Predicting volume responsiveness by using the end-expiratory occlusion in mechanically ventilated intensive care unit patients

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Objective: **During mechanical ventilation, inspiration cyclically decreases the left cardiac preload. Thus, an end-expiratory occlusion may prevent the cyclic impediment in left cardiac preload and may act like a fluid challenge. We tested whether this could serve as a functional test for fluid responsiveness in patients with circulatory failure.**

Design: **Prospective study.**

Setting: **Medical intensive care unit.**

Patients: **Thirty-four mechanically ventilated patients with shock in whom volume expansion was planned.**

Intervention: **A 15-second end-expiratory occlusion followed by a 500 mL saline infusion.**

Measurements: **Arterial pressure and pulse contour-derived cardiac index (PiCCOplus) at baseline, during passive leg raising (PLR), during the 5-last seconds of the end-expiratory occlusion, and after volume expansion.**

Main Results: **Volume expansion increased cardiac index by >15% (2.4 ± 1.0 to 3.3 ± 1.2 L/min/m^2, $p < 0.05$) in 23 patients ("responders"). Before volume expansion, the end-expiratory occlusion significantly increased arterial pulse pressure by 15% ± 15% and cardiac index by 12% ± 11% in responders whereas arterial pulse pressure and cardiac index did not change significantly in nonresponders. Fluid responsiveness was predicted by an increase in pulse pressure ≥5% during the end-expiratory occlusion with a sensitivity and a specificity of 87% and 100%, respectively, and by an increase in cardiac index ≥5% during the end-expiratory occlusion with a sensitivity and a specificity of 91% and 100%, respectively. The response of pulse pressure and cardiac index to the end-expiratory occlusion predicted fluid responsiveness with an accuracy that was similar to the response of cardiac index to PLR and that was significantly better than the response of pulse pressure to PLR (receiver operating characteristic curves area 0.957 [95% confidence interval {CI:} 0.825–0.994], 0.972 [95% CI: 0.849–0.995], 0.937 [95% CI: 0.797–0.990], and 0.675 [95% CI: 0.497–0.829], respectively).**

Conclusions: **The hemodynamic response to an end-expiratory occlusion can predict volume responsiveness in mechanically ventilated patients. (Crit Care Med 2009; 37:951–956)**

Key Words: fluid responsiveness; end-expiratory occlusion; heart–lung interactions; passive leg raising

Because only half of the patients with circulatory failure positively respond to fluid administration (1), the concept of predicting fluid responsiveness has emerged in the recent past years. For this purpose, considering static measures of cardiac preload is unhelpful and must be discouraged (2, 3). By contrast, the decision to give fluid should be based on a "functional" hemodynamic assessment (4), i.e., fluid should be delivered only if changes in preload result in significant changes in stroke volume. In this regard, variables that reflect cyclic changes in stroke volume or its surrogates induced by tidal mechanical ventilation are increasingly used. However, they suffer from the limitation that they cannot be used in case of irregular cardiac rhythm or of spontaneous triggering of the ventilator by the patient (5).

In patients receiving mechanical ventilation, the increase in the intrathoracic pressure impedes the venous return (6). It also compresses the pulmonary vasculature which results, after an initial flush of blood toward the pulmonary veins, in a squeezing of the intraalveolar pulmonary vessels (7). In turn, the decrease in venous return and the squeezing of pulmonary vasculature reduce the left cardiac preload. In line with this, the positive end-expiratory pressure decreases the central blood volume, reduces the cardiac output (8), and increases the preload responsiveness (9). During tidal ventilation, each inspiration cyclically exerts the same effect. Thus, a short end-expiratory occlusion, as it is commonly performed for measuring the intrinsic positive end-expiratory pressure, may prevent the cyclic impediment in left cardiac preload and, thus, may act like a fluid challenge. This could serve as a functional test for fluid responsiveness. Because its duration encompasses several cardiac cycles, the prediction of fluid responsiveness could be independent from cardiac arrhythmias. The test could also be used in patients with a spontaneous breathing activity mild enough for enabling an end-expiratory occlusion.

