Cardiac Preload Assessment / Beurteilung der kardialen Vorlast

Global end-diastolic volume as an indicator of cardiac preload in patients with septic shock

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Objective: To assess the value of the global end-diastolic volume (GEDV) evaluated by transpulmonary thermodilution as an indicator of cardiac preload.

Design: Prospective clinical study in 36 patients with septic shock treated in a medical ICU of a university hospital.

Measurements and results: Hemodynamic parameters were evaluated in triplicate by the transpulmonary thermodilution technique: (1) before and after 66 fluid challenges in 27 patients, and (2) before and after 28 increases in dobutamine infusion rate in 9 patients. Volume loading induced a significant increase in central venous pressure (CVP), in global end-diastolic volume index (GEDVI), in stroke volume index (SVI), and in cardiac index (CI). Changes in GEDVI were correlated with changes in SVI, while changes in CVP were not. The preinfusion GEDVI was lower in the cases of positive response, and was negatively correlated with the percentage increase in GEDVI and in SVI. Dobutamine infusion induced an increase in SVI and in CI but no significant change in CVP and in GEDVI.

Conclusions: In patients with septic shock, the results demonstrate that, in contrast to CVP, the GEDVI behaves as an indicator of cardiac preload.

PULSION Comment: This study demonstrates the following: (1) GEDVI is a valuable indicator of cardiac preload, in contrast to CVP. (2) Mathematical coupling of CI and GEDVI can be excluded. (3) The lower GEDVI, the higher the probability of a marked hemodynamic effect of volume loading. (4) The transpulmonary thermodilution technique with the PiCCO is easy to use and provides an operator independent determination of cardiac output and cardiac preload with a reproducibility close to 5%, as often as is necessary.

Zweck: Überprüfung der Nützlichkeit von globalem end-diastolischem Volumen (GEDV) aus der transpulmonalen Thermodilution als Indikator der kardialen Vorlast.

Design: Prospektive klinische Studie an 36 Patienten mit septischem Schock in einer medizinischen Intensivstation einer Universitätsklinik.

Messungen und Ergebnisse: Hämodynamische Parameter wurden durch Dreifachmessung mittels der transpulmonalen Thermodilutionstechnik bestimmt: (1) vor und nach 66 Volumengaben bei 27 Patienten und (2) vor und nach 28 Steigerungen der Dobutamin-Dosis bei 9 Patienten. Volumengaben führten zu einem signifikanten Anstieg des zentralvenösen Drucks (CVP), des globalen end-diastolischen Volumen Index (GEDVI), des Schlagvolumen Index (SVI) und des Herzindex (CI). Änderungen des GEDVI korrelierten mit Änderungen des SVI, jedoch nicht mit Änderungen des CVP. Im Falle einer positiven Reaktion auf die Volumengabe, lag GEDVI vor Volumengabe im niedrigen Bereich und korrelierte negativ mit dem prozentualen Anstieg von GEDVI und SVI. Dobutamin-Gabe führte zu einem Anstieg von SVI und CI aber zu keiner signifikanten Änderung von CVP und GEDVI.

Zusammenfassung: Bei Patienten mit septischem Schock zeigen diese Ergebnisse, dass GEDVI, im Gegensatz zu CVP, ein guter Indikator der kardialen Vorlast ist.

Global End-Diastolic Volume as an Indicator of Cardiac Preload in Patients With Septic Shock*

Frédéric Michard, MD, PhD; Sami Alaya, MD; Véronique Zarka, MD; Mabrouk Bahloul, MD; Christian Richard, MD; and Jean-Louis Teboul, MD, PhD

**Study objective:** To assess the value of the global end-diastolic volume (GEDV) evaluated by transpulmonary thermodilution as an indicator of cardiac preload.

