An Increase in Aortic Blood Flow after an Infusion of 100 ml Colloid over 1 Minute Can Predict Fluid Responsiveness

The Mini-fluid Challenge Study

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ABSTRACT

Background: Predicting fluid responsiveness remains a difficult question in hemodynamically unstable patients. The author's objective was to test whether noninvasive assessment by transthoracic echocardiography of subaortic velocity time index (VTI) variation after a low volume of fluid infusion (100 ml hydroxyethyl starch) can predict fluid responsiveness.

Methods: Thirty-nine critically ill ventilated and sedated patients with acute circulatory failure were prospectively studied. Subaortic VTI was measured by transthoracic echocardiography before fluid infusion (baseline), after 100 ml hydroxyethyl starch infusion over 1 min, and after an additional infusion of 400 ml hydroxyethyl starch over 14 min. The authors measured the variation of VTI after 100 ml fluid (ΔVTI_{100}) for each patient. Receiver operating characteristic curves were generated for (ΔVTI_{100}). When available, receiver operating characteristic curves also were generated for pulse pressure variation and central venous pressure.

Results: After 500 ml volume expansion, VTI increased ≥ 15% in 21 patients (54%) defined as responders. $\Delta VTI_{100} \geq 10\%$ predicted fluid responsiveness with a sensitivity and specificity of 95% and 78%, respectively. The area under the receiver operating characteristic curves of ΔVTI_{100} was 0.92 (95% CI: 0.78–0.98). In 29 patients, pulse pressure variation and central venous pressure also were

What We Already Know about This Topic

- Predicting fluid responsiveness in a noninvasive fashion remains a difficult clinical problem in hemodynamically unstable and mechanically ventilated patients

What This Article Tells Us That Is New

- In patients with low-volume mechanical ventilation and acute circulatory failure, transthoracic echocardiography of the subaortic velocity time index variation after a low volume of hydroxyethyl starch is infused accurately predicts fluid responsiveness

◆ This article is accompanied by an Editorial View. Please see: Vincent J-L: "Let's give some fluid and see what happens" *versus* the "mini-fluid challenge." ANESTHESIOLOGY 2011; 115:455–6.

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Received from the Division Anesthésie Réanimation Urgences Douleur, Groupe Hospitalo-Universitaire Caremeau, CHU Nîmes, Place du Professeur Robert Debré; Faculté de Médecine, Université Montpellier 1 Equipe d'Accueil 2992; Laboratoire de Physiologie Cardiovasculaire et d'Anesthésie Expérimentale, Faculté de Médecine, Place du Professeur Robert Debré, Nîmes, France. Submitted for publication June 22, 2010. Accepted for publication May 9, 2011. Support was provided solely from institutional and/or departmental sources.

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 Anesthesiology 2011; 115:541–7

available. In this subgroup of patients, the area under the receiver operating characteristic curves for ΔVTI_{100}, pulse pressure variation, and central venous pressure were 0.90 (95% CI: 0.74–0.98, $P < 0.05$), 0.55 (95% CI: 0.35–0.73, NS), and 0.61 (95% CI: 0.41–0.79, NS), respectively.

Conclusion: In patients with low volume mechanical ventilation and acute circulatory failure, ΔVTI_{100} accurately predicts fluid responsiveness.

IN intensive care units (ICUs), decisions regarding volume expansion are challenging but frequently required. Treatment of hypovolemia requires rapid fluid infusion, but excessive fluid loading can induce peripheral and pulmonary edema and compromise microvascular perfusion and oxygen delivery.[1,2] In the last decade, dynamic variables such as stroke volume variation, pulsed pressure variation (PPV), respiratory variation of aortic blood flow (monitored with esophageal Doppler), and aortic peak velocity (assessed by echocardiography) have been shown to be more accurate in predicting fluid responsiveness than classically used static variables (central venous pressure [CVP]) and pulmonary artery occlusion pressure in mechanically ventilated patients.[3–12] However, dynamic indicators cannot be used in spontaneously breathing patients and those with cardiac arrhythmia. In addition, because the variation of aortic blood flow is generated by the pressure transmitted from the airways to the pleural and pericardial spaces, these dynamic variables have been shown to be less predictive of fluid responsiveness when a tidal volume less than 8 ml · kg^{-1} is applied and/or in patients with low pulmonary compliance.[13] Because of these limitations, a new concept centering on a "noninvasive fluid challenge" has been developed recently.[14] The passive leg-raising test was shown to mimic a volume expansion of approximately 300 ml *via* the recruitment of the blood fraction contained in the venous reservoir.[14,15] This maneuver converts unstressed volume to stressed volume and accurately predicts fluid responsiveness.[15,16] In some situations, such as complex leg and/or pelvic trauma, passive leg-raising tests cannot be performed. Therefore, it can be useful to develop a third type of test that does not require leg raising to test fluid responsiveness and avoid the deleterious effects of an unnecessary fluid challenge.