Our aim was to test whether the hemodynamic effects of a 15-second end-expiratory occlusion were able to predict fluid responsiveness in ventilated patients with an irregular cardiac rhythm or a spontaneous respiratory activity of mild amplitude. We also compared this prediction to that afforded by passive leg raising (PLR), a postural test that has also been demonstrated to predict fluid responsive-

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ness in patients with arrhythmias and spontaneous breathing activity (10).

PATIENTS AND METHODS

Patients. This study was conducted in the 24-bed medical Intensive Care Unit of a University Hospital. It was approved by the Institutional Review Board of our institution (Comité pour la protection des personnes de l'Hôpital de Bicêtre) and all patients or their surrogates accepted to participate to the study.

We studied 34 patients with an acute circulatory failure under conventional mechanical ventilation for whom the attending clinician had decided to administer fluid. This decision was based on the presence of at least one clinical sign of inadequate tissue perfusion in the absence of contraindication for fluid infusion. Clinical signs of inadequate tissue perfusion were defined as 1) systolic blood pressure <90 mm Hg (or a decrease >50 mm Hg in previously hypertensive patients) or the need of vasopressive drugs (dopamine >5 μg/kg/min or norepinephrine), 2) urine output <0.5 mL/kg/hr for at least 2 hrs, 3) tachycardia (heart rate [HR] >100/min), or 4) presence of skin mottling (5). The cause of circulatory failure was sepsis in 32 patients and was drug poisoning in two patients (Table 1). The ventilator (Evita 4, Dräger Medical, Lübeck, Germany) was set in the volume assist-control mode in all patients. The trigger was set at 2 L/min. Eleven patients (32%) presented cardiac arrhythmias (atrial fibrillation in nine, frequent supraventricular extrasystoles in one and frequent ventricular extrasystoles in one). The remaining patients exhibited a spontaneous respiratory activity, as assessed by a patient respiratory rate higher than the ventilator respiratory rate. No patient exhibited both spontaneous respiratory activity and cardiac arrhythmia. The level of positive end-expiratory pressure under which the end-expiratory occlusion was performed was the level that had been set before inclusion into the study. The following criterion was required: the patient's respiratory activity must have been sufficiently mild for rending the respiratory spontaneous inspiratory breathes unable to interrupt a 15-second end-expiratory occlusion. Ten patients who were initially planned for being included in the study were excluded because the end-expiratory occlusion was interrupted by triggering of the ventilator by the patient's inspiratory effort. We did not attempt to perform end-expiratory occlusions again and these patients were definitively excluded from the study.

Hemodynamic Measurements. All patients had an internal jugular vein catheter and a thermistor-tipped arterial catheter (PV2024 Pulsion Medical Systems, Munich, Germany) in the femoral artery that was connected to the PiCCOplus monitoring device (Version 6.0, Pulsion Medical Systems) for measuring the cardiac index (through transpulmonary thermodilution and pulse contour analysis). The heart rhythm and the systemic arterial pressure were continuously computerized using the HEM3.5 software (Notocord, Croissy-sur-Seine, France). In the subgroup of patients exhibiting spontaneous breathing activity but no cardiac arrhythmia, the respiratory variation of the arterial pulse pressure and of the pulse contour analysis-derived stroke volume displayed by the PiCCOplus device were recorded. The cardiac index derived from pulse contour analysis was continuously computerized using the PiCCO Win 4.x software (Pulsion Medical Systems). All continuous values were averaged over a 5-second period.

Study Design. At baseline ("Base 0"), a first set of hemodynamic measurements was performed, including systemic arterial pressure, HR and cardiac index (transpulmonary thermodilution). Patients underwent a PLR test, as previously described (5). The effects of PLR were assessed by measuring its maximal effects on the pulse contour-derived cardiac index.

