Cardiac output monitoring: aortic transpulmonary thermodilution and pulse contour analysis agree with standard thermodilution methods in patients undergoing lung transplantation

[Le monitorage du débit cardiaque : la thermodilution aortique transpulmonaire et l'analyse de la conformation du pouls concordent avec les méthodes de thermodilution normalisées chez des patients qui subissent une greffe pulmonaire]

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Purpose: The PiCCO System is a relatively new device allowing intermittent cardiac output monitoring by aortic transpulmonary thermodilution technique (Aorta intermittent) and continuous cardiac output monitoring by pulse contour analysis (Aorta continuous). The objective of this study was to assess the level of agreement of Aorta intermittent and Aorta continuous with intermittent (PA intermittent) and continuous cardiac output (PA continuous) measured through a special pulmonary artery catheter (Vigilance System SvO_2/CCO Monitor) in patients undergoing single- or double-lung transplantation.

Methods: Measurements were obtained in 58 patients: at four time points in patients undergoing single-lung transplantation and at six time points in those undergoing double-lung transplantation. Bland and Altman and correlation analyses were used for statistical evaluation.

Results: We found close agreement between the techniques. Mean bias between Aorta intermittent and PA intermittent and between Aorta continuous and PA continuous was 0.18 $L \cdot min^{-1}$ (2SD of differences between methods = 1.59 $L \cdot min^{-1}$) and -0.07 $L \cdot min^{-1}$ (2SD of differences between methods = 1.46 $L \cdot min^{-1}$) respectively. Mean bias between PA continuous and PA intermittent and Aorta continuous and PA intermittent was 0.15 $L \cdot min^{-1}$ (2SD of differences between methods = 1.39 $L \cdot min^{-1}$) and 0.08 $L \cdot min^{-1}$ (2SD of differences between methods = 1.43 $L \cdot min^{-1}$).

Conclusion: Measurements with the aortic transpulmonary thermodilution technique give continuous and intermittent values that agree with the pulmonary thermodilution method which is still the current clinical standard.

Objectif : *Le PiCCO System est un appareil, relativement nouveau, de monitorage intermittent du débit cardiaque par la technique de thermodilution aortique transpulmonaire (aortique intermittente) et de monitorage continu du débit cardiaque par l'analyse de la conformation du pouls (aortique continue). L'objectif de l'étude était d'évaluer le degré de concordance entre la technique aortique intermittente et aortique continue, réalisée par la mesure du débit cardiaque intermittente (AP intermittente) et continue (AP continue) par un cathéter artériel pulmonaire spécial (Vigilance System SvO_2/CCO Monitor) chez des patients qui subissent la greffe d'un ou des deux poumons.*

Méthode : *Les mesures ont été prises à quatre moments déterminés chez 58 patients devant subir une greffe unipulmonaire et à six moments chez ceux qui devaient subir une greffe bipulmonaire. L'analyse de Bland et Altman et l'analyse de corrélation ont servi à l'évaluation statistique.*

Résultats : *Nous avons trouvé une étroite concordance entre les techniques. Le biais moyen entre la technique aortique intermittente et AP intermittente et entre Aortique continue et AP continue a été respectivement de 0,18 $L \cdot min^{-1}$ (différence de 2 écarts types entre les méthodes = 1,59 $L \cdot min^{-1}$) et -0,07 $L \cdot min^{-1}$ (différence de 2 écarts types = 1,46 $L \cdot min^{-1}$). Le biais moyen entre AP continue et AP intermittente, et entre Aortique continue et Aortique intermittente a été de 0,15 $L \cdot min^{-1}$ (différence de 2 écarts types = 1,39 $L \cdot min^{-1}$) et 0,08 $L \cdot min^{-1}$ (différence de 2 écarts types = 1,43 $L \cdot min^{-1}$).*

Conclusion : *Les mesures obtenues selon la technique de thermodilution aortique transpulmonaire ont fourni des valeurs continues et intermittentes qui concordent avec celle de la thermodilution pulmonaire, laquelle demeure la norme clinique.*

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EXTENDED cardiovascular monitoring is used commonly during anesthesia for lung transplantation. Cardiac output (CO) is measured with the use of a pulmonary artery catheter (PAC). During the procedure, the intermittent measure of CO can miss transient changes in CO.

We compared the intermittent transpulmonary thermodilution indicator method (Aorta intermittent) and two methods of continuous measurement (pulse contour analysis = Aorta continuous, and continuous pulmonary artery thermodilution = PA continuous) to the current clinical standard: intermittent pulmonary artery thermodilution (PA intermittent) in patients undergoing lung transplantation.