**Design:** Prospective clinical study.

**Setting:** Medical ICU of a university hospital (20 beds).

**Patients:** Thirty-six patients with septic shock.

**Interventions:** Volume loading and dobutamine infusion.

**Measurements and results:** Hemodynamic parameters were evaluated in triplicate by the transpulmonary thermodilution technique: (1) before and after 66 fluid challenges in 27 patients, and (2) before and after 28 increases in dobutamine infusion rate in 9 patients. Volume loading induced a significant ($p < 0.001$) increase in central venous pressure (CVP) from $10 \pm 4$ to $13 \pm 4$ mm Hg, in GEDV index from $711 \pm 164$ to $769 \pm 144$ mL/m$^2$, in stroke volume index (SVI) from $36 \pm 12$ to $42 \pm 12$ mL/m$^2$, and in cardiac index (CI) from $3.4 \pm 1.1$ to $3.9 \pm 1.2$ L/min/m$^2$ (mean $\pm$ SD). Changes in GEDV index were correlated ($r = 0.72$, $p < 0.001$) with changes in SVI, while changes in CVP were not. The increase in SVI was $> 15\%$ in 32 of 66 instances (positive response). The preinfusion GEDV index was lower ($637 \pm 134$ mL/m$^2$ vs $781 \pm 161$ mL/m$^2$, $p < 0.001$) in the cases of positive response, and was negatively correlated with the percentage increase in GEDV index ($r = -0.65$, $p < 0.001$) and in SVI ($r = -0.5$, $p < 0.001$). Dobutamine infusion induced an increase in SVI ($32 \pm 11$ mL/m$^2$ vs $35 \pm 12$ mL/m$^2$, $p < 0.05$) and in CI ($2.8 \pm 0.6$ L/min/m$^2$ vs $3.2 \pm 0.6$ L/min/m$^2$, $p < 0.001$) but no significant change in CVP ($13 \pm 3$ mm Hg vs $13 \pm 3$ mm Hg) and in GEDV index ($823 \pm 221$ mL/m$^2$ vs $817 \pm 202$ mL/m$^2$).

**Conclusion:** In patients with septic shock, our findings demonstrate that, in contrast to CVP, the transpulmonary thermodilution GEDV index behaves as an indicator of cardiac preload. *(CHEST 2003; 124:1900–1908)*

**Key words:** cardiac preload; central venous pressure; dobutamine; fluid responsiveness; global end-diastolic volume; septic shock; transpulmonary thermodilution; volume expansion

**Abbreviations:** CI = cardiac index; CVP = central venous pressure; GEDV = global end-diastolic volume; SVI = stroke volume index; SVRI = systemic vascular resistance index

Optimal monitoring of cardiac preload is of paramount importance for the hemodynamic management of patients with septic shock. Indeed, because of sepsis-induced venous pooling and systemic capillary leaking, hypovolemia is a common cause of acute circulatory failure and maintenance of adequate cardiac preload remains the primary target to optimize hemodynamics.\(^1\) Clinical examination has been shown to be of minimal value in detecting inadequate cardiac preload\(^2\)–\(^5\); therefore, hemodynamic parameters reflecting cardiac preload are of particular interest to the clinician.

Various methods for preload determination are commonly used today, principally the measurement of the central venous pressure (CVP) and pulmonary artery wedge pressure\(^6\); however, cardiac filling pressures are not always accurate indicators of ventricular preload because of erroneous readings of pres-
Most septic patients have a diastolic volume in the four heart chambers, called the assessment of the largest volume of blood contained as an alternative technique for assessing cardiac single-indicator (cold bolus) dilution, also called the volume dilution technique. However, the double-indicator (thermo-dye) dilution technique is relatively time consuming (due to the preparation of the indocyanine green solution), cumbersome, and expensive. More recently, the single-indicator (cold bolus) dilution, also called the transpulmonary thermodilution, has been proposed as an alternative technique for assessing cardiac preload. Indeed, the mathematical analysis of the transpulmonary thermodilution curve allows the assessment of the largest volume of blood contained in the four heart chambers, called the global end-diastolic volume (GEDV). Most septic patients with acute circulatory failure are instrumented with a central venous line (at least for vasoactive agents administration) and estimation of BP using a cuff is commonly inaccurate in shock states, such that the use of an arterial cannula is recommended. In this context, transpulmonary thermodilution simply requires the use of a specific thermodilution-tipped arterial catheter, and GEDV measurements are an indicator of cardiac preload that remains to be proved.

The aim of the present study was to test the hypothesis that the GEDV behaves as an indicator of cardiac preload in patients with septic shock. In this hypothesis, the GEDV should increase with volume loading but not with dobutamine, and the lower the preinfusion GEDV, the more marked should be the hemodynamic effects of volume loading.

Materials and Methods

The institutional review board for human subjects (Comité Consultatif de Protection des Personnes dans la Recherche Biomédicale, Bicêtre Hospital) considered the protocol to be a part of routine clinical practice so that no written informed consent was obtained from the patients next of kin.

