Cardiac output monitoring: less invasiveness, less accuracy?

Bernd Saugel¹ · Julia Y. Wagner¹ · Thomas W. L. Scheeren²

Received: 11 June 2016 / Accepted: 13 June 2016 / Published online: 17 June 2016
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Measuring and optimizing cardiac output (CO) as one major determinant of oxygen delivery is a mainstay in the treatment of hemodynamically unstable patients in intensive care and perioperative medicine. Advanced hemodynamic monitoring using technologies allowing the assessment of stroke volume and thus CO is therefore highly recommended in these patients [1–3].

Although intermittent pulmonary artery thermodilution using a pulmonary artery catheter is still supposed to be the clinical gold standard for the assessment of CO [4], less-invasive and even non-invasive technologies have been developed in growing numbers in recent years and proposed for CO monitoring—including single-indicator transpulmonary thermodilution and calibrated or uncalibrated pulse contour analysis [3, 5].

While less- and non-invasive hemodynamic monitoring is certainly a striking concept in terms of patient safety and clinical applicability, the “measurement performance” of those monitoring technologies with regard to accuracy and precision of CO measurements in comparison with intermittent pulmonary artery thermodilution has repeatedly been questioned.

Therefore, the question arises whether “less invasiveness” necessarily means “less accuracy”. Cho et al. [6] need to be commended for aiming to answer this clinically

relevant question by performing a very elegant study published in this issue of the journal. In their method comparison study, they compared agreement and trending ability between different methods for CO assessment with different degrees of invasiveness in patients undergoing off-pump coronary artery bypass surgery. As the reference method they used intermittent pulmonary artery thermodilution and evaluated the measurement performance of different test methods, namely continuous pulmonary artery thermodilution, transpulmonary thermodilution, pulse contour analysis calibrated to transpulmonary thermodilution, and uncalibrated pulse contour analysis.

Interestingly, the percentage error of CO measurements using continuous versus intermittent pulmonary artery thermodilution was 27 %. The percentage errors observed for transpulmonary thermodilution, pulse contour analysis calibrated to transpulmonary thermodilution, and uncalibrated pulse contour analysis were 13, 29, and 34 %, respectively. Only transpulmonary thermodilution showed a good ability to follow CO changes as determined by intermittent pulmonary artery thermodilution.

We don't want to discuss statistical problems related to the percentage error [7, 8], the trending analysis [9, 10], and the definition of “acceptable agreement” in CO method comparison studies in this editorial.

Yet the findings of Cho and colleagues warrant some further discussion regarding the selection of monitoring technologies for our patients. Of note, the authors' findings show better agreement between pulse contour analysis-derived CO and CO assessed with pulmonary artery thermodilution than most previous studies [11–13]. But yet, the study demonstrates that “invasive” transpulmonary thermodilution shows better agreement with pulmonary artery thermodilution compared with calibrated pulse contour analysis (that in turn showed better agreement than

✉ Bernd Saugel
bernd.saugel@gmx.de

¹ Department of Anesthesiology, Center of Anesthesiology and Intensive Care Medicine, University Medical Center Hamburg-Eppendorf, Martinistrasse 52, 20246 Hamburg, Germany

² Department of Anesthesiology, University of Groningen, University Medical Centre Groningen, Groningen, The Netherlands

uncalibrated pulse contour analysis). As the study design allowed simultaneously comparing the various technologies for CO assessment (characterized by different degrees of invasiveness) it very elegantly shows that less invasiveness indeed seems to imply less accuracy.

This leads to the question how the clinician should choose the appropriate hemodynamic monitoring technology for the individual patient from the arsenal of the numerous commercially available systems.