Material and methods

We obtained approval from the Ethics Committee and written informed consent from 58 patients (30 male, 28 female) who were about to undergo single-lung (SLT 15 patients) or double-lung transplantation (DLT 43 patients). Anesthetic technique was standardized in all patients. A 4-Fr gauge, 20 cm-long arterial catheter with a thermistor embedded in its wall was inserted (Pulsiocath PV2014L, Pulsion Medical System; Munich, Germany) in the femoral artery via a 5-Fr gauge introducer (Adam Spence Europe Ltd. Abbeytown, Boyle, CR, Ireland). The arterial catheter was connected to the pulse contour analysis computer (PiCCO System, version 4.1. Pulsion.) for monitoring of arterial blood pressure, heart rate, temperature,

TABLE I Cardiac output measurements as mean (SD), range (lower line), obtained during lung transplantation

	Before incision	*Lung 1*	*Rep 1*	*Lung 2*	*Rep 2*	*Final*
Aorta intermittent*	6.07 (1.5)	6.2 (1.7)	7.7 (2.0)†	5.3 (1.7)†	5.7 (1.4)	6.0 (1.8)
($L \cdot min^{-1}$)	(3.3-10)	(3.0-10.7)	(3.1-12.6)	(2.7-11)	(2.8-8.4)	(3.6-12)
PA intermittent*	5.7 (1.5)	6.2 (1.7)	7.5 (2.1)†	5.2 (1.7)†	5.6 (1.5)	5.8 (1.8)
($L \cdot min^{-1}$)	(3.3-9.4)	(3.5-11.8)	(3.6-12.1)	(2.3-12)	(2.3-8.3)	(3.3-12)
Aorta continuous*	5.9 (1.4)	6.3 (1.7)	7.5 (1.9)†	5.2 (1.7)†	5.6 (1.4)	5.9 (1.8)
($L \cdot min^{-1}$)	(3.3-8.9)	(3.3-10.8)	(3.6-12)	(3.2-11.1)	(2.5-8)	(2.7-12)
PA continuous*	5.9 (1.5)	6.2 (1.7)	7.5 (1.9)†	5.5 (1.8)†	5.7 (1.5)	6.0 (1.7)
($L \cdot min^{-1}$)	(3.3-10.1)	(3.5-11)	(3.0-11)	(3.1-13)	(2.5-8.3)	(4.0-12)

Lung 1 = during first lung implantation; Rep1 = after first lung reperfusion; Lung 2 = during second lung implantation; Rep 2 = after reperfusion of the second lung; Final = at the end of surgery. *Significant changes during all the study period (analysis of variance); †significantly different from the previous phase ($P < 0.05$).

TABLE II Bias and 95% limits of agreement between methods at each stage of surgery

	Phase	*Bias ($L \cdot min^{-1}$)*	*95% limits of agreement*	r^2
PA intermittent *vs* Aorta intermittent	Before incision	0.37	-0.89 to 1.63	0.83•
PA intermittent *vs* Aorta continuous	Before incision	0.26	-0.87 to 1.39	0.86•
PA intermittent *vs* PA continuous	Before incision	0.20	-1.00 to 1.40	0.85•
PA intermittent *vs* Aorta intermittent	Lung 1	0.05	-1.43 to 1.53	0.82•
PA intermittent *vs* Aorta continuous	Lung 1	0.07	-1.14 to 1.28	0.88•
PA intermittent *vs* PA continuous	Lung 1	0.04	-1.34 to 1.42	0.84•
PA intermittent *vs* Aorta intermittent	Rep 1	0.17	-1.82 to 2.16	0.79•
PA intermittent *vs* Aorta continuous	Rep 1	0.01	-1.84 to 1.86	0.81•
PA intermittent *vs* PA continuous	Rep 1	0.05	-1.59 to 1.86	0.85•
PA intermittent *vs* Aorta intermittent	Lung 2	0.10	-1.63 to 1.83	0.76•
PA intermittent *vs* Aorta continuous	Lung 2	0.02	-1.56 to 1.60	0.80•
PA intermittent *vs* PA continuous	Lung 2	0.32	-0.98 to 1.62	0.87•
PA intermittent *vs* Aorta intermittent	Rep 2	0.13	-1.52 to 1.78	0.71•
PA intermittent *vs* Aorta continuous	Rep 2	0.00	-1.35 to 1.35	0.80•
PA intermittent *vs* PA continuous	Rep 2	0.06	-1.54 to 1.52	0.79•
PA intermittent *vs* Aorta intermittent	Final	0.24	-1.14 to 1.62	0.86•
PA intermittent *vs* Aorta continuous	Final	0.09	-1.28 to 1.46	0.86•
PA intermittent *vs* PA continuous	Final	0.27	-1.02 to 1.56	0.87•

Lung 1 = during first lung implantation; Rep1 = after first lung reperfusion; Lung 2 = during second lung implantation; Rep 2 = after reperfusion of the second lung; Final = at the end of surgery. •$P < 0.0001$ (for linear regression coefficient).

