Review of the PiCCO device; our experience in the ICU

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Reply. The authors, Lemson and Van der Hoeven, do not agree with us that the PiCCO system is of limited value in monitoring cardiothoracic patients. They feel that we omitted several potentially beneficial possibilities of the PiCCO device that might be of interest to the readers of the Netherlands Journal of Critical Care.

Before responding to this discussion about the limitations of the PiCCO system, we need to draw attention to the main assumptions made in the calculation of (transpulmonary) thermodilution cardiac output. Furthermore, definitions of accuracy and precision of cardiac output methods and of interpretation of differences between methods must be made.

Introduction

In the analysis of accuracy (also called bias) and precision (standard deviation of measurements), the thermodilution method is generally considered accurate but not precise, whereas pulse contour methods are considered precise but inaccurate, Figure 1. However, after calibration by thermodilution, pulse contour methods are supposed to be accurate and precise.

What makes thermodilution methods less precise? Or what causes sequential measurements to differ so much? The thermodilution method is based on the law of conservation of thermal energy. If, and only if, blood flow is constant, if no loss of indicator between injection site and detection site occurs, if mixing of blood and indicator is complete and if a bolus injection of a limited amount of cold indicator is applied, then the classical Steward-Hamilton equation can be used. Neglecting these assumptions may lead to considerable spread in cardiac output (CO) values as has been reported by several authors. So, the results of many CO measurements must be averaged to acquire one accurate estimate of mean cardiac output. More then 25 years ago we developed an equation that did not require the assumption of constant blood flow (patent NL 189547, Patent USA 4595015). However, for this solution a relative measure of blood flow is needed. For this purpose we used pulse contour analysis. A simplified schematic graphical representation of the underlying mathematics is given in Figure 2. In this figure we illustrate the effects of non-constant blood flow, panel a, on the thermodilution curve, panel b. During periods of no flow the temperature change measured with a thermistor is constant, panel b. In panel c, the temperature change after weighing with a measure of relative flow is given (CTIF). It is obvious that there is no transport of cold indicator during periods of no flow and the area under the temperature curve is zero during these periods as it should be. In panel d, a normal dilution curve is found after transformation of the time axis according to our invention. This is the curve that might be found if a measurement with a constant flow and averaged value as indicated by the dashed line in panel a.

In animal experiments as well as in patients we showed that during mechanical ventilation cardiac output can be estimated with high accuracy and precision by single measurements (precision improved from 10-15% to 3-5% [2]). These findings were confirmed in many of our studies as well as in those of others, among them Groeneveld et al [3]. We still support our conclusion that in the ICU and OR the estimation of cardiac output by thermodilution can be accurate and precise if the limitations of the method are taken into account.

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The PiCCO device with its incorporated transpulmonary thermodilution technique calculates CO using the Steward-Hamilton equation based on the assumption of constant blood flow. However, the same device may show, by pulse contour analysis, that stroke volume varies with the phase of mechanical ventilation (SVV), implying a violation of the Steward-Hamilton equation. This limits the application of the PiCCO device.

What is the meaning of the conclusion of several authors that a clinical acceptable agreement between transpulmonary thermodilution and pulmonary thermodilution exists? Comparing the results of two methods that have a large spread (low precision) (Figure 2, a, c and d) may easily lead to the invalid conclusion that no significant difference between methods exists and that one method...
can replace the other. Whereas, comparing two methods with high precision (Figure 1, a and b) would show a significant difference. Therefore, it is highly relevant to improve the precision of the methods. This is especially of importance for the reference method or gold standard.

**Determination of cardiac output**

Based on the forgoing one may conclude that we should consider a precision of 10 to 15% for thermodilution unacceptable. We therefore consider it premature to accept the transpulmonary thermodilution as gold standard in critically ill pediatric patients.

The remark of Lemson and Van der Hoeven that the continuous pulmonary thermodilution technique is not continuous is wrong, it is most certainly a continuous measurement but its value will not necessarily change in synchrony with fast changes in cardiac output. According to the definition given for accuracy and precision, the accuracy (not the precision) of PiCCO’s pulse contour method is less than that of the thermodilution method and, indeed, frequent recalibration may be needed. However, this frequent need for recalibration turns the method from a continuous into an intermittent one. The uncertainty to measure cardiac output correctly, shortly after a recalibration, limits the applicability of the method. It is our experience that during the first hour after admission of a patient to the ICU, regular recalibration is needed. After the first hour intervals of 8 hours between calibrations will normally be sufficient under standard clinical conditions.

Lemson and Van der Hoeven are off the mark in stating that the Modelflow and Hemac methods do not have the essential ability to be calibrated against an established method. We have given extensive attention to this item in several publications [6-9]. In several comparative studies [10-13] the PiCCO device was ranked low with respect to accuracy and precision. Therefore, we have arguments to reinforce our conclusion that the PiCCO device has been outperformed by its competitors. With this conclusion, we intend to push forward the development of pulse contour methods with a better performance, so that changes in cardiac output during passive leg raising or during small amounts of fluid loading can be used to predict fluid responsiveness of a patient reliably and safely.

**Determination of fluid response**

One of our statements mentioned by Lemson and Van der Hoeven is that because of commonly observed irregular heart rates in the ICU, the use of SVV and PPV to predict fluid responsiveness is limited. In their letter they mention that in a recent series from their own hospital (CORRAD database registration UMC St Radboud) an episode of atrial fibrillation developed in only 7.7% of postoperative cardiac surgery patients during their ICU treatment. Their results differ from ours and also from results given in literature [14,15]. According to Parrikka et al [14] during the first two to three days after cardiothoracic surgery postoperative arrhythmias occur in up to 43% of the patients. We would be very interested in the explanations for this difference and look forward to a publication on this subject. Based on the relatively high incidence of arrhythmias, we still come to the conclusion that the PiCCO device is limited in its use.

Of course the use of SVV and PPV is of no value in patients with spontaneous breathing activity. This is indeed illustrated, for instance, by the fact that even in patients with a regular breathing pattern (constant tidal volume and rate of ventilation) the sensitivity to predict fluid responsiveness is low. Lemson and Van der Hoeven state that the opinion that SVV influences the precision of the GEDV measurement, has never been substantiated. From the introduction given in the current reply it must be clear that this is not an opinion but a conclusion based on scientific work performed more then 25 years ago [4,5]. Indeed, neglecting the modulation on stroke volume by mechanical ventilation (duration approximately 5 sec) may clearly influence the determination of the down slope time of the transpulmonary dilution curve. We encourage the readers of the Netherlands Journal of Critical Care to discuss this item with the developers of the PiCCO system in order to gain more accurate and precise apparatus (with fewer limitations) in the near future.

**Conclusion**

Lemson and Van der Hoeven’s letter did not change our opinion on the use of the PiCCO device. This letter illustrates that definitions of accuracy and precision are needed and, in addition, that a comparison between methods is only valid if the reference method is precise and accurate. Thermodilution methods as reference methods with a precision of 10-15% are unacceptable. To archive unambiguous results, knowledge of basic physiology and physics is imperatively needed. Only then, with data that can be relied on, the development of an appropriate scientifically based protocol is possible which can help the doctors and nurses to cure the patient.
References

10. JRC. Jansen and PC.M. van den Berg. Cardiac output by both thermodilution and arterial pulse contour techniques: Update in intensive care and emergency medicine, section “Functional hemodynamic monitoring” 2004; Editors: Michael R. Pinsky and Didier Payen.