Patients

We studied 36 patients with a diagnosis of septic shock. This group comprised 25 men and 8 women (age range, 32 to 89 years; mean ± SD age, 61 ± 16 years). All patients were receiving mechanical ventilation and vasopressors (dopamine, >5 μg/kg/min, or norepinephrine). Twelve patients also received dobutamine. Inclusion criteria were as follows: (1) septic shock as defined by the criteria of the American College of Chest Physicians/Society of Critical Care Medicine Consensus Conference, (2) instrumentation with a central venous (jugular or subclavian) catheter and a thermolusion femoral arterial catheter (PulsoCath PV 2015L20; Pulsion Medical Systems; Munich, Germany) for hemodynamic monitoring, and (3) the clinical requirement for a volume challenge of 500 mL of 6% hydroxyethylstarch or for an increase in dobutamine infusion rate according to the attending physician, at any time during the course of septic shock.

Hemodynamic Measurements

Patients were studied in a supine position, and zero pressure was measured at the midaxillary line. The CVP was recorded throughout the respiratory cycle and measured at end-expiration. Cardiac output and GEDV were evaluated in triplicate by transpulmonary thermodilution using a commercially available device (PiCCO; Pulsion Medical Systems). After injection of a cold saline solution bolus in the superior vena cava, a thermistor in the tip of the femoral arterial catheter is used to measure the downstream temperature changes. The cardiac output is then calculated by the analysis of the thermodilution curve using the Stewart-Hamilton algorithm. The measurement of cardiac output by transpulmonary thermodilution has been previously validated against the pulmonary thermodilution and the Fick method. The monitor (PiCCO; Pulsion Medical Systems) also calculates the mean transit time and the exponential downslope time of the transpulmonary thermodilution curve. The product of cardiac output and mean transit time is the volume of distribution of the thermal indicator. This volume of distribution, the so-called “intrathoracic thermal volume,” is made up of the intrathoracic blood volume and the extravascular lung water. The product of cardiac output and exponential downslope time is the “pulmonary thermal volume,” which is composed of the pulmonary blood volume and the extravascular lung water; therefore, the GEDV is calculated by the monitor as the difference between the intrathoracic thermal volume and the pulmonary thermal volume.

Cardiac index (CI), stroke volume index (SVI), GEDV index, and systemic vascular resistance index (SVRI) were calculated using standard formula. The reproducibility (SD/mean of three successive measurements) of cardiac output and GEDV measurement was 4 ± 2% and 5 ± 3%, respectively (mean ± SD).

Study Protocol

Measurements were performed before and immediately after volume loading using 500 mL of 6% hydroxyethylstarch (Hestéril; Frésenius Kabi; Sèvres, France) over a short period (<30 min).
or, in patients who were already receiving dobutamine, before and 20 to 30 min after an increase in dobutamine infusion rate. In all instances, the decision regarding volume loading and an increase in dobutamine infusion rate was made by the treating physician. Ventilatory settings and dosages of vasopressors were held constant.

**Statistical Analysis**

Results were expressed as mean ± SD. The hemodynamic effects of volume loading and of dobutamine infusion were assessed using a Wilcoxon nonparametric rank-sum test. Volume challenges were divided into three equal GEDV groups (low, intermediate, and high) according to the preinfusion GEDV index value. The fluid challenges associated with the lowest preinfusion values of GEDV constituted the low GEDV group. Similarly, the fluid challenges associated with the highest preinfusion values of GEDV constituted the high GEDV group. The remaining fluid challenges were considered to belong to the intermediate GEDV group. Assuming that a 15% change in SVI was needed for clinical significance, a positive response to volume loading was defined by an increase in SVI > 15%. A 2 × 3 contingency table was used to compare the rates of positive response between the three (low, intermediate, and high) GEDV groups. A nonparametric Mann-Whitney U test was used to compare hemodynamic parameters before volume loading in the cases of positive and negative responses to volume loading. Linear correlations were tested using the Spearman rank method. A p value < 0.05 was considered statistically significant.

**Results**

**Patient Characteristics**

All patients had clear evidence of sepsis (bacterial pneumonia, 29 patients; abdominal sepsis, 6 patients; urosepsis, 1 patient). Underlying diseases included COPD (n = 14), hypertension (n = 10), ischemic cardiopathy (n = 9), peripheral vascular disease (n = 5), chronic renal failure (n = 4), and diabetes mellitus (n = 5). Nineteen patients survived (mortality rate of 47%).