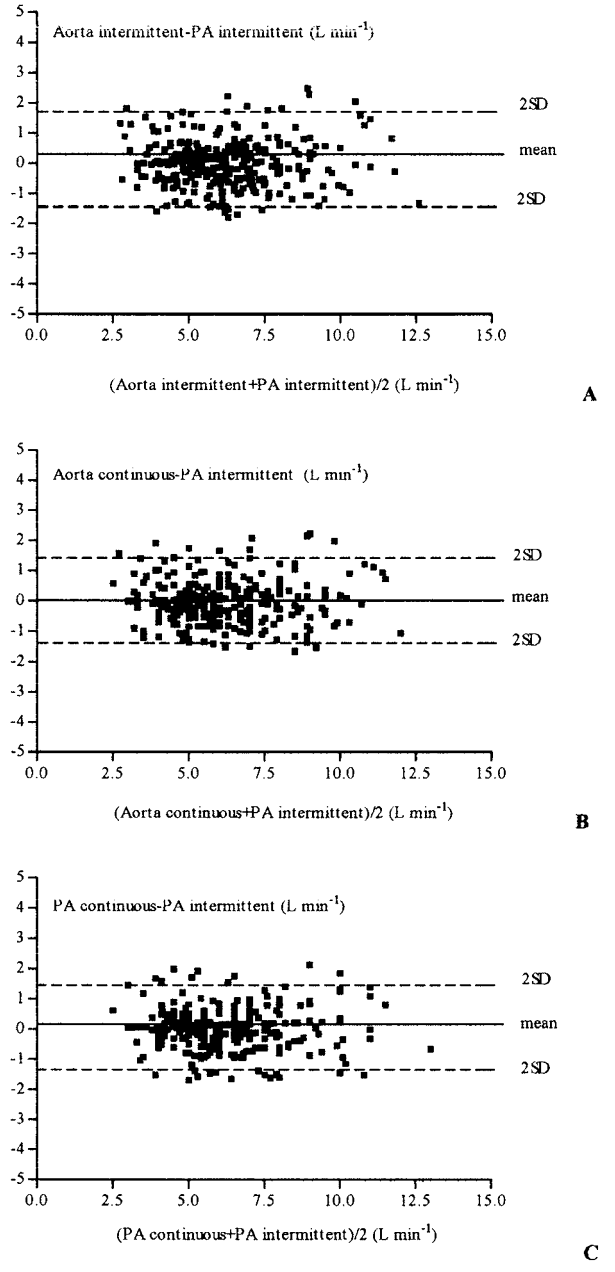

FIGURE 1 Bland and Altman plots between A): Aorta intermittent and PA intermittent (0.18 [1.59] L·min^{-1}); B): Aorta continuous and PA intermittent (0.08 [1.43] L·min^{-1}); C): PA continuous and PA intermittent (0.15 [1.39] L·min^{-1}) for all measurements. The solid line shows the mean difference and the dotted lines show the 2SD limits of agreement.

Aorta intermittent, Aorta continuous and measurements derived from the arterial pressure wave. The pulse contour device was calibrated by the mean values of three consecutive cardiac output measurements, randomized within the respiratory cycle, by injection of 15 mL saline solution at a temperature lower than 7°C, via a central venous catheter with subsequent detection by the femoral artery thermistor, as described in a previous experimental model.[1]

A modified 7.5-Fr gauge PAC for SvO_2 and CCO was inserted via an introducer (8.5-Fr Baxter Edwards Laboratories, Irvine, CA, USA) into the right internal jugular vein and connected to the Vigilance system (Baxter Edwards Laboratories, Irvine, CA, USA) for PA intermittent and PA continuous monitoring. A single operator obtained three consecutive measurements over a two-minute period without regard to the phase of the respiratory cycle.[1]

After the achievement of stable cardiovascular conditions, calibration of the pulse contour analysis system was done. During SLT and DLT, Intermittent CO measurements were obtained:

Before incision: after induction of anesthesia; *Lung 1:* during implantation of the first lung; *Rep 1*: after reperfusion of the first lung; *Final*: at the end of surgery; and only in DLT: *Lung 2*: during implantation of the second lung; *Rep 2*: after reperfusion of the second lung.

All results are expressed as mean and standard deviation (SD) unless indicated otherwise.

Statistical analysis used the method described by Bland and Altman.[2] The upper and the lower limits of agreement were calculated as bias (2SD), and defined the range in which 95% confidence interval (CI) of the differences between the methods were expected to lie.

Delta (Δ) in CO were calculated by subtracting the first from the second measurement (Δ_1 = Lung 1-Before incision), the second from the third (Δ_2), and so on (Δ_3, Δ_4, and Δ_5) and were analyzed using linear regression. We measured the bias between techniques in measuring those differences in CO.

Results

We obtained a total of 318 measurements, i.e., the sum of four time points in 15 SLT patients (60 measurements) and six time points in 43 DLT patients (258 measurements; Table I).

Mean bias between Aorta intermittent, Aorta continuous and PA continuous *vs* the clinical standard PA intermittent is reported in Figure 1. Bias and coefficient of correlation during the predefined analyzed steps are reported in Table II.

Correlations between delta 1 (Δ_1) in PA intermittent, *vs* Aorta intermittent, Aorta continuous and PA continuous are reported in Figure 2.

The other correlations in terms of Δ_2, Δ_3, Δ_4, and Δ_5 between the techniques *vs* PA intermittent were,

