% in our study. Finally, most of the patients were supported with norepinephrine, which has been shown to blunt the effect of mechanical ventilation on PPV [35].

Despite different findings, the present study should not be understood as challenging the ability of PPV to predict fluid responsiveness. Indeed, a PPV value $\geq 7\%$ has a positive predictive value = 96%, meaning that high PPV values (>7%) were associated with fluid responsiveness. The use of VT <8 ml kg^{-1} IBW could be suggested to decreases the threshold to predict responsiveness and to enlarge the overlap between responders and non-responders (classically called the grey zone). In seven anesthetized and mechanically ventilated dogs, Kim and Pinsky [32] recently showed that PPV decreases from 20.1 ± 10.8 to $9.5 \pm 5.4\%$ when VT decreases from 20 to 5 ml kg^{-1}.

In the present study, several limitations could be advanced. Firstly, the fluid challenge was not standardized, but was achieved according to the risk/benefit ratio of fluid challenge assessed by the attending physician. There is no consensus concerning the product and the volume of fluid challenge [36]. Secondly, the use of triplicate injections for CO measurement could increase the amount of fluid challenge. These first two limitations could lead to giving a greater amount of fluid, shifting a non-responder to being a responder. However, the main message of the present study remains similar: a low PPV value does not rule out the efficacy of fluid challenge, and the threshold of PPV to discriminate R from NR could be decreased less than 10%. Thirdly, PPV was measured using a manual method as initially reported by Michard et al. [7]. A recent study demonstrated that sampling duration alters pulse pressure variation [32]. Therefore, we cannot assume that the same findings would be reported if PPV was automatically measured and recorded. Fourthly and importantly, even if a PPV value <13% in responders was always associated with a driving pressure ≤ 20 mmHg, some responders with PPV >13% showed an airways driving pressure <20 mmHg. This limitation could challenge the findings of the present study. However, the main result is that a low PPV value could be associated with fluid responsiveness, especially in patients in whom the transmission of pleural pressure to the pericardial space could be compromised, such as in ALI and ARDS.

In daily clinical practice, the present study confirms the predictive values of a high PPV. However, a PPV <13% cannot rule out fluid responsiveness, especially when pulmonary driving pressure ≤ 20 cmH$_2$O is applied in mechanically ventilated patients, corresponding to tidal volume <8 ml kg^{-1}.

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