At the time when all hemodynamic variables had returned to their baseline value ("Base 1"), a set of hemodynamic measurements was performed, including systemic arterial pressure, HR, and cardiac index (the latter through transpulmonary thermodilution). A 15-second end-expiratory occlusion was then applied using the automatic device of the ventilator for measuring the total positive end-expiratory pressure. Systemic arterial pressure, HR, and pulse contour-derived cardiac index were averaged during the 5 last seconds of the end-expiratory occlusion because the maximal hemodynamic effects of the occlusion were observed at this time. The changes in systemic arterial pressure and in cardiac index were expressed as percent changes from base 1. Thirty seconds after releasing of the occlusion, systemic arterial pressure, HR, and pulse contour-derived cardiac index were recorded ("Base 2"). The patients then received a 10-minute infusion of 500 mL saline. A last set of hemodynamic measurements, including systemic arterial pressure, HR, and cardiac index, was recorded after fluid infusion.

Statistical Analysis. Patients in whom the fluid administration had induced an increase in cardiac index larger than 15% were defined as "*volume responders*" and the remaining ones as "*volume nonresponders*" according to previous studies (5, 11–13).

In a subset of 15 successive patients, three values of pulse contour-derived cardiac index, all averaged over 5 seconds, were successively recorded within 2 minutes at base 1 to assess reproducibility. The coefficient of variation calculated for pooled data obtained in triplicate was 1.76%.

All the continuous variables were normally distributed (Kolmogorov-Smirnov test for normality). Comparisons of hemodynamic parameters between before vs. after intervention were assessed by using a paired Student's *t* test and the comparisons between responders vs. nonresponders were assessed by using a two sample Student's *t* test. Receiver operating characteristic (ROC) curves (with 95% confidence interval, [CI]) were constructed for the following variables: a) percent changes in systolic pressure, pulse pressure, and in cardiac index induced by the end-expiratory occlusion, b) percent changes in pulse pressure and in cardiac index induced by the PLR, cardiac index at base 2, and in patients with spontaneous breathing activity, c) the respiratory variation of pulse pressure and of pulse contour analysis-derived stroke volume at base 2. The areas under the ROC curves were compared using a Hanley-McNeil test (14). Results are expressed as mean ± SD. A p value <0.05 was considered statistically significant. The statistical analysis was performed by using Statview5.0 software (Abacus concepts, Berkeley, CA) for all tests except the Hanley-McNeil test, which was performed with MedCalc8.1.0.0 Software (Mariakerke, Belgium).

Table 1. Patient characteristics of the study population

	Responders (n = 23)	Nonresponders (n = 11)
Sepsis (n)	22	10
ARDS (n)	18	5
Tidal volume (mL/kg)	6.8 ± 1.1	6.8 ± 1.1
Total PEEP (cm H_2O)	8 ± 3	7 ± 2
LV ejection fraction (%)	53 ± 9	53 ± 5
Pao/FIO_2 (mm Hg)	123 ± 57	195 ± 122
I/E ratio	0.4 ± 0.1	0.3 ± 0.1
Patients receiving norepinephrine (n)	18	5
Rate of norepinephrine infusion (μg/kg/min)	1.0 ± 0.3	1.1 ± 0.4

ARDS, acute respiratory distress syndrome; PEEP, positive end-expiratory pressure; LV, left ventricular; I/E, inspiratory over expiratory.

Values are mean ± SD.

RESULTS

Patients. Volume expansion induced an increase in cardiac index ≥15% from base 2 in 23 patients (volume responders). In these patients, cardiac index increased from 2.4 ± 1.0 L/min/m^2 at base