In the current study, we tested the hypothesis that a low volume (100 ml) of rapidly delivered fluid can predict fluid responsiveness. By using a low volume for this "mini-fluid" challenge, the deleterious effects of fluid among nonresponders would be limited hypothetically. According to the Frank-Starling cardiac function curve, the concept of fluid responsiveness is defined as a significant increase in stroke volume secondary to an increase in cardiac preload. Moreover, because of the form of the curve, the increase in stroke volume theoretically would be greater in the steep portion of the Frank-Starling curve at the beginning (in particular, the first 100 ml) of the fluid challenge. In addition, the stroke volume theoretically would be greater at the beginning of the fluid challenge, especially when the rate of fluid administration is increased. A positive response to volume expansion usually is defined as a 15% increase in cardiac output or cardiac index after a fluid challenge over 10–30 min.[17] Transthoracic echocardiography provides a rapid, simple, and noninvasive assessment of stroke volume *via* the measurement of the subaortic velocity time index (VTI). Therefore, the primary hypothesis of the current study was that the increase of VTI after the infusion of the first 100 ml (ΔVTI_{100}) of colloid over 1 min could predict fluid responsiveness after a total fluid challenge of 500 ml over 15 min (ΔVTI_{500}).

Materials and Methods

The current study was approved by the Institutional Review Board of the Nîmes University Hospital (Nîmes, France). The patient's closest family member was informed of the study.

Sedated (Ramsay score = 4–6)[18,19] and mechanically ventilated ICU patients without spontaneous breathing and with acute circulatory failure were eligible to participate in this study. Acute circulatory failure was defined as systolic arterial blood pressure less than 90 mmHg or the need for vasopressors (norepinephrine more than 0.1 $\mu g \cdot kg^{-1} \cdot min^{-1}$) to maintain a systolic blood pressure more than 90 mmHg.[4] The association of a clinical infection, the presence of systemic inflammatory response syndrome, and acute circulatory failure defined septic shock.[20]

Inclusion and Exclusion Criteria

Mechanically ventilated and sedated ICU patients with acute circulatory failure in whom a fluid challenge was indicated because of signs of hypoperfusion (oliguria less than 0.5 ml · $kg^{-1} \cdot h^{-1}$, cardiac index inadequate for tissue needs, attempt to decrease vasopressor infusion rate) were eligible for the current study.

Patients with cardiac arrhythmias, with known tricuspid insufficiency, or cardiogenic pulmonary edema were excluded. Moribund or parturient patients and those younger than 18 yr were not included. Patients in whom the echocardiography could not be performed also were excluded.

Fluid Challenge Procedure and Fluid Challenge Responsiveness

The fluid challenge was given intravenously *via* a specific venous line. The first 100 ml was regularly infused over 1 min. After echographic assessment at 1 min, the remaining 400 ml was infused at a constant rate over 14 min. The fluid challenge was performed with a 6% hydroxyethyl starch solution 130/0.4 (Voluven®; Fresenius-Kabi, Louviers, France). Fluid responsiveness was defined as an increase in the subaortic VTI ≥15% ($\Delta VTI_{500} \geq 15\%$) after the infusion of 500 ml hydroxyethyl starch solution, separating the studied population into responders and nonresponders, as described previously.[4]