**Fluid Challenges**

Sixty-six fluid challenges were studied in 27 patients. Fifteen patients received two fluid challenges, and 12 patients received three fluid challenges. The hemodynamic effects of volume loading are presented in Table 1 and Figure 1. Volume loading induced a significant (p < 0.05) decrease in heart rate and a significant (p < 0.001) increase in CVP, GEDV index, SVI, CI, and mean arterial pressure. The preinfusion GEDV index was significantly correlated (r = -0.65, p < 0.001) with the percentage increase in GEDV index such that the lower GEDV index before volume loading, the greater was the increase in GEDV index (Fig 2). Volume loading-induced changes in GEDV index were significantly correlated with changes in SVI (r = 0.72, p < 0.001) [Fig 3], changes in CI (r = 0.67, p < 0.001), and changes in mean arterial pressure (r = 0.55, p < 0.001). In contrast, volume loading-induced changes in CVP were not correlated in anyway with changes in SVI, CI, and mean arterial pressure.

The changes in SVI ranged from -7 to +68%, and were > 15% in 32 of 66 instances (49%) [positive response]. The preinfusion GEDV index was significantly lower (637 ± 134 mL/m² vs 781 ± 161 mL/m², p < 0.001) in patients who had a positive response compared with those who had a negative response to volume loading. In contrast, the preinfusion CVP was not significantly different (10 ± 4 mm Hg vs 9 ± 4 mm Hg, p = 0.62) between the two groups.

The preinfusion GEDV index ranged from 413 to 611 mL/m² (mean, 546 ± 52 mL/m²) in the low GEDV group (n = 22), from 615 to 781 mL/m² (mean, 681 ± 60 mL/m²) in the intermediate GEDV group (n = 22), and from 816 to 1,174 mL/m² (mean, 907 ± 86 mL/m²) in the high GEDV group (n = 22). The rate of positive response to volume loading was significantly different between the three groups (p = 0.0013): 77% in the low GEDV group, 45% in the intermediate GEDV group, and 23% in the high GEDV group (Fig 4). The rate of positive response was 20% (2 of 10 instances) and 0% (0 of 5 instances) when the preinfusion GEDV index was > 900 mL/m² and 950 mL/m², respectively; conversely, the rate of positive response was 89% (8 of 9 instances) and 100% (4 of 4 instances) when the GEDV index was < 550 mL/m² and < 500 mL/m², respectively.

**Dobutamine Infusion**

Twenty-eight changes in dobutamine infusion rate were studied in nine patients receiving dobutamine. The mean increase in infusion rate was 6.5 ± 2.4 µg/kg/min. The hemodynamic effects of dobutamine are presented in Table 2 and Figure 1. Dobutamine

<table>
<thead>
<tr>
<th>Variables</th>
<th>Before Loading</th>
<th>After Loading</th>
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<tbody>
<tr>
<td>Heart rate, beats/min</td>
<td>97 ± 19</td>
<td>95 ± 20†</td>
</tr>
<tr>
<td>CVP, mm Hg</td>
<td>10 ± 4</td>
<td>13 ± 4†</td>
</tr>
<tr>
<td>GEDV index, mL/m²</td>
<td>711 ± 164</td>
<td>769 ± 144†</td>
</tr>
<tr>
<td>SVI, mL/m²</td>
<td>36 ± 12</td>
<td>42 ± 12†</td>
</tr>
<tr>
<td>CI, L/min/m²</td>
<td>3.4 ± 1.1</td>
<td>3.9 ± 1.2†</td>
</tr>
<tr>
<td>Mean arterial pressure, mm Hg</td>
<td>71 ± 11</td>
<td>83 ± 14†</td>
</tr>
<tr>
<td>SVRI, dyne.s/cm².m²</td>
<td>1,545 ± 536</td>
<td>1,516 ± 578</td>
</tr>
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</table>

*Values are expressed as mean ± SD.
†p < 0.05.
‡p < 0.001.
induced a significant increase in heart rate, SVI, and CI, and a significant decrease in systemic vascular resistance, while the CVP, GEDV index, and mean arterial pressure remained unchanged.