Table 2. Evolution of hemodynamic parameters in responders and nonresponders

	Base 0	Passive Leg Raising	Base 1	End-Expiratory Pause	Base 2	Post Volume Expansion
Heart rate (beats/min)						
Responders	107 ± 25	106 ± 23	103 ± 30	97 ± 17	101 ± 29	102 ± 24
Nonresponders	106 ± 30	110 ± 31	106 ± 30	106 ± 42	104 ± 27	95 ± 18
Systolic arterial pressure (mm Hg)						
Responders	99 ± 21	106 ± 22§	97 ± 24	105 ± 25[c]	99 ± 25	125 ± 26[a,d]
Nonresponders	110 ± 23	113 ± 24	110 ± 22	109 ± 22	108 ± 24	103 ± 18
Diastolic arterial pressure (mm Hg)						
Responders	49 ± 12	50 ± 14	48 ± 13	50 ± 14[c]	50 ± 14	60 ± 16[d]
Nonresponders	52 ± 17	52 ± 16	51 ± 14	51 ± 14	51 ± 14	49 ± 13
Arterial pulse pressure (mm Hg)						
Responders	50 ± 19	56 ± 20[b]	49 ± 19	55 ± 20[c]	49 ± 17	66 ± 21[d]
Nonresponders	58 ± 19	61 ± 18	58 ± 20	58 ± 20	58 ± 20	57 ± 19
Cardiac index (L/min/m)						
Responders	2.3 ± 1.1[a]	2.9 ± 1.2[b]	2.4 ± 1.0[a]	2.7 ± 1.0[c]	2.4 ± 1.0[a]	3.3 ± 1.2[d]
Nonresponders	3.4 ± 1.3	3.4 ± 1.4	3.4 ± 1.2	3.4 ± 1.2	3.5 ± 1.3	3.5 ± 1.4

Mean ± SD.

[a] $p < 0.05$, responders vs. nonresponders; [b] $p < 0.05$, Passive leg raising vs. base 0; [c] $p < 0.05$, End-expiratory pause vs. base 1; [d] $p < 0.05$, Postvolume expansion vs. base 2.

2 to 3.3 ± 1.2 L/min/m^2 after volume expansion ($p < 0.01$). In the 11 nonvolume responders, the cardiac index did not change significantly (from 3.5 ± 1.4 L/min/m^2 at base 2 to 3.5 ± 1.3 L/min/m^2 after volume expansion).

Hemodynamic Effects of PLR. In volume responders, PLR induced a significant increase in cardiac index of 22% ± 18% and in arterial pulse pressure of 15% ± 20% (Table 2). In nonvolume responders, neither cardiac index nor arterial pulse pressure changed significantly during PLR.

Hemodynamic Effects of the End-expiratory Occlusion. In volume responders, cardiac index increased by 12% ± 11% from base 1 during the end-expiratory occlusion. By contrast in nonvolume responders, the end-expiratory occlusion did not change cardiac index (Table 2).

In volume responders, arterial pulse pressure increased by 15% ± 15% from base 1 during the end-expiratory occlusion. By contrast in nonvolume responders, the end-expiratory occlusion did not change arterial pulse pressure (Table 2). In volume responders, the increase in arterial pulse pressure induced by the end-expiratory occlusion was of variable magnitude: in 14 patients, the end-expiratory occlusion induced a progressive increase in arterial pulse pressure, such that an overshoot of arterial pressure was observed during the last seconds of the occlusion (as depicted in Fig. 1). In the nine remaining responders, the end-expiratory occlusion increased arterial pulse pressure by a lower magnitude with no typical overshoot. In the latter patients, the increase in cardiac index induced by volume expansion (+23% ± 10%) was of significantly lower magnitude than in patients who exhibited an overshoot in arterial pulse pressure (+60% ± 40%).