Measured Variables and Time of Measurement

Patient characteristics, including age, sex, height, weight, and Acute Physiology and Chronic Health Evaluation (APACHE) II score,[21] were recorded at admission. The ideal body weight (kg) was defined as follows: X + 0.91(height (cm) − 152.4); (X = 50 for male and 45.5 for female). The cause of acute circulatory failure, the inotropic and/or vasopressive support (epinephrine, norepinephrine, dobutamine, and dopamine, expressed as $\mu g \cdot kg^{-1} \cdot min^{-1}$), and the number of organ dysfunctions using the Organ Dysfunction and/or Infection (ODIN) score[22] were recorded. The following mechanical ventilation variables were recorded: tidal volume ($ml \cdot kg^{-1}$ of ideal body weight), respiratory rate (cycles/min), inspiratory oxygen fraction (F_iO_2), the level of positive end-expiratory pressure, and plateau pressure (cm H_2O). The following hemodynamic variables were recorded: heart rate (beats/min) and mean arterial blood pressure (mmHg). These variables were collected at baseline (T_0), after 1 min (*i.e.*, infusion of the first 100 ml = T_1), and after the end of the fluid challenge (T_{15}).

Echocardiographic assessment was performed by an experienced physician (level 2 or 3[23]), using a General Electric Vivid3 machine (GE Healthcare, Chalfont St. Giles, Buckinghamshire, United Kingdom). The VTI was recorded classically by pulse waved Doppler on a 5-chamber apical view.[24] The pictures were stored anonymously to allow the calculation of the VTI and stroke index by another blinded physician experienced in echocardiography (level 3). For each step of the study, VTI was measured in triplicate and averaged for the determination of the VTI value.

When available, CVP (mmHg) and PPV (%) were recorded. The CVP and mean arterial blood pressure 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.*,[4] using the recording of invasive arterial pressure on the monitor screen (Intellivue MP 160; Philips, Eindhoven, The Netherlands). Maximal (PP_{max}) and minimal pulse pressures (PP_{min}) were calculated as described by Michard *et al.*[4] The pulse pressure variation (PPV, %) was calculated as follows: $PPV = 100 \times 2[(PPmax - PP_{min})/(PP_{max} + PP_{min})]$. PPV was evaluated in triplicate over each of three consecutive respiratory cycles.

Statistical Analysis

Data are expressed as medians with fifth and ninety-fifth percentiles. For the comparison between responders and nonresponders, Mann–Whitney, Student *t*, and Fisher exact tests were performed where appropriate. Receiver operator characteristic (ROC) curves were constructed to evaluate the ability of VTI to predict fluid responsiveness. When the area under the ROC curve (AUC) was greater than 0.5, the best cutoff value was defined by the closest value to the Youden index[25] and higher than the reproducibility of echocardiography. We also tested for a correlation between ΔVTI_{100} and ΔVTI_{500}. When available, ROC curves of CVP and PPV were constructed and compared with the ROC curve of the VTI for the same patients using the Hanley test.[26]

In previous studies assessing the ability of PPV to predict fluid responsiveness in mechanically ventilated ICU patients with tidal volumes less than 8 $ml \cdot kg^{-1}$, De Backer *et al.*[27], Vallée *et al.*,[28] and Muller *et al.*[29] reported AUC of 0.71 ± 0.09, 0.63 [0.45–0.81] and 0.77 [0.65–0.90], respectively. We assumed that ΔVTI_{100} would be clinically relevant if the 95% CI of its AUC was more than 0.75, corresponding to an AUC of a good clinical tool, as reported by Ray *et al.*[25] For this purpose, 39 patients had to be included. Statistical analysis was performed using SAS version 8.1 software (SAS Institute, Cary, NC). All *P* values were two-tailed and a *P* value <0.05 was considered significant.

Results

During the study period (February–December 2009), 607 patients were admitted to our ICU. Among 211 patients with acute circulatory failure, 169 (80%) were not included because of: cardiac arrhythmia (n = 51) (24%), a decision to withdraw care (n = 30) (14%), or a lack of echocardiographies and thus no assessment of the fluid challenge (n = 19) (9%). In addition, in some patients the fluid challenge was not performed because it was assessed as unnecessary (n = 47) (22%) or hazardous (n = 22) (10%). Thus, 42 patients were eligible for the current study; in 3 patients, echocardiographic exploration could not be performed because of bad echogenicity. Therefore, 39 (18%) patients were included (table 1). The intra- and interobserver variabilities were 4% and 5%, respectively. The causes of circulatory failure were severe sepsis or septic shock (n = 32) (82%), traumatic shock (n = 4) (10%), and systemic inflammatory response syndrome (n = 3) (8%). Among included patients, 30 (77%) were given norepinephrine. After fluid challenge, VTI increased ≥ 15% in 21 patients (54%), who were defined as responders. There were no significant differences in patient characteristics, tidal volume, or severity score between the two groups, except for the plateau pressure, which was higher in the responders (table 1). At baseline, VTI was significantly lower in responders (14 [12–16] cm) than in nonresponders (20 [12–16] cm) ($P = 0.02$). Heart rate did not change between T_0 and T_{15} for either group.

