Comparative evaluation of stroke volume variation and inferior vena cava distensibility index for prediction of fluid responsiveness in mechanically ventilated patients

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ABSTRACT

Objectives: To evaluate the correlation between stroke volume variation (SVV) and inferior vena cava distensibility index (dIVC) as a marker for fluid responsiveness in mechanically ventilated hypotensive intensive care unit (ICU) patients.

Methodology and Design: This study is designed as prospective observational study conducted in patients admitted to an ICU who were mechanically ventilated and experienced a hypotensive episode.

Intervention: A fluid challenge of 10 mL/kg ringer’s lactate was given over 20 min.

Measurements: Hemodynamic parameters as well as SVV, IVCmax, IVCmin, dIVC, and cardiac output (CO), were recorded at a different time interval. An increase in ≥15% of CO was taken as fluid responsiveness.

Results: Out of 67 patients, 67.2% responded to fluid challenge. Pearson's correlation graph at baseline showed a strong positive correlation between dIVC and SVV with r = 0.453, (P < 0.002). Non-responders also had a strong positive correlation (r = 0.474) at the baseline. Bland Altman's analysis of the correlation between dIVC and SVV post-fluid challenge showed a mean difference of – 4.444, with 1.49% of the values falling outside the limits of agreement (18.418 and -27.306). This difference was clinically significant. Pearson's correlation graph post-fluid challenge showed a moderately strong positive correlation between dIVC and SVV with r = 0.298 and P value = 0.047, which was statistically significant. Also, non-responders had a weak correlation as compared to the responder's group, r = 0.364 and P value = 0.095, which was not clinically significant. There was no significant difference in the trend of dIVC and SVV values between the non-surgical and surgical groups, nor was there any gender difference analyzed in the study.

Conclusion: This study ascertains the positive correlation between dIVC and SVV and justifies its use in a clinical setting of hypotension suspected to be due to hypovolemia.

Keywords: Cardiac output, distensibility index, inferior vena cava, intensive care unit, stroke volume variation

INTRODUCTION

Fluid replacement is considered the keystone of resuscitation in the intensive care unit (ICU). In critically ill patients, evaluation of the hemodynamic status is of utmost importance, since circulatory insufficiency is very
commonly encountered.\(^{[1]}\) Circulatory failure, as a result of low cardiac output (CO), may lead to inadequate tissue perfusion and oxygenation.\(^{[2]}\) Despite improvements in resuscitation and supportive care, progressive organ dysfunction occurs in a significant proportion of these patients.\(^{[3]}\) The resuscitation, therefore, requires an accurate assessment of the patients’ intravascular volume status. Clinical determination of the intravascular volume and its responsiveness to fluid can be challenging in critically ill patients. On the other hand, the overzealous fluid resuscitation can lead to excessive intravascular volume, which can be futile and even deleterious. Hence, finding a balance and correct estimation of the requirement is the need of the hour.

Dynamic indicators of fluid responsiveness on cardiopulmonary interactions considered more accurate indicators of preload than static indicators.\(^{[4]}\) The distensibility index of the inferior vena cava (dIVC), which reflects the increase in the IVC diameter on inspiration (mechanical ventilation), can predict fluid responsiveness satisfactorily.\(^{[5,6]}\) But the requirement for 24-hour availability of the echocardiographic inputs and the non-continuous nature of the data limits its applicability in the ICU environment.

A new dynamic predictor of fluid responsiveness obtained from arterial waveforms called stroke volume variation (SVV) has been proposed to assess fluid responsiveness.\(^{[4,5,7]}\) The advantage of VigileoFloTrac, being minimally invasive, automatically calculated SVV and continuous display on the screen, makes it more compatible for use in the ICU.\(^{[8]}\)

This study aimed to evaluate the correlation, comparing SVV and dIVC as a marker for fluid responsiveness in mechanically ventilated hypotensive ICU patients.

**METHODS**

This study was carried out at the Level I tertiary hospital. After approval from the institutional ethics committee, written informed consent was obtained from close relatives of the patients. This prospective observational study includes both surgical and non-surgical ICU patients who were mechanically ventilated and experienced a hypotensive episode. The participants’ relatives were provided all the specifics about the purpose of the study. They were assured about the confidentiality of the information and their participation was entirely optional. Critically ill ICU patients between 18 and 60 years of age on ventilatory support requiring invasive blood pressure (IBP) monitoring were included. Patients with known impaired cardiac function, chronic kidney disease, or ongoing pregnancy were excluded from the study. During the study period, volume-controlled ventilation with the administration of muscle relaxants (0.5 mg/kg of Atracurium) was used. Tidal volume 8 to 10 mL/kg of ideal body weight with positive end-expiratory pressure (PEEP) of 5 cm of water was maintained.