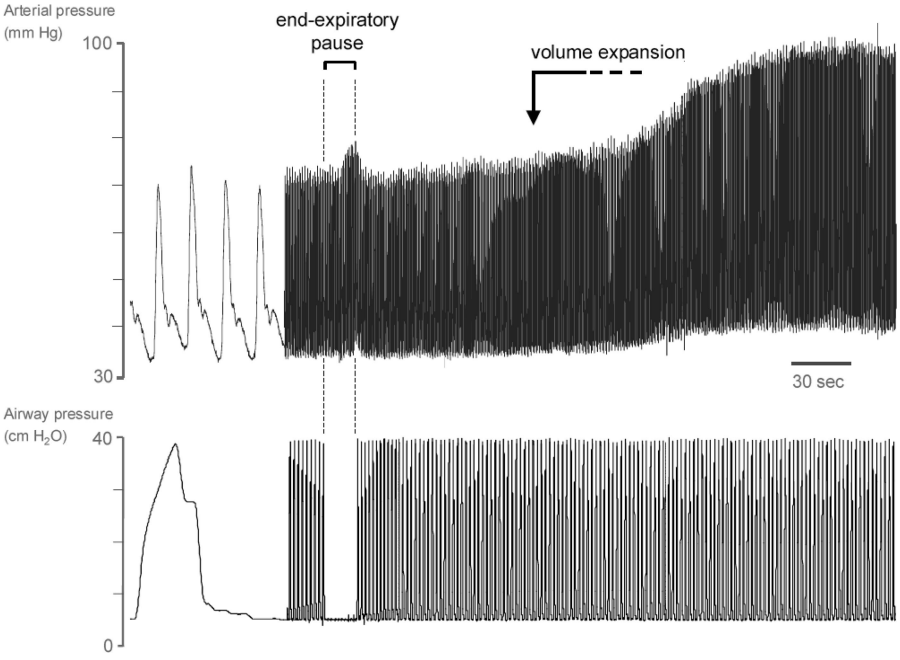

Figure 1. Typical recording of the arterial pressure curve before and during an end-expiratory occlusion and then before and during fluid expansion. The increase in arterial pulse pressure induced by fluid expansion was preceded by an 11% increase in arterial pressure during the end-expiratory occlusion.

Prediction of Fluid Responsiveness. An increase in arterial pulse pressure ≥5% during the end-expiratory occlusion enabled to diagnose a positive response to fluid administration with a sensitivity of 87% (95% CI, 66%–97%) and a specificity of 100% (95% CI, 71%–100%) (Table 3, Fig. 2). An increase in cardiac index ≥5% during the end-expiratory occlusion enabled to diagnose a positive response to fluid administration with a sensitivity of 91% (95% CI, 72%–99%) and a specificity of 100% (95% CI, 72%–100%) (Table 3, Fig. 2).

Table 3. Comparison of the areas under the ROC curves for the indicators used for predicting fluid responsiveness

	ROC Area	95% CI	Threshold Value	Sensitivity (%)	Specificity (%)	p^a
Effects of the end-expiratory pause on arterial pulse pressure	0.957	0.825–0.994	5%	87	100	—
Effects of the end-expiratory pause on pulse contour-derived cardiac index	0.972	0.849–0.995	5%	91	100	0.587
Effects of the end-expiratory pause on arterial systolic pressure	0.714	0.528–0.859	4%	67	82	0.001
Effects of passive leg raising on pulse contour-derived cardiac index	0.937	0.797–0.990	10%	91	100	0.672
Effects of passive leg raising on arterial pulse pressure	0.675	0.497–0.829	11%	48	91	0.002
Cardiac index at base 2	0.648	0.466–0.803	2.8 L/min/m^2	78	54	<0.001

ROC, receiver operating characteristics; CI, confidence interval.

[a]*p* value of the Hanley-McNeil test for the equality of the ROC area for the effects of the end-expiratory pause on pulse contour-derived cardiac index vs. the other ROC areas.