**DISCUSSION**

In patients with septic shock, our study demonstrates that the GEDV evaluated by the single-indicator dilution technique behaves as an indicator of cardiac preload. The increase in atrial and ventricular end-diastolic volumes as a result of fluid therapy depends on the partitioning of the fluid administered into the different cardiovascular compartments organized in series. In other words, the increase in GEDV index as a result of volume loading should depend both on venous capacitance (usually increased in septic patients because of sys-

![Graph showing percentage changes in CI and GEDV index induced by volume loading and dobutamine infusion.](image)

**Figure 1.** Percentage changes in CI and GEDV index induced by volume loading and dobutamine infusion.

![Graph showing relationship between preinfusion GEDV index and volume loading-induced changes in GEDV index.](image)

**Figure 2.** Relationship between the preinfusion GEDV index and volume loading-induced changes in GEDV index.
temic vasodilation) and on cardiac chambers compliance. Because of the physiologic negative relationship between end-diastolic volumes and end-diastolic compliances, the lower the preinfusion end-diastolic volumes, the greater should be the increase in end-diastolic volumes as a result of volume loading. In this regard, we observed a significant relationship between the preinfusion GEDV index and the percentage increase in GEDV index (Fig 2). We did not observe any relationship between

![Graph showing relationship between volume loading-induced changes in GEDV index and changes in SVI.](image)

**Figure 3.** Relationship between volume loading-induced changes in GEDV index and changes in SVI.

![Bar chart showing rates of positive response to volume loading.](image)

**Figure 4.** Rates of positive response to volume loading (defined as an increase in stroke volume $>15\%$) in patients with a low, intermediate, and high preinfusion GEDV index. The rate of positive response was significantly different ($p = 0.0013$) between the three groups.
the preinfusion systemic vascular resistance and the percentage increase in GEDV index. But since the systemic vascular resistance may not accurately reflect the venous capacitance, our findings cannot be used to draw any definitive conclusions concerning the influence of venous pooling on the hemodynamic response to volume loading.

According to the Frank-Starling mechanism, the greater the increase in preload, the greater should be the increase in stroke volume. We also observed a significant relationship between volume loading-induced changes in GEDV index and changes in SVI such that the greater the increase in GEDV index, the greater was the increase in SVI (Fig 3).

Interestingly, the preinfusion GEDV index was also significantly correlated with the percentage increase in SVI that resulted from the volume loading. In this regard, the preinfusion GEDV index was significantly lower in the cases of patients who had a positive response compared with those who had a negative response to volume loading. These findings are consistent with echocardiographic studies reporting lower preinfusion left ventricular end-diastolic area in responders compared with nonresponders to volume loading, and a significant relationship between the preinfusion left ventricular end-diastolic area and the percentage increase in SVI in response to volume loading.

Because the slope of the relationship between preload and stroke volume depends on ventricular contractility, the preinfusion cardiac preload is not the only factor influencing the response to volume loading. However, when preload is low, an increase in preload usually induces a significant increase in stroke volume whatever the ventricular function; similarly, when preload is high, a significant increase in stroke volume is rarely observed (Fig 5). In contrast, for the intermediate values of preload, the

Table 2—Hemodynamic Effects of Dobutamine Infusion*

<table>
<thead>
<tr>
<th>Variables</th>
<th>Baseline</th>
<th>Dobutamine Increase</th>
</tr>
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<tbody>
<tr>
<td>Heart rate, beats/min</td>
<td>95 ± 25</td>
<td>99 ± 25‡</td>
</tr>
<tr>
<td>CVP, mm Hg</td>
<td>13 ± 3</td>
<td>13 ± 3</td>
</tr>
<tr>
<td>GEDV index, mL/m²</td>
<td>823 ± 221</td>
<td>817 ± 202</td>
</tr>
<tr>
<td>SVI, mL/m²</td>
<td>32 ± 11</td>
<td>35 ± 12†</td>
</tr>
<tr>
<td>CI, L/min/m²</td>
<td>2.8 ± 0.6</td>
<td>3.2 ± 0.61</td>
</tr>
<tr>
<td>Mean arterial pressure, mm Hg</td>
<td>79 ± 13</td>
<td>82 ± 11</td>
</tr>
<tr>
<td>SVRI, dyne · s/cm²/m²</td>
<td>1,993 ± 687</td>
<td>1,816 ± 550†</td>
</tr>
</tbody>
</table>

*Values are expressed as mean ± SD.

†p < 0.05.

‡p < 0.001.

