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Bioreactance is not reliable for estimating cardiac output and the effects of passive leg raising in critically ill patients

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Editor's key points

- Data are conflicting regarding the accuracy and validity of non-invasive cardiovascular monitoring devices in the critically ill.
- This study compared changes in cardiac index in response to passive leg raising (PLR) and volume expansion using the NICOM® and $PiCCO_2$™ devices.
- There was poor correlation between the two monitors after volume expansion.
- The NICOM® did not predict fluid responsiveness to PLR.

Background. Bioreactance estimates cardiac output in a non-invasive way. We evaluated the ability of a bioreactance device (NICOM®) to estimate cardiac index (CI) and to track relative changes induced by volume expansion.

Methods. In 48 critically ill patients, we measured CI estimated by the NICOM® device (CI_{Nicom}) and by transpulmonary thermodilution (CI_{td}, $PiCCO_2$™ device) before and after a 500 ml saline infusion. Before volume expansion, we performed a passive leg raising (PLR) test and measured the changes it induced in CI_{Nicom} and in pulse contour analysis-derived CI.

Results. Considering the values recorded before PLR and before and after volume expansion (n=144), the bias (lower and upper limits of agreement) between CI_{td} and CI_{Nicom} was 0.9 (−2.2 to 4.1) litre min^{-1} m^{-2}. The percentage error was 82%. There was no significant correlation between the changes in CI_{td} and CI_{Nicom} induced by volume expansion (P=0.24). An increase in CI estimated by pulse contour analysis >9% during the PLR test predicted fluid responsiveness with a sensitivity of 84% (95% confidence interval 60–97%) and a specificity of 97% (95% confidence interval 82–100%). The area under the receiver operating characteristic curve constructed to test the ability of the PLR-induced changes in CI_{Nicom} in predicting fluid responsiveness did not differ significantly from 0.5 (P=0.77).

Conclusions. The NICOM® device cannot accurately estimate the cardiac output in critically ill patients. Moreover, it could not predict fluid responsiveness through the PLR test.

Keywords: equipment, monitors; dobutamine; measurement, cardiac output; measurement techniques; shock

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Several new devices that monitor haemodynamics have been introduced with the aim of reducing the need for haemodynamic invasive monitoring. Bioreactance is potentially attractive since it only requires four electrodes stickers placed on the thorax.[1] This technique is based upon the measurement of frequency modulation and signal phase shift of an electrical current crossing the thorax, the variations of which are related to changes in the volume of the thoracic aorta.[2] This allows estimation of the volume of blood ejected in the thoracic aorta with each heart beat.

The validation of this technique is still ongoing and initial results are conflicting. While some studies found good agreement between bioreactance and a reference technique,[3–5] others found less promising results.[6–9] Our aim was to compare the values of cardiac output measured by a bioreactance device (NICOM®, Cheetah Medical, Tel Aviv, Israel) with the values provided by transpulmonary thermodilution. Particularly, we evaluated the capacity of the NICOM® to track the changes in cardiac index (CI) during a passive leg raising (PLR) test and to predict fluid responsiveness.

Methods

Population

This prospective study took place in the medical intensive care unit (ICU) of a university hospital. It was approved by the institutional review board of our institution (Comité pour la Protection des Personnes Ile de France VII). All patients (or next of kin) gave informed consent. The inclusion criteria were (i) the presence of an acute haemodynamic failure, as defined by a

systolic arterial pressure ≤90 mm Hg or a decrease ≥40 mm Hg compared with the usual systolic arterial pressure, skin mottling, blood lactate ≥2 mmol litre^{-1}, urine output ≤0.5 ml kg^{-1} h^{-1} for at least 2 h, tachycardia ≥100 beats min^{-1}, (ii) a decision by the clinician in charge to perform a PLR test and to administer a volume expansion, and (iii) a transpulmonary thermodilution device in place (PiCCO$_2$™, Pulsion Medical Systems, Munich, Germany). Patients were excluded if there was a contra-indication to the PLR test (intracranial hypertension, venous compression stocking).

Bioreactance and transpulmonary thermodilution measurements

Derived from the original bioimpedance technique, the NICOM® system sends a high-frequency current with known low amplitude through the thorax using four electrodes and measures the frequency-modulation and phase-modulation resulting from the changes in the thoracic blood volume through four other adjacent electrodes. After placing the electrodes and recording patients' characteristics, the NICOM® automatically calibrates and then provides a continuous CI value.