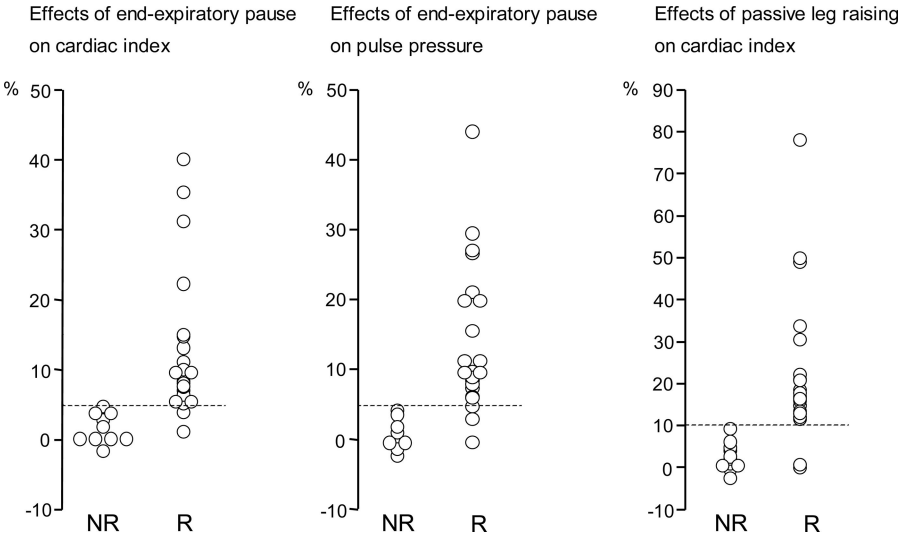

Figure 2. Individual values of changes in cardiac index during an end-expiratory occlusion, in arterial pulse pressure during an end-expiratory occlusion and in cardiac index during a passive leg raising test (expressed as percent change from baseline) in volume responders (*R*) and nonvolume responders (*NR*). *$p < 0.05$ vs. NR. *Dash line* represents the threshold value of each method determined as discriminating R and NR.

An increase in cardiac index ≥10% during PLR enabled to diagnose a positive response to fluid administration with a sensitivity of 91% (95% CI, 71%–99%) and a specificity of 100% (95% CI, 71%–100%) (Table 3, Fig. 2).

The areas under the ROC curves established for the effects of the end-expiratory occlusion on arterial pulse pressure, for the effects of the end-expiratory occlusion on cardiac index, and for the effects of PLR on cardiac index were not significantly different (Table 3, Fig. 3). The areas under these three ROC curves were all significantly larger than that under the ROC curves established for the effects of PLR on arterial pulse pressure, for the effects of the end-expiratory occlusion on arterial systolic pressure, and for the cardiac index at base 2 (Table 3, Fig. 3).

In the subgroup of 23 patients with spontaneous breathing activity but without cardiac arrhythmia (16 responders and 7 nonresponders), a respiratory variation of pulse pressure at base 2 ≥11% predicted fluid responsiveness with a sensitivity of 100% (95% CI, 78%–100%) and a specificity of 37% (95% CI, 9%–75%). In those patients, a respiratory variation of stroke volume at base 2 ≥10% predicted fluid responsiveness with a sensitivity of 100% (95% CI, 78%–100%) and a specificity of 50% (95% CI, 16%–84%). The areas under the ROC curves established for the effects of the end-expiratory occlusion on arterial pulse pressure, for the effects of the end-expiratory occlusion on cardiac index and for the effects of PLR on cardiac index (0.990 [95% CI, 0.827–1.000], 0.971 [95% CI, 0.796–0.989], and 0.888 [95% CI, 0.674–0.980], respectively) were all significantly larger than that under the ROC curves established for the respiratory variation of pulse pressure and of stroke volume (0.679 [95% CI, 0.450–0.880] and 0.571 [95% CI, 0.340–0.781], respectively).

DISCUSSION

This study conducted in patients with acute circulatory failure, mild spontaneous breathing activity, or cardiac arrhythmias, demonstrates that an increase in pulse pressure or in pulse contour cardiac output greater than 5% during an end-expiratory occlusion predicted fluid responsiveness with accuracy. If arterial pulse pressure was the only hemodynamic variable taken into account, its changes during the end-expiratory occlusion predicted fluid responsiveness with a better accuracy than its changes during PLR.

It is now well established that fluid responsiveness is better predicted by dynamic indices of preload reserve than by static measures of preload (2, 3). Functional hemodynamic assessment consists of measuring cardiac output during a short change in cardiac preload (of any sort) and of administering fluid only if preload changes have changed the cardiac output (4). As an application, the hemodynamic consequences of the heart–lung interactions offer the opportunity to predict fluid responsiveness at the bedside. The concept of detecting hypovolemia by observing the effects of interrupting tidal mechanical ventilation has been introduced years ago by Perel et