Figure 5. Schematic representation of the ventricular preload/stroke volume relationship of a normal ventricle (black line) and a failing ventricle (gray line). When preload is low, an increase in preload (ΔP) induces a significant increase in stroke volume (ΔSV) whatever the ventricular function, while when preload is high a significant increase in stroke volume is very unlikely. In contrast, for the intermediate values of preload, the increase in stroke volume depends more on ventricular function (ie, on the slope of the curve) than on the preinfusion cardiac preload; therefore, assessing preload may be helpful to predict fluid responsiveness when preload is low or high, but not for intermediate values.
increase in stroke volume depends more on ventricular function (ie, on the slope of the curve) than on the preinfusion cardiac preload (Fig 5). In this regard, the rate of response to volume loading was high (77%) in patients with a low preinfusion GEDV index, low (23%) in patients with a high preinfusion GEDV index, and approximately 50% in the intermediate group (Fig 4). These findings are consistent with other studies demonstrating that a positive response to volume loading is frequently observed in patients with a low (<90 mL/m²) preinfusion right ventricular end-diastolic volume index, rarely observed when the right ventricular end-diastolic volume index is >140 mL/m², and unpredictable for the intermediate values.10–12 Therefore, our findings are quite consistent with cardiac physiology, in agreement with previous clinical studies,10–12 and suggest that the easily obtainable GEDV may help in the decision-making process concerning volume loading. However, it must be noted that our results have been observed in a population of patients with septic shock, and hence that they cannot necessarily be extrapolated to other clinical situations.

Dobutamine is a synthetic catecholamine with inotropic and chronotropic properties resulting in an increase in stroke volume, heart rate, and hence in cardiac output.36 Dobutamine has also a vasodilatory effect that explains the lack of increase in BP usually observed in patients with septic shock.36 In this regard, increasing the dobutamine infusion rate in our patients resulted in a significant rise in heart rate, stroke volume, and cardiac output, while mean arterial pressure remained unchanged and hence systemic vascular resistance decreased. Usually, dobutamine has no effect on right and left ventricular dimensions, as demonstrated by pulmonary artery thermodilution, scintigraphic, and echocardiographic studies.37–39 In the present study, the GEDV was not significantly modified by dobutamine, a finding that also illustrates the fact that the GEDV behaves as an indicator of cardiac preload.

As expected, volume loading induced a significant increase in CVP; however, the volume loading-induced changes in CVP were not proportional to the changes in stroke volume and the preinfusion CVP was not significantly lower in cases of positive response than in cases of negative response to volume loading. These findings are in agreement with previous reports,10–12,17,18,34 and confirm the limited value of CVP both as an indicator of cardiac preload and as a predictor of fluid responsiveness. Like CVP, the pulmonary artery wedge pressure is widely used to guide fluid therapy in critically ill patients.6 Although the pulmonary artery wedge pressure is probably useful to identify patients at risk of acquiring pulmonary edema, several clinical studies have already emphasized its little value in accurately reflecting cardiac preload9,40 or predicting fluid responsiveness.34 Because our patients were not instrumented with a pulmonary artery catheter, we were not able to confirm these previous studies.

An important consideration concerns the possible mathematical coupling between GEDV and cardiac output since both of these parameters are derived from the same thermodilution curve.41 Such mathematical coupling may be advocated to explain, at least in part, some of the significant relationships reported in the present study. Nevertheless, McLuckie and Bihari42 have shown that the mean transit time of an indicator may change independently of changes in cardiac output. Perhaps more importantly, in patients receiving a volume load, we observed a positive relationship between changes in GEDV index and changes in mean arterial pressure. Because GEDV and mean arterial pressure cannot be mathematically coupled (these parameters are evaluated by independent techniques), and because volume loading does not increase systemic vascular tone (systemic vascular resistance remained unchanged), such a relationship confirms that the greater was the increase in GEDV index, the more marked was the increase in SVI. Furthermore, by increasing CI with dobutamine and observing GEDV index to be unchanged, we have also demonstrated in the present study that the GEDV index and the CI can change independently. Our findings are consistent with those of another study43 that reported large changes in cardiac output without any contemporary change in GEDV during esmolol administration in cardiac surgery patients. In summary, these findings strongly support the notion that the relationships reported in the present study are not due to a mathematical coupling but are related to the physiologic relationship between an indicator of preload (ie, GEDV) and the stroke volume.

Since most patients with septic shock are instrumented with central venous and arterial lines, the transpulmonary thermodilution technique can be regarded as a less invasive method than pulmonary artery catheterization to assess cardiac preload. Moreover, in contrast to echocardiography, transpulmonary thermodilution provides an operator-independent determination of cardiac output and cardiac preload with a reproducibility close to 5%, as often as is necessary.

To summarize, our study demonstrates that the GEDV increases with volume loading but not with dobutamine, and the lower the preinfusion GEDV, the more marked the hemodynamic effects of volume loading. Therefore, in patients with septic shock, we conclude that the GEDV behaves as an indicator of cardiac preload. Further studies are
required to confirm the usefulness of transpulmonary thermodilution for assessing cardiac preload in other clinical situations.

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REFERENCES
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