The AUC under the ROC curve of ΔVTI_{100} was 0.92 (95% CI: 0.78–0.98) (fig. 1). Individual values of ΔVTI_{100} according to the fluid responsiveness are shown in figure 2. The best cutoff value of ΔVTI_{100} was 3%, which was lower than the reproducibility of echocardiography (sensitivity = 95% [76–99%], specificity = 78% [52–94%]). Taking into account reproducibility, the best cutoff value was 10% (sensitivity = 95% [87–99], specificity = 78% [59–97], positive predictive value = 0.83 [0.68–0.98], negative predictive value = 0.93 [0.81–0.99], positive likehood ratio = 4.32, and negative likehood ratio = 0.064). A correlation (r = 0.81 [0.66–0.90], $P < 0.0001$) between ΔVTI_{100} and

Table 1. Characteristics of the General Population and Comparison between Responders and Nonresponders

Studied Parameters	All Patients (n = 39)	Responder (n = 21)	Nonresponder (n = 18)	*P* Value —
Age (yr)	66 [59–74]	65 [52–79]	68 [57–77]	0.80
Weight (kg)	72 [70–82]	72 [62–85]	72 [68–97]	0.51
Height (cm)	170 [168–172]	170 [166–175]	170 [164–173]	0.36
Sex (male/female)	30/9	16/5	14/4	0.79
APACHE II	19 [17–24]	21 [15–25]	18 [16–25]	0.90
SAPS II	47 [35–55]	47 [33–59]	46 [34–60]	0.78
LVEF (%)	50 [45–50]	50 [44–50]	50 [45–60]	0.26
MAP (mmHg)	77 [66–87]	70 [63–86]	83 [63–90]	0.48
HR (beats/min)	88 [80–105]	98 [83–108]	84 [77–111]	0.25
CVP (mmHg)	10 [7–14]	8 [5–15]	10 [7–14]	0.68
PPlat (cm H_20)	17 [15–20]	20 [15–24]	15 [13–18]	0.02
PEEP(cm H_20)	5 [5–6]	6 [5–7]	5 [4–6]	0.18
Vt (ml)	420 [402–450]	430 [400–452]	420 [400–450]	0.51
Vt/IBW (ml/kg)	6.6 [6.3–7.1]	6.8 [6.3–7.3]	6.6 [6.0–7.3]	0.45
VTI T_0 (cm)	16 [13–18]	14 [12–16]	20 [15–28]	0.004

Percentages are rounded, so the total may not equal 100%.

APACHE = Acute Physiology and Chronic Health Evaluation; CVP = central venous pressure; HR = heart rate; IBW = ideal body weight; LVEF = left ventricular ejection fraction; MAP = mean arterial pressure; PEEP = positive end-expiratory pressure; PPlat = Plateau pressure; SAPS II = Simplified Acute Physiology Score; Vt = tidal volume; VTI = velocity time index.

ΔVTI_{500} (fig. 3) was found. The AUC for baseline VTI, when predicting fluid responsiveness, was 0.77 [95% CI: 0.61–0.89]. The increase in VTI was always greater in responders than in nonresponders between baseline and T_1 (3 [3–4] *vs.* 0 [−0.75 to +0.5] cm, $P < 0.01$), between baseline and T_{15} (5 [4–7] *vs.* 1 [0–1] cm, $P < 0.001$), and between T_1 and T_{15} (2 [1–3] *vs.* 0 [−1 to +2] cm, $P < 0.04$).

In 29 patients, PPV and CVP were available. The AUCs for ΔVTI_{100}, PPV, and CVP were 0.90 [95% CI: 0.74–0.98], 0.55 [95% CI: 0.35–0.73], and 0.61 [95% CI: 0.41 to 0.79], respectively (fig. 4). There was a significant difference between the AUCs for ΔVTI_{100} and PPV ($P = 0.01$) and between the AUCs for ΔVTI_{100} and CVP ($P = 0.07$). There was no significant difference between the AUCs for PPV and CVP ($P = 0.65$).