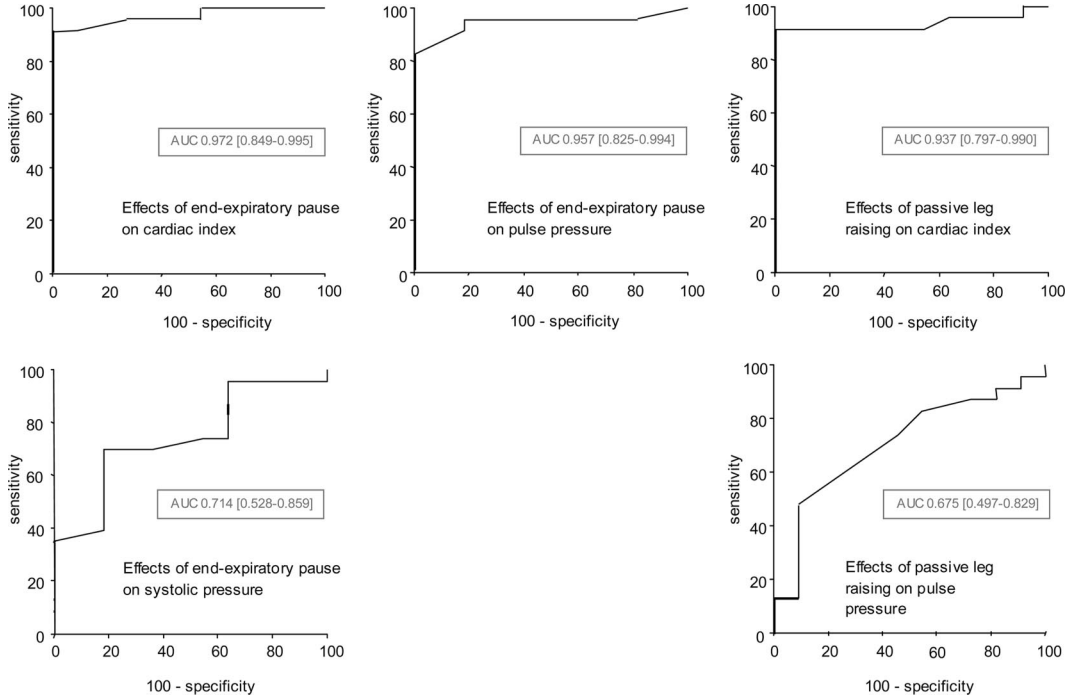

Figure 3. Receiver operating curves comparing the ability of changes in cardiac index, arterial pulse pressure, arterial systolic pressure induced by an end-expiratory occlusion and of changes in cardiac index and arterial pulse pressure induced by a passive leg raising test (expressed as percent variation from baseline) to discriminate volume responders and nonvolume responders. *AUC*, area under the curve, expressed as mean (95% confidence interval).

al (15). Our group later demonstrated that the variations of pulse pressure induced by tidal ventilation predict fluid responsiveness with accuracy (13). The respiratory variation of numerous surrogates of stroke volume has also demonstrated a similar accuracy (11, 12, 16–18).

In line with these previous studies, the underlying concept of this study was that, by abolishing the inspiratory increase in intrathoracic pressure, the end-expiratory occlusion may allow an increase in venous return. In case of preload reserve of the right ventricle, this should result in an increase in right ventricular stroke volume in comparison with the preceding tidal ventilation. It is also likely that by abolishing the inspiratory increase in transpulmonary pressure, the end-expiratory occlusion enabled the pulmonary vasculature to remain open inside the deflated alveoli. In turn, the end-expiratory occlusion likewise resulted in an increase in left ventricular preload that acted like a volume challenge of sufficient magnitude for detecting preload responsiveness.

In 14 of the 23 volume-responder patients, we observed that the arterial pressure at the end of the end-expiratory occlusion reached a higher level than the maximum blood pressure occurring before occlusion, an effect that has not been previously reported (19). This discrepancy could have two explanations. First, we performed a longer end-expiration occlusion. It can be postulated that the prolonged end-expiratory occlusion could let the venous return progressively rise to a higher value than that achieved during tidal ventilation. As a consequence, after the few seconds that were necessary to the increased flow for crossing the pulmonary circulation, this additional increase in left cardiac preload resulted in an increase in stroke volume, and thus arterial pulse pressure, to a level that it had not reached during tidal ventilation. Another potential difference with other studies could be that the response to fluid administration was of particular magnitude in our volume-responders. In this regard, the pressure "overshoot" was evident especially in patients who experienced a large increase in cardiac index in response to fluid administration while it was not observed in any nonvolume responder. It is noteworthy that in the study by Tavernier et al (19) who performed an end-expiratory occlusion (during 7–12 seconds), no "overshoot" effect was reported but no patient experienced an increase of stroke volume larger than 58% after infusion of 500 mL of fluid.

