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Comparison of arterial pressure and plethysmographic waveform-based dynamic preload variables in assessing fluid responsiveness and dynamic arterial tone in patients undergoing major hepatic resection

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Editor's key points

- Changes in blood pressure and central venous pressure are unreliable indicators of optimal intravascular volume status.
- Both (semi-invasive) arterial pressure and plethysmographic waveform analyses can be used to estimate fluid responsiveness.
- The ratio of pressure-to-stroke volume variation reflects arterial elastance (vascular tone).
- Knowledge of arterial elastance may be helpful to guide vasopressor or fluid therapy.

Background. Dynamic preload variables to predict fluid responsiveness are based either on the arterial pressure waveform (APW) or on the plethysmographic waveform (PW). We compared the ability of APW-based variations in stroke volume (SVV) and pulse pressure (PPV) and of PW-based plethysmographic variability index (PVI) to predict fluid responsiveness and to track fluid changes in patients undergoing major hepatic resection. Furthermore, we assessed whether the PPV/SVV ratio, as a measure of dynamic arterial elastance (Ea_{dyn}), could predict a reduction in norepinephrine requirement after fluid administration.

Methods. Thirty patients received i.v. fluid (15 ml kg^{-1} in 30 min) after hepatic resection and were considered responders when stroke volume index (SVI) increased $\geq$20% after fluid administration. SVV and SVI were measured by the FloTrac-Vigileo® device, and PVI was measured by the Masimo Radical 7 pulse co-oximeter®.

Results. The areas under a receiver operating characteristic curve for SVV, PPV, and PVI were 0.81, 0.77, and 0.78, respectively. In responders, all dynamic variables, except PVI, decreased after fluid administration. Ea_{dyn} predicted a reduced norepinephrine requirement (AUC = 0.81).

Conclusions. In patients undergoing major hepatic resection, both APW- and PW-based dynamic preload variables predict fluid responsiveness (*preload*) to a similar extent. Most variables (except PVI) also tracked fluid changes. Ea_{dyn}, as a measure of arterial elastance (*afterload*), might be helpful to distinguish the origin of hypotension.

Clinical trial registration. ClinicalTrials.gov, NCT01060683.

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Adequate assessment of volume status in patients undergoing major surgery is imperative to prevent both inadvertent hypovolaemia and fluid overload, both of which are associated with increased morbidity and mortality.[1] Static indicators of cardiac preload, such as central venous pressure (CVP) and pulmonary artery occlusion pressure, have repeatedly been shown to be inaccurate measures of volume status and are unable to predict fluid responsiveness reliably.[2–4] Instead, current research has focused on the use of dynamic preload variables for the prediction of fluid responsiveness to predict whether fluid administration will increase cardiac output (CO).[5–7] These dynamic preload variables are based on the heart–lung interaction and are derived from circulatory fluctuations secondary to changes in intrathoracic pressure during volume-controlled mechanical ventilation.

Dynamic preload variables are either pressure-based (e.g. pulse pressure variation; PPV), flow-based (e.g. stroke volume variation; SVV), or volume-based (plethysmographic variability index; PVI) and are obtained either from the arterial pressure waveform (APW; semi-invasive) or from the plethysmographic waveform (PW; non-invasive).

A comparable ability to predict fluid responsiveness between APW- and PW-derived PPV has recently been demonstrated in critically ill patients.[8] A recent report[9]

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however showed the reduced accuracy of dynamic preload variables to predict fluid responsiveness under 'normal' clinical conditions in the intra-operative setting and another report[10] illustrated that in <30% of intra-operative cases, all conditions are met for the use of dynamic preload variables to predict fluid responsiveness.

In addition, even when preload dependency is assessed correctly, an assessment of cardiac afterload (i.e. arterial tone) might be additionally useful for guidance of appropriate vasopressor or i.v. fluid therapy to provide adequate organ perfusion. Recently, the ratio between the pressure-based PPV and the flow-based SVV has been proposed to reflect dynamic arterial elastance (Ea_{dyn}; i.e. a surrogate of cardiac afterload).[11] By this means it becomes possible to differentiate arterial vasodilatation from hypovolaemia as a cause of hypotension.