We obviously need to be aware that every single hemodynamic monitoring technology has its own technical limitations. Knowledge of these specific limitations is a prerequisite for a wise use of these technologies. CO assessment with pulmonary artery thermodilution can only be accurate if there is no loss of thermal indicator between the injection site and the thermistor and no recirculation of the indicator [14, 15]. Therefore, pulmonary artery thermodilution measurements can be falsified by tricuspid or pulmonary valve insufficiency, intracardiac shunts, low CO states, or technical errors related to indicator injection (temperature, volume, timing, and duration of indicator injection) or catheter positioning [14, 15]. Transpulmonary thermodilution-derived CO measurements are basically affected by the same limiting factors related to the thermal indicator loss and recirculation, but compared with pulmonary artery thermodilution they are less influenced by CO variations over the respiratory cycle [15]. For both techniques, a close visual observation of the thermodilution curve is therefore key to verify correct CO measurements. For pulse contour analysis, several factors might influence the measurement performance. Self-evidently, pulse contour analysis depends on the signal quality of the arterial pressure waveform. Moreover, changes in vasomotor tone can impair the measurement performance of pulse contour analysis that might however be improved by frequent calibration to CO assessed with a more invasive technology (e.g. transpulmonary thermodilution) [16–19]. In addition, the proprietary pulse contour analysis algorithms consider biometric patient data or properties of the arterial pressure waveform to derive CO; in certain patients or clinical situations these mathematical assumptions might not hold true [19]. Various limitations regarding technical problems and mathematical algorithms have also been described for all completely non-invasive technologies for CO assessment [5].

Besides potential limitations, we need to consider various other properties of different monitoring modalities when choosing the optimal tool for the individual patient; this includes accuracy, precision, and trending ability of the CO measurements, continuity of measurements (continuous, semi-continuous, or intermittent CO might be required in different clinical situations), and options to calibrate to reference CO values [2]. For instance, in many occasions it may not be essential to know if the actual CO is 3.9 or 4.2

L/min rather than to reliably track its changes after a certain intervention, e.g. volume expansion. In this context, we need to balance the risk of invasive hemodynamic monitoring tools against the limited accuracy of less-invasive technologies for the individual patient. We also need to consider which additional variables each monitoring technology is able to provide in addition to CO. Therefore, pulmonary artery catheterization might be indicated in a critically ill patient with circulatory shock and right ventricular failure or pulmonary artery hypertension [3] but not in a low or intermediate risk non-cardiac surgery patient. Transpulmonary thermodilution additionally allows the assessment of extravascular lung water and therefore might be a good way to monitor a patient with circulatory shock and acute respiratory failure [3]. During dynamic tests of fluid responsiveness (i.e. passive leg raising [20] or fluid challenge [21] tests) pulse contour analysis can be a monitoring option allowing the continuous real-time monitoring of changes in CO. In addition, in the perioperative setting, pulse contour analysis-based monitoring can be indicated to apply goal-directed hemodynamic therapy [2, 22].

Finally, institutional factors, costs, and personal experience with and confidence in different monitoring systems may play a role which technology we use for the individual patient.

To achieve our ultimate goal—improving the individual patient's outcome by monitoring and optimizing cardiovascular dynamics—we need to understand and integrate all aspects related to invasiveness and measurement performance of the different monitoring technologies. This allows responsibly applying hemodynamic monitoring to the individual patient based on a differential indication.

Compliance with ethical standards

Conflict of interest BS collaborates with Pulsion Medical Systems SE (Feldkirchen, Germany) as a member of the medical advisory board and received honoraria for giving lectures and refunds of travel expenses from Pulsion Medical Systems SE. BS received research support from Edwards Lifesciences (Irvine, CA, USA). BS and JYW received institutional research grants, unrestricted research grants, and refunds of travel expenses from Tensys Medical Inc. (San Diego, CA, USA). BS received honoraria for giving lectures from CNSystems Medizintechnik AG (Graz, Austria). BS and JYW received refunds of travel expenses from CNSystems Medizintechnik AG (Graz, Austria). TS received honoraria from Edwards Lifesciences and Masimo Inc. (Irvine, CA, USA) for consulting. TS received honoraria from Pulsion Medical Systems SE for lecturing.

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