An advantage of testing fluid responsiveness by using the end-expiratory occlusion is that the test can be used instead of the respiratory variation of hemodynamic parameters in case of spontaneous respiratory activity. In fact, our study confirmed that the respiratory variation of hemodynamic parameters is not accurate for predicting fluid responsiveness in this case, as it was already reported (5, 20, 21). Interestingly, the ROC curves analysis showed that the end-expiratory occlusion remained a valuable test in the subgroup of patients with spontaneous breathing. This dynamic test could also replace the respiratory variation of hemodynamic parameters in case of cardiac arrhythmias because it encompasses several cardiac cycles.

PLR is another method that has also been advocated as an alternative to the respiratory variations of hemodynamic parameters in cases of spontaneous breathing or arrhythmia (5). By shifting blood from the lower part of the body toward the intrathoracic compartment, PLR simulates volume loading and predicts fluid responsiveness with reliability (10). This reliability was previously demonstrated by measuring its effects on the descending aortic blood flow measured by esophageal Doppler (5, 22) and on the subaortic velocity time integral at echocardiography (23, 24). An important result of this study was that the pulse contour-derived cardiac output measured by

the PiCCO system can be also reliably used to assess the hemodynamic response to PLR with a similar cutoff diagnostic value than for the ultrasound technique (5).

Nonetheless, this study confirmed a limitation of PLR we have previously pointed out (5), i.e., the prediction of fluid responsiveness by PLR was poor if one considered only its effects on arterial pulse pressure. This suggests that the changes in arterial pulse pressure do not accurately reflect the changes in stroke volume in the particular circumstance of PLR. Although we did not investigate this issue, we can speculate that this is related to a PLR-induced change in arterial compliance that physiologically links arterial pulse pressure and stroke volume together. Interestingly, the predictive value of the end-expiratory occlusion test was equally accurate if its hemodynamic response was estimated by arterial pulse pressure or by pulse contour-derived cardiac index, suggesting that during the end-expiratory occlusion the reliability of the estimation of stroke volume by arterial pulse pressure is not altered, perhaps because it does not include any postural change or because it has a shorter duration than PLR. Thus, the end-expiratory occlusion could be particularly advantageous in patients with no other hemodynamic monitoring than arterial pressure, arming the clinician with additional tool for functional hemodynamic monitoring in this case.

The main limitation of the end-expiratory occlusion test is that it becomes ineffective if the spontaneous breathing activity is too marked for sustaining the 15-second end-expiratory occlusion, as it was the case in a number of patients we excluded from the study. In the patients included in the study, the spontaneous inspiratory effort was not sufficient to interrupt the occlusion. This was favored by setting the inspiratory trigger at a high level. The occlusion test is also not suitable for patients who are not intubated. In such cases, the PLR test should rather be considered (10, 23, 24). Another limitation of the test might be that the cutoff of cardiac index and pulse pressure changes, we found as predicting fluid responsiveness was relatively low. Nonetheless, it was largely above the coefficient of variation we measured for the pulse contour-derived cardiac output (25). Finally a limitation of our study could be that a larger proportion of responders than nonresponders had acute lung injury/acute respiratory distress syndrome. Although there was not any predefined strict protocol for the fluid management of our acute respiratory distress syndrome patients, we are used to follow a restrictive rather than a liberal fluid strategy in this category of patients. Our results should, thus, be confirmed in a more general population of patients with shock.

To conclude, this study suggests that analyzing the changes in pulse contour-derived cardiac index or in pulse pressure in response to an end-expiratory occlusion represents a valuable functional hemodynamic test for predicting the fluid response in mechanically ventilated patients experiencing cardiac arrhythmias or a spontaneous breathing activity of mild magnitude.

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