The hypotensive episode was defined as an absolute value of systolic blood pressure (SBP) ≤90 mmHg or mean arterial pressure (MAP) ≤65 mmHg or a fall of ≥20 mmHg SBP from the baseline with or without inotropes, observed for at least 5 mins. A fluid challenge of 10 mL/kg Ringer's lactate fluid was given over 20 min to all the hypotensive patients. Static parameters like heart rate (HR), Oxygen Saturation (SpO2), SBP, diastolic blood pressure (DBP), MAP and the dynamic parameters like dIVC, SVV, and CO were recorded before (baseline) and at the end of fluid challenge (0 min, 15 min and 30 min). Responders were defined as an increase in CO of 15% from baseline. Measurement of SVV and CO was carried out with Vigileo Flo Trac. IVC diameter at end-expiration (Dmin) and end-inspiration (Dmax) was measured subcostal approach ultrasonography. dIVC was calculated and expressed as a percentage (dIVC = Dmax - Dmin/Dmin).

**Statistical analysis**

SPSS (Statistical Package for Social Sciences) Software Version 16.0 was used for statistical analysis. Results were expressed as the means, standard deviations (SD), numbers, and percentages (%). The measure of the strength of the association between the two variables to determine the correlation coefficient was done by using Pearson’s correlation coefficient analysis and Bland Altman analysis. \(P\) value ≤0.05 was considered to be significant. The receiver operator characteristic (ROC) curve was obtained for SVV values in comparison to dIVC values before the fluid challenge to find out the sensitivity and specificity of SVV. The correlation between changes in SV and changes in hemodynamic variables was assessed by using Pearson's correlation. To determine the ability of different hemodynamic variables in determining the positive (>15% increase in CO) and negative (<15% increase in CO) response to a fluid challenge, ROC curves were generated for dIVC and SVV varying the discriminating threshold of each variable.

**RESULTS**

In this prospective observational study, 55.2% (37/67) of the patients were of age group 51-60 years and only
three percent (2/67) patients were less than 20 yrs. Out of 67 patients enrolled, 36 were males (53.7%) and 31 were females (46.3%).

Of the 67 patients studied, 67.2% responded to fluid challenge. Baseline SVV values were significantly higher in responder group (22.53 ± 6.89) vs. non-responders (14.27 ± 4.87), (P < 0.001) [Table 1]. This difference diminished over 30 minutes but was statistically significant at all the time intervals, post-fluid challenge. Baseline dIVC values were higher in the responder group (32.28 ± 13.23) vs. non-responders (26.09 ± 16.64) [Table 1]. This difference was significant only at zero minute post fluid challenge (P < 0.01), not thereafter. Both baseline Dmax and Dmin values were higher in the responder group than non-responders [Table 1]. This difference diminished over time but was not clinically significant at any point in time. However, significant difference was maintained in CO value at all time intervals.

Bland Altman analysis of the correlation between dIVC and SVV at baseline before fluid bolus showed a mean difference of –11.0262 with 4.48% of the values falling outside the limits of agreement (16.996 and -39.048) [Figure 1]. This difference was statistically significant. Pearson’s correlation graph at baseline showed a strong positive correlation between dIVC and SVV with r = 0.453 (P < 0.002) [Figure 2]. Non-responders also had a strong positive correlation (r = 0.474) at the baseline.

Bland Altman’s analysis of the correlation between dIVC and SVV post-fluid challenge showed a mean difference of –4.444, with 1.49% of the values falling outside the limits of agreement (18.418 and -27.306). This difference was statistically significant. Pearson’s correlation graph post-fluid challenge showed a moderately strong positive correlation between dIVC and SVV with r = 0.298 and P value = 0.047, which was statistically significant. Also, non-responders had a weak correlation as compared to the responder’s group, r = 0.364 and P value = 0.095, which was not clinically significant.