The individual VTI data at baseline, T_1, and T_{15} are shown in figure 5. Figure 5A shows individual VTI data at baseline T_1 and T_{15} for responders and figure 5B for nonresponders.

Discussion

In the current study, a 10% increase in VTI after a rapid infusion of 100 ml (ΔVTI_{100}) of hydroxyethyl starch accurately predicted a 15% increase in VTI after a 500-ml infusion. The ability of ΔVTI_{100} to predict fluid responsiveness was greater than that of PPV or CVP. Moreover, the relatively high (r = 0.81) correlation coefficient between ΔVTI_{100} and ΔVTI_{500} suggests that the greater the increase in ΔVTI_{100}, the more we can expect a similar increase in (ΔVTI_{500}). It follows that greater and greater fluid volumes can be given, indicating that further fluid challenges can be attempted in patients with large ΔVTI_{100}. This maneuver can be considered as an alternative way to trace Frank-Starling curves, based on a three-point method: baseline VTI, VTI 100 ml, and VTI 500 ml.

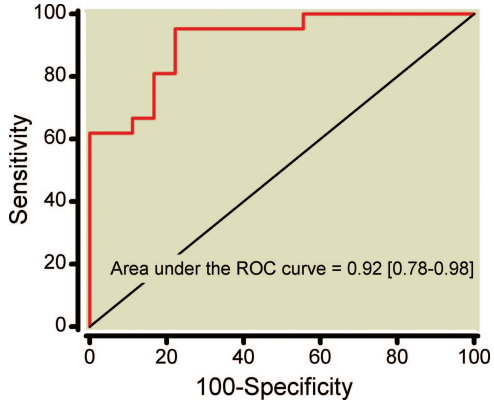

Fig. 1. Receiver operator characteristic (ROC) curves for variation of velocity time index (VTI) (cm) after infusion of 100 ml fluid over 1 min (ΔVTI_{100}) (%).

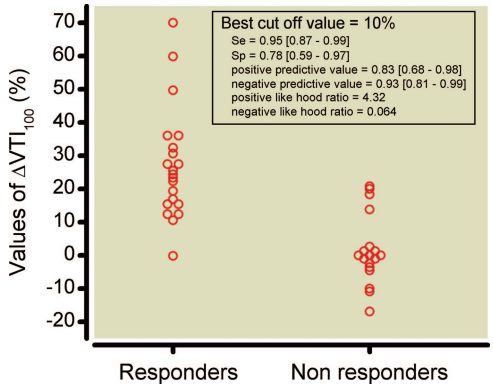

Fig. 2. Individual values of variation of velocity time index (VTI) after infusion of 100 ml fluid over 1 min (ΔVTI_{100}) (%) with the best cutoff value. Sp = specificity; Se = sensitivity.

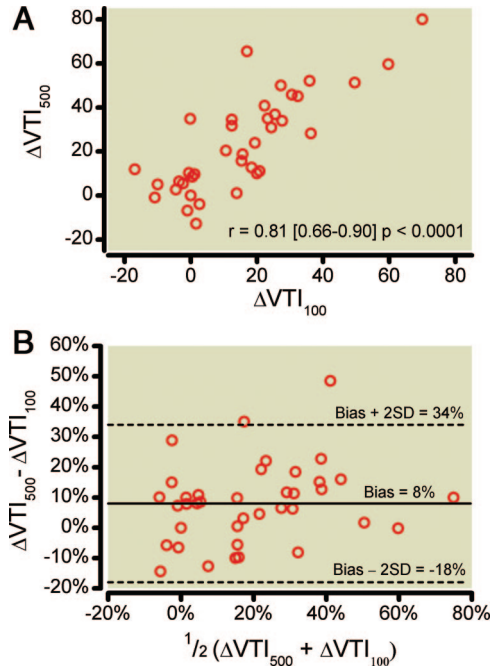

Fig. 3. Correlation (*A*) and Bland and Altman diagram (*B*) between variation of velocity time index (VTI) (cm) after infusion of 100 ml fluid over 1 min (ΔVTI_{100}) and variation of VTI after infusion of 500 ml fluid over 15 min (ΔVTI_{500}).