The aim of this study was to assess an estimate of both cardiac preload and dynamic arterial elastance in a clinical setting of patients undergoing major hepatic resection. Therefore, we provide a comparison of the ability of the most commonly used APW- and PW-based dynamic preload variables to predict fluid responsiveness and to track its changes after fluid administration. We hypothesized that PVI was as good as the arterial pressure-based dynamic preload variables in predicting and tracking changes induced by fluid administration. In addition, we assessed whether Ea_{dyn} was able to predict changes in arterial tone in response to changes in norepinephrine requirement after fluid administration.

Methods

We evaluated 30 patients involved in a previous study investigating the accuracy of continuous non-invasive measurement of haemoglobin concentration using the Masimo Radical 7 device (Masimo, Inc., Irvine, CA, USA), which additionally records the PVI from the same waveform.[12] In these patients, the other CO-based data were obtained as part of routine clinical monitoring. Each patient served as his/her own control. The original study was approved by the local ethics committee (Ref: 2009/174, University Medical Centre Groningen, The Netherlands) and was registered at clinicaltrials.gov (NCT01060683).

All eligible ASA I–III patients undergoing major hepatic resection were included into this study after written informed consent had been obtained. Patients with intra-operatively diagnosed incurable disease, cardiac dysrhythmia, or patients who required additional i.v. fluids to maintain haemodynamic stability before the fluid bolus was administered (the latter was required for the aim of the original study) were excluded. All patients received a standardized general anaesthesia after placement of a thoracic epidural catheter, as described previously.[12]

A radial artery was cannulated (20 G) for continuous monitoring of arterial blood pressure and for blood gas analysis and the right internal jugular vein was cannulated (7F triple lumen) for monitoring CVP and drug infusion. Both pressure transducers were, after zeroing, adjusted to the height of the right atrium.

Norepinephrine was administered when mean arterial pressure (MAP) decreased to <60 mm Hg and adjusted to keep MAP between 60 and 80 mm Hg. Patients were mechanically ventilated with a mixture of O_2 ($F_{IO_2} = 0.30–0.35$), air, and isoflurane in a volume-controlled mode with tidal volumes of 8 ml kg^{-1} lean body mass, with PEEP 5 cm H_2O. The respiratory rate was adjusted to maintain end-tidal CO_2 pressure between 4.5 and 5.5 kPa. Respiratory settings were not changed throughout the measurements.

Immediately after completion of hepatic resection, all patients received a fluid bolus of 15 ml kg^{-1} within 30 min. As per original protocol,[12] patients were allocated to receive a fluid bolus of either colloids (n=15) or crystalloids (n=15). Patients were considered fluid responsive when stroke volume index (SVI, stroke volume divided by body surface area for normalization) increased by at least 20% after fluid administration compared with the value before administration of fluid. SVI was measured continuously using the FloTrac-Vigileo device (Edwards Lifesciences, Irvine, CA, USA).

Dynamic preload variables

The FloTrac-Vigileo® device (software V03.02) analyses continuously the APW for estimation of CO and cardiac index (CI). The device also calculates SVV over a 20-s time frame using the formula: $SVV = SV_{max} - SV_{min}/SV_{mean}$.

The FloTrac sensor was attached to the arterial catheter and the Vigileo® was connected to the vital signs monitor (Philips MP70; Philips, Eindhoven, Netherlands) for continuous data registration.

The Masimo Radical 7 SET (V7.6.0.1, sensor version R2–25, Rev E) uses transcutaneous multi-wavelength analysis for non-invasive measurement of arterial oxygen saturation and total haemoglobin concentration with the use of a finger clip. This device also calculates PVI, which is based on the perfusion index (PI). The PI represents the ratio between pulsatile and non-pulsatile blood and is a measure of local blood flow. PVI is subsequently calculated as $[(PI_{max} - PI_{min})/PI_{max}] \times 100$ over a period of time sufficient to include multiple respiratory cycles. The Masimo sensor was attached to the index finger contralateral to the arterial catheter according to the manufacturer's instructions.

The APW-based pulse pressure variation (PPV) was recorded online by the clinically used vital signs monitor and calculated off-line afterwards using dedicated software developed by the authors. For the interested reader, also systolic pressure variation (SPV; APW-based), the PW-based variation in peak amplitude (PW_{peak}), and pulse amplitude (PW_{pulse}) were calculated. The results of these three dynamic preload variables are presented in supplementary material. All dynamic preload variables were, after synchronization, calculated over a time frame of 20 s. Obvious artifacts were eliminated by visual inspection of waveforms. Ea_{dyn} was calculated as the SVV/PPV ratio, as described previously.[11]

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