SVV >15% before volume expansion discriminated between responders and non-responders with 62.2% sensitivity and 81.8% specificity at 95% CI. dIVC >17.86% before volume expansion discriminated between responders and non-responders with 68.9% sensitivity and

| Parameters | Before fluid challenge | 0 min after fluid challenge | 15 min after fluid challenge | 30 min after fluid challenge |
|------------|------------------------|----------------------------|-----------------------------|-----------------------------|
| SBP        | 91.59±7.18             | 94.00±7.68                 | 97.86±11.04                 | 100.59±13.2                |
| R          | 90.47±13.71            | 96.91±13.59                | 102.64±15.44                | 103.38±14.10               |
| P value    | 0.72                   | 0.35                       | 0.19                        | 0.44                        |
| DBP        | 52.18±8.97             | 53.9±9.81                  | 55.59±10.24                 | 58.41±11.54                |
| R          | 50.69±12.02            | 53.38±11.19                | 56.44±11.99                 | 57.62±11.62                |
| P value    | 0.60                   | 0.65                       | 0.77                        | 0.79                        |
| MAP        | 65.36±7.69             | 66.68±8.52                 | 69.82±9.97                  | 72.45±11.36                |
| R          | 63.9±11.68             | 67.89±11.07                | 71.84±12.4                  | 72.89±11.82                |
| P value    | 0.60                   | 0.65                       | 0.50                        | 0.88                        |
| HR         | 104.23±7.88            | 104.00±29.13               | 101.68±29.27                | 100.27±28.06               |
| R          | 110.02±23.04           | 106.78±22.26               | 104.51±21.58                | 103.58±21.10               |
| P value    | 0.37                   | 0.66                       | 0.65                        | 0.59                        |
| SpO2       | 98.00±3.41             | 98.36±2.96                 | 98.98±1.78                  | 99.00±1.68                 |
| R          | 97.5±4.46              | 97.86±3.96                 | 98.36±3.44                  | 98.4±3.35                 |
| P value    | 0.61                   | 0.57                       | 0.33                        | 0.33                        |
| SVV        | 14.27±4.87             | 13.27±4.32                 | 10.27±3.07                  | 9.05±2.72                  |
| R          | 22.53±6.89             | 17.69±6.45                 | 14.09±5.42                  | 13.04±5.46                 |
| P value    | 0.001                  | 0.001                      | 0.003                       | 0.002                       |
| dIVC       | 26.09±16.64            | 24.67±13.35                | 16.79±14.51                 | 20.22±10.91                |
| R          | 32.28±13.23            | 16.61±7.88                 | 16.32±10.66                 | 19.10±10.51                |
| P value    | 0.001                  | 0.014                      | 0.011                       | 0.009                       |
| IVC max    | 1.76±0.39              | 1.93±0.36                  | 2.11±0.3                    | 2.03±0.26                  |
| R          | 1.89±0.46              | 2.01±0.42                  | 2.23±0.32                   | 2.15±0.33                  |
| P value    | 0.23                   | 0.42                       | 0.14                        | 0.09                        |
| IVC min    | 1.33±0.35              | 1.57±0.34                  | 1.83±0.3                    | 1.72±0.25                  |
| R          | 1.56±0.45              | 1.74±0.42                  | 1.9±0.49                    | 1.81±0.34                  |
| P value    | 0.023                  | 0.07                       | 0.48                        | 0.20                        |
| CO         | 3.52±0.84              | 3.82±0.83                  | 4.06±0.68                   | 4.16±0.76                  |
| R          | 2.55±0.5               | 3.15±0.54                  | 3.52±0.53                   | 3.6±0.53                   |
| P value    | 0.001                  | 0.001                      | 0.001                       | 0.001                       |

# R-Responders, NR-Non responders, SBP- Systolic blood pressure, DBP-diastolic blood pressure, MAP-Mean arterial pressure, HR- Heart rate, SpO2- oxygen saturation, SVV- Stroke volume variation, IVCmax-Inferior vena cava maximum diameter, IVCmin-Inferior vena cava minimum, dIVC-Inferior vena cava distensibility index, CO-cardiac output
72.7% specificity at 95% CI. ROC for dIVC and SVV is represented in Figure 3.

A statistically significant difference was noted in blood pressure, HR, SVV, and CO after fluid challenge [Table 2].
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| Table 2: Hemodynamic parameters before and after fluid administration in responders and non-responders |
|-------------------------------------------------------------|
| **Hemodynamics** | **Response** | **Mean±SD** | **Value** |
| Systolic Blood Pressure (SBP) | R | -6.44±8.75 | 0.03 |
| Disystolic Blood Pressure (DBP) | R | -2.69±4.26 | 0.04 |
| Mean Blood Pressure (MAP) | R | -3.96±5.38 | 0.02 |
| Heart Rate (HR) | R | 3.24±6.14 | 0.04 |
| Oxygen saturation (SpO₂) | R | -0.36±1.28 | 0.44 |
| Stroke Volume variation (SVV) | R | 2.84±2.75 | 0.01 |
| Dmax | R | -0.17±0.15 | 0.13 |
| Dmin | R | -0.24±0.13 | 0.05 |
| dIVC | R | 10.28±12.1 | 0.05 |
| Cardiac output (CO) | R | -0.60±0.34 | 0.001 |

R-Responders, NR-Non responders, Dmax-Inferior vena cava maximum diameter, Dmin-Inferior vena cava minimum, dIVC-Distensibility index of inferior vena cava

**DISCUSSION**

An accurate assessment of the fluid status of critically ill patients is of foremost importance for early fluid resuscitation, to reverse tissue hypoxia, prevent organ damage, and improve outcomes. A landmark study of Rivers et al. demonstrated a protocol of early goal-directed therapy, which reduces organ failure and improves survival in patients with severe sepsis and septic shock.[9] Less severe organ dysfunction in the patients assigned to early goal-directed therapy was established than those assigned to standard treatment (13.0+/−6.3 vs. 15.9+/−6.4, P = 0.001). On the other hand, over-perfusion has also been associated with increased complications and mortality. A study conducted by Berkenstadt et al. concluded that the SVV value of ≥9.5% would foresee a rise in the SV of almost 5% in response to 100 mL volume load with high sensitivity and specificity (79%, 93%).[10] Marx et al. studied assessing fluid responsiveness by SVV in mechanically ventilated patients in sepsis.[11] Changes in cardiac index were significantly correlated to percentage changes in SVV (r = −0.65, P < 0.001) and changes in intrathoracic blood volume index (r = 0.52, P = 0.002), whereas changes in cardiac index reported no significant correlation to changes in central venous pressure (r = 0.28, P = 0.07) and changes in pulmonary arterial occlusion pressure (r = 0.29, P = 0.06). In our study, an increase in CO was taken as a reference guide to confirm the response to the fluid challenge and was significantly correlated to changes in SVV.

Rathore and colleagues compared SVV and pulse pressure value (PPV) in predicting fluid responsiveness.[7] Fifty patients undergoing major surgeries were monitored for PPV and SPV. In responders, PPV before and after fluid loading was strongly correlated with SVV before fluid loading (Pearson’s correlation coefficient = 0.875, 0.685, and 0.769, respectively, P < 0.001). A similar significant positive correlation was observed in non-responders. SVV and PPV were found to have a direct relation with the degree of fluid responsiveness.

Both SVV and IVC distensibility index are dynamic methods to predict fluid responsiveness and have been compared to other dynamic and static parameters in various studies. There is, however, no study that formally studied the association between dIVC and SVV.

Barbier and colleagues determined that the dIVC expressed as a percentage was predictive of fluid responsiveness with a sensitivity of 90% and a specificity of 90%. They concluded that a dIVC above 18% was predictive of an increase in the cardiac index of at least 15% with fluid loading.[12] Our study also supported the conclusions given by the study of Barbier et al. dIVC >17.86% showed increased cardiac output after fluid challenge and was clinically significant but then increased, confirming the hypovolemia in continuous demand. Fiessel and colleagues used a slightly different index to reach similar findings.[13]

Christophe Barbier and colleagues studied the respiratory changes in inferior vena cava diameter to help predict fluid responsiveness in ventilated septic patients. The base-line central venous pressure did not accurately predict fluid responsiveness.[12] Also, in patients with isolated left ventricular dysfunction, dIVC alone should be used with caution. Zhang H, et al. in their study concluded that isolated left ventricular systolic abnormality poorly predicts fluid responsiveness in critically ill patients.[14]

In this study, considering the effect of inotropes in critically ill patients and patients showing arrhythmia on SVV were beyond the scope of this study, which was considered a limitation. Echocardiography to assess dIVC requires initial training, which has a long learning curve with a lack of reproducibility. Vasopressors also have a significant impact on SVV and its ability to assess volume status, but it was ignored assuming vasopressors to affect both our variables equally without affecting the primary aim of comparison and correlation between the said indices.
CONCLUSION

This study recommends the use of SVV and echocardiography-based dIVC as markers for fluid responsiveness wherever a setup of invasive arterial monitoring is available. The estimation of SVV is a useful way of guiding fluid therapy in ventilated patients who are critically ill because it allows the estimation of preload and prediction of cardiac index changes in response to fluid loading. Further large-scale tests of diagnostic accuracies may be required to explore the utility of SVV alone and dIVC with SVV together in predicting fluid responsiveness with gold standard criteria defining fluid responsiveness.

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Conflicts of interest
There are no conflicts of interest.

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