Echocardiography is considered a major hemodynamic diagnostic tool for intensivists treating circulatory failure.[30] Transthoracic echocardiography provides an accurate and noninvasive measurement of cardiac output with an excellent correlation with thermodilution measurements.[24] Cardiac output is the product of stroke volume and heart rate. The stroke volume is calculated by the product of the subaortic VTI recorded with pulse Doppler in the left ventricle outflow chamber on an apical 5-chamber view and the subaortic left ventricular area (following the formula : subaortic left ventricular area = πD2/4, where D is the measured ventricle outflow diameter).[24] Assuming that the diameter of the left

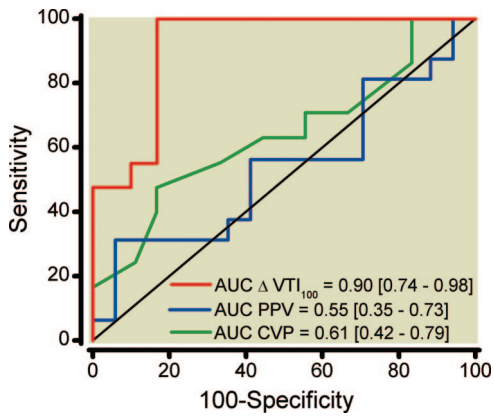

Fig. 4. Receiver operator characteristic (ROC) curves of variation of velocity time index (VTI) (cm) after infusion of 100 ml fluid over 1 min (ΔVTI_{100}), pulse pressure variation (PPV) (%), and central venous pressure (CVP) (mmHg) in 29 patients in whom VTI, PPV, and CVP were measured.

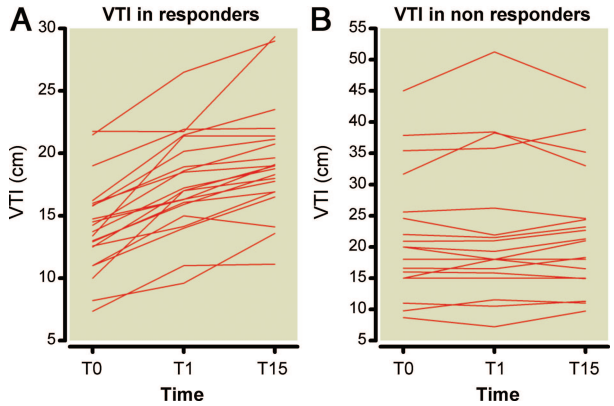

Fig. 5. Individual data for velocity time index (VTI) at baseline (T_0), 1 min (T_1), and 15 min (T_{15}) in responders (*A*) and nonresponders (*B*).

ventricle outflow chamber is constant in a given patient and that variations of heart rate are low, the variations in cardiac output are related to VTI variations. Thus, the measurement of VTI and its variations are directly correlated with variations in cardiac output, avoiding the potential error in the measurement of the left ventricle outflow diameter chamber. This approach has been used in several studies.[31–33] The ability of baseline VTI to predict fluid responsiveness could be questioned. Despite a significant lower value of VTI in the responder group, the AUC of ROC curve for baseline VTI was only 0.77, so baseline VTI remains less pertinent than ΔVTI_{100}.

Historically, volume status was assessed by measuring individual values of preload, such as cardiac filling pressure or volume (static parameters). However, during the last decade numerous studies have demonstrated that an isolated value of preload cannot predict fluid responsiveness.[5,34–36] In fact, the relationship between ventricular preload and cardiac output (represented by the Frank-Starling curve) varies according to cardiac function. An intermediate value of preload can correspond to a positive response to fluid infusion in a patient with normal ventricle function and a negative response in a subject with impaired ventricle function. In other words, in a normal subject, the Frank Starling curve has a predominant steep portion, suggesting a frequent positive response to fluid. In contrast, for abnormal ventricle function, the shape of the Frank Starling curve is predominantly flat, suggesting a low probability of positive response to fluid loading. It follows that determining the shape of the Frank Starling curve could be of particular interest. The current study reports a low AUC for CVP, thus confirming its inadequacy for predicting fluid responsiveness.[4,5] The dynamic variable approach was promising because, under mechanical ventilation, large respiratory variations (more than 10%) of pulse pressure or stroke volume correspond to the steep portion of the Frank-Starling curve, regardless of ventricle function. Therefore, the dynamic indices were thought to predict accurately the fluid responsiveness in mechanically ventilated ICU patients, regardless of their Frank Starling curve. The drastic condi-

