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Clinical Investigation

CLINICAL INVESTIGATION

Estimating the rapid haemodynamic effects of passive leg raising in critically ill patients using bioreactance

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Abstract

Background: Rapid detection of changes in cardiac index (CI) in real time using minimally invasive monitors may be of clinical benefit. We tested whether the Starling-SV bioreactance device, which averages CI over a short 8 s period, could assess the effects of passive leg raising (PLR), a clinical test that is recommended to assess fluid responsiveness during septic shock.

Methods: In 32 critically ill patients, we measured CI by transpulmonary thermodilution (PiCCO2, CI_{td}), pulse contour analysis (PiCCO2, CI_{Pulse}), and the Starling-SV device ($CI_{Starling}$) at baseline. CI_{Pulse} and $CI_{Starling}$ were measured again at the end of a PLR test. In the 13 patients with a positive PLR test, CI_{td}, CI_{Pulse}, and $CI_{Starling}$ were measured before and after a 500 ml saline infusion. The primary outcome was relative changes from baseline measurements in CI_{td}, CI_{Pulse}, and $CI_{Starling}$. Secondary outcomes compared absolute values measured by each method.

Results: Relative changes in CI_{Pulse} and CI_{td} were significantly correlated (r=0.82; n=45; P<0.001), with an 89% concordance rate (n=45 paired measurements). Relative changes in $CI_{Starling}$ and CI_{td} were also significantly correlated (r=0.59; n=45; P<0.001) with a 78% concordance rate. For absolute measures of CI (n=77 paired measurements), the bias between CI_{Pulse} and CI_{td} was 0.01 L min^{-1} m^{-2} (limits of agreement, −0.49 and 0.51 L min^{-1} m^{-2}; 15% percentage error). Bias between $CI_{Starling}$ and CI_{td} was 0.03 L min^{-1} m^{-2} (limits of agreement, −1.61 and 1.67 L min^{-1} m^{-2}; 48% percentage error).

Conclusions: In critically ill patients, a non-invasive bioreactance device with a shorter averaging period assessed a passive leg raising test with reasonable accuracy.

Keywords: equipment; monitors; measurement; cardiac output; measurement techniques

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Editor's key points

- Rapid detection of changes in cardiac index (CI) using minimally invasive monitoring may enhance the assessment of fluid responsiveness in critical illness.
- This small single-centre study compared a bioreactance monitor, which averages CI over a short 8 s period, with transpulmonary thermodilution and pulse contour analysis to detect haemodynamic changes during passive leg raising.
- The error in measuring cardiac index was large for bioreactance.
- The clinical utility of less invasive bioreactance monitoring to assess fluid responsiveness remains uncertain.

Reliable monitoring of cardiac output in the intensive care unit has mostly been achieved by invasive methods. More recently, interest has increased in the utility of minimally invasive techniques,[1] including bioreactance.[2] Bioreactance is based on the measurement of the phase shift of an oscillating low voltage current that occurs when it crosses the thorax.[3,4] In contrast to other reports,[5] we found a bioreactance device (Nicom; Cheetah Medical, Newton Center, MA, USA) was unable to track changes in cardiac index (CI) in critically ill patients with haemodynamic compromise.[6] In particular, this device was unable to detect changes in CI during a passive leg raising (PLR) test, a postural change used to detect preload dependence[7] and which is now recommended to assess fluid responsiveness during septic shock.[8] However, the PLR test requires a direct and real-time measurement of cardiac output.[9] These conflicting results may, therefore, be related to the long period of sampling time (30 s) over which previous bioreactance devices averaged CI.[10,11]

In the present study, we tested whether a bioreactance (hereafter Starling-SV) device, for which the averaging time of CI had been reduced to 8 s, could accurately assess the effects of a passive leg raise test and predict fluid responsiveness.

Methods

Patients

This prospective study was carried out in a 25-bed medical intensive care unit of a university hospital during a 12 month period. It was approved by our local institutional review board (Comité pour la protection des personnes Ile-de-France VII). All patients or their relatives gave informed consent.

The inclusion criteria were: age ≥18 yr, a transpulmonary thermodilution device in place for clinical purposes (PiCCO2; Pulsion Medical Systems, Feldkirchen, Germany) and a decision by the clinicians in charge to perform a PLR test. Patients were excluded if the investigators were not available or if the PLR manoeuvre was not clinically inadvisable (intracranial hypertension, venous compression stocking, intra-abdominal hypertension).

Bioreactance measurements

The Starling bioreactance system requires the application of four double electrode sensors on the skin of the thorax.[12] Upper sensors were placed on the mid-left and mid-right clavicles and lower sensors in the mid-left and mid-right last rib. The outer electrodes in each electrode pair delivers a known alternating high-frequency current that is sensed by the inner electrode pair. Changes in thoracic pulsatile blood volume alter the phase modulation between currents recorded at inner and outer electrodes. A proprietary algorithm computes CI from this change in phase.[12]

In a previous version of the (Nicom) bioreactance device, the value of CI displayed on the screen of the device results from averaging of the values of CI recorded during the past 30 s. For the purpose of the study, we used a device (hereafter Starling-SV) that was modified in order to shorten the time of this moving average to 8 s.

Measurements by transpulmonary thermodilution and pulse contour analysis

The PICCO2 device requires a central venous catheter in the superior vena cava and a thermistor-tipped catheter inserted through the femoral artery. It measures CI through two methods. The first method, transpulmonary thermodilution, requires the injection in the superior vena cava of 15 ml cold saline. CI is estimated from the analysis of the thermodilution curve recorded at the tip of the arterial catheter.[13] Provided that three measurements are averaged, the least significant change of the measurement is between 10% and 15%.[14] The second method used by the PiCCO2 device for measuring CI is pulse contour analysis.[15] It is based on a proprietary algorithm analysing the waveform of the arterial curve obtained through the femoral catheter.[13] It provides a beat-by-beat estimation of CI that is averaged over 12 s. This estimation of CI (CI_{Pulse}), which may drift over time, is 'recalibrated' when transpulmonary thermodilution is performed. This technique has been demonstrated to be precise.[13]

Study design

At Baseline #1, a set of thermodilution measurements was performed in order to calibrate CI_{Pulse} (Supplementary Fig. S1). We recorded the values of CI provided by the bioreactance device ($CI_{Starling}$), CI_{td} and CI_{Pulse}. We also recorded heart rate and central venous and arterial pressures. A PLR test was then performed. By using the automated bed adjustment, the patient was moved from the semi-recumbent position to a position where the trunk was horizontal and the lower limbs lifted at 45°.[9] When CI_{Pulse}, CI_{Pulse} and $CI_{Starling}$ had reached their maximal value during PLR, they were recorded (Supplementary Fig. S1). No thermodilution measurement was performed at this time, because the effects of PLR must be assessed in real time.[9] Then, the patient was moved back in the semi-recumbent position and CI_{Pulse} was allowed to return to baseline (Baseline #2). A set of transpulmonary thermodilution measurements was performed. We performed the same measurements as at Baseline #1 (Supplementary Fig. S1). At this time, CI_{Pulse} was measured before CI_{td}, such that it was not calibrated by transpulmonary thermodilution (Supplementary Fig. S1).

If CI_{Pulse} increased ≥10% during PLR compared with the Baseline #1 value, the patient was considered 'preload responsive'[13] and was administered 500 ml of normal saline over 10 min. After volume expansion in these patients, a last set of haemodynamic measurements was obtained, including the same variables as at Baselines #1 and #2 (Supplementary Fig. S1). In patients with a negative PLR test ('non-preload