The PiCCO$_2$™ system requires a central venous catheter in the superior vena cava territory and a femoral thermistor-tipped arterial catheter (PV2024 Pulsion Medical Systems). The latter is connected to a pressure sensor (PV8115 Pulsion Medical Systems). The PiCCO$_2$ device measures CI in two different ways. First, transpulmonary thermodilution principle provides an intermittent measure of CI. After injection of a 15 ml cold bolus through the central venous line, cardiac output is computed from the blood temperature curve recorded by the arterial catheter. With this technique, if CI is calculated as the average of three consecutive thermodilution measurements, its least significant is 12%.[10] Secondly, pulse contour analysis provides a continuous and real-time estimation of CI. It is based upon the principle that the area under the systolic part of the arterial signal is physiologically proportional to stroke volume. The PiCCO$_2$™ calibrates the initial value of CI by transpulmonary thermodilution. After calibration, pulse contour analysis allows the continuous display of CI values.

Study design

At baseline, the CI values provided by the NICOM® (CI_{Nicom}) and PICCO$_2$™ (transpulmonary thermodilution, Cl_{td}) devices were recorded simultaneously. A PLR test was then performed by moving the patient's bed from a semi-recumbent position to a position in which the trunk was horizontal and lower limbs raised at 45°. At the time when PLR induced its maximal haemodynamic effects (i.e. within 1 min), CI_{Nicom} and CI provided by pulse contour analysis were recorded. Then, the patient was placed back into the semi-recumbent position and CI values were allowed to return to baseline. The PiCCO$_2$™ device was recalibrated and the CI_{Nicom} and CI_{td} were recorded.

During the next 10 min, 500 ml saline was infused to cause intravascular volume expansion. After volume expansion, CI_{Nicom} and CI_{td} were again recorded simultaneously.

Data analysis

The normality of data distribution was tested with the Anderson–Darling test. Data are expressed as mean [standard deviation (SD)] or median (IQR), as appropriate. Comparisons of haemodynamic variables between the different study times were assessed using a paired Student *t*-test or a Wilcoxon test, as appropriate. Comparisons between volume-responders *vs* non-volume-responders were assessed using a two-sample Student *t*-test or a Mann–Whitney *U*-test, as appropriate.

Values of CI_{td} (recorded at baseline, after return to the semi-recumbent position, and after volume expansion) *vs* CI_{Nicom} were compared using the Bland–Altman analysis. CI was used for analysis considering that the reliability of a device for measuring absolute variables of CI is similar than for cardiac output. The percentage error was calculated as 2SD divided by the mean of CI_{td}.

The percentage changes in CI_{td} and CI_{Nicom} induced by volume expansion were compared by linear regression analysis (for per cent change). Percentage changes were taken into account rather than the absolute changes because they take into consideration that the impact of an error in cardiac output measurement is not the same depending upon the absolute value of cardiac output measured by the reference technique. For assessing the ability of CI_{Nicom} to follow trends, we constructed a four-quadrant plot, as described by Critchley and colleagues.[11]

We considered as 'volume-responders' patients responding to volume expansion by an increase of at least 15% of CI_{td}. The other patients were considered as 'non-volume-responders'. For testing the ability of the changes in CI_{Nicom} and CI provided by pulse contour analysis induced by the PLR test to predict fluid responsiveness, we constructed receiver operating characteristics (ROC) curves. Sensitivity and specificity are expressed as median (95% confidence interval). The cut-off values of changes in CI_{Nicom} and CI provided by pulse contour analysis for predicting volume responsiveness by the PLR test were considered as those providing the lowest Youden index. A *P*-value of <0.05 was considered statistically significant. The statistical analysis was performed with the MedCalc 8.1.0.0 software (Mariakerke, Belgium).

Results

Patients

Forty-eight patients were included in the study (Table 1). No patient was excluded. Sepsis was the aetiology of shock in 83% of the patients and a majority presented an acute respiratory distress syndrome. Eleven patients presented cardiac arrhythmias, spontaneous breathing activity, or both.

Comparison of absolute values of CI_{td} and CI_{Nicom}

When considering all pairs of CI_{td} and CI_{Nicom} measurements (at baseline before PLR, before volume expansion, and after volume expansion, $n=144$), the bias between CI_{td} and CI_{Nicom} was −0.9 litre min^{-1} m^{-2}. The limits of agreement