tion of dynamic variable measurement (controlled mechanical ventilation with no inspiratory efforts, sinus cardiac rhythm) and the widespread use of low tidal volume (less than 8 ml · kg^{-1} of ideal body weight) to avoid lung barotraumas recently challenged the clinical usefulness of dynamic indices.[27,29] In the current study, the mean tidal volume was 6.6 ml · kg^{-1} of ideal body weight, leading to an AUC of PPV of 0.55 in 29 patients in whom PPV was assessed. This finding is lower than that reported in our previous study, in which more patients were responders because more patients with hemorrhagic shock were included.[29]

A more recent method for evaluating the steep portion of the Frank Starling curve was to study the real-time increase of cardiac output or stroke volume (recorded by transthoracic echocardiography or esophageal Doppler) after passive leg raising that mimics a 300-ml fluid infusion.[15] A 15% increase in aortic or subaortic VTI after passive leg raising was shown to accurately predict fluid responsiveness.[15,16,31,33] However, the use of this simple and clever maneuver may be inappropriate in trauma patients or in patients after major surgery.

Because the previous indices have limitations, we postulated that a significant increase in VTI after a very low volume of rapid fluid infusion corresponds to the steep portion of the Franck Starling curve, regardless of cardiac function. The current findings confirm that a rapid infusion of 100 ml fluid induces a significant increase in subaortic VTI, which subsequently predicts a 15% increase in cardiac output after a 500-ml volume infusion. The use of a low fluid volume is expected to limit the deleterious effect of an unnecessary fluid infusion in nonresponders. Although a 3% increase in VTI (ΔVTI_{100} = 3%) was the best cutoff value, this threshold is inferior to the interobserver variability for the measure of VTI, which is usually reported at approximately 3–8%.[24,37] A cutoff value of 10% has a sensitivity and a specificity of 95% and 78%, respectively. The use of a 10% cutoff value for ΔVTI_{100} could be more clinically relevant when limiting the influence of interobserver variability in the measurement of subaortic VTI.

Hydroxyethyl starch infusion was chosen to guarantee a sustained plasma volume expansion equal to the volume infused. Experimental and clinical studies have shown that crystalloid infusion induces capillary leaks that limit the increase in cardiac output.[38–40] Moreover, plasma expansion is less sustained with a crystalloid than with a colloid.[39] The choice of a 500-ml fluid infusion for the fluid challenge also can be discussed. As showed in figure 5, some responders did not have increased VTI between T_1 and T_{15}. This means that some patients may benefit from 500 ml, but other patients may need smaller volumes. An alternative approach would be repeated administration of 100-ml boluses for as long as there is a significant increase in VTI after each bolus, and then stopping when ΔVTI_{100} no longer increases.[41] This hypothesis was not tested in the current study, and additional studies are required to address this point. Our choice of a 100-ml bolus was arbitrary. Because the response to passive leg raising was very rapid, a lower volume could be more accurate and more precisely analyze the dose/response during a fluid challenge.

This study has some limitations, and the current findings can not be extrapolated to patients with cardiac arrhythmias. Cardiac arrhythmias can cause high VTI variability in this setting. One hypothetical way to overcome this problem would be to average ΔVTI_{100} for several cardiac cycles when working with cardiac arrhythmia. This hypothesis should also be tested in future studies. Because all of the patients included in this study were mechanically ventilated, our results should be confirmed in patients with spontaneous ventilation. Another limitation is that few patients had severe ventricular dysfunction. Theoretically, in a patient with significant hypovolemia, the relation between preload and cardiac output remains steep, regardless of the systolic function. In other words, VTI variation probably helps identify the steep portion of Frank Starling curve independent of cardiac function. This deserves to be verified by future studies. Finally, the study design and analytical plan of the current study could be better and allow regression toward the mean to enter into the interpretation: the differences observed in the baseline status on VTI are consistent with what would be expected if these results were at least partially driven by regression to the mean. The use of a control group would be an excellent design to rule out the effect of regression to the mean and to confirm our findings.

In summary, a 10% increase in subaortic VTI after administrations of 100 ml hydroxyethyl starch over 1 min accurately predicted fluid responsiveness in patients with acute circulatory failure and mechanical ventilation with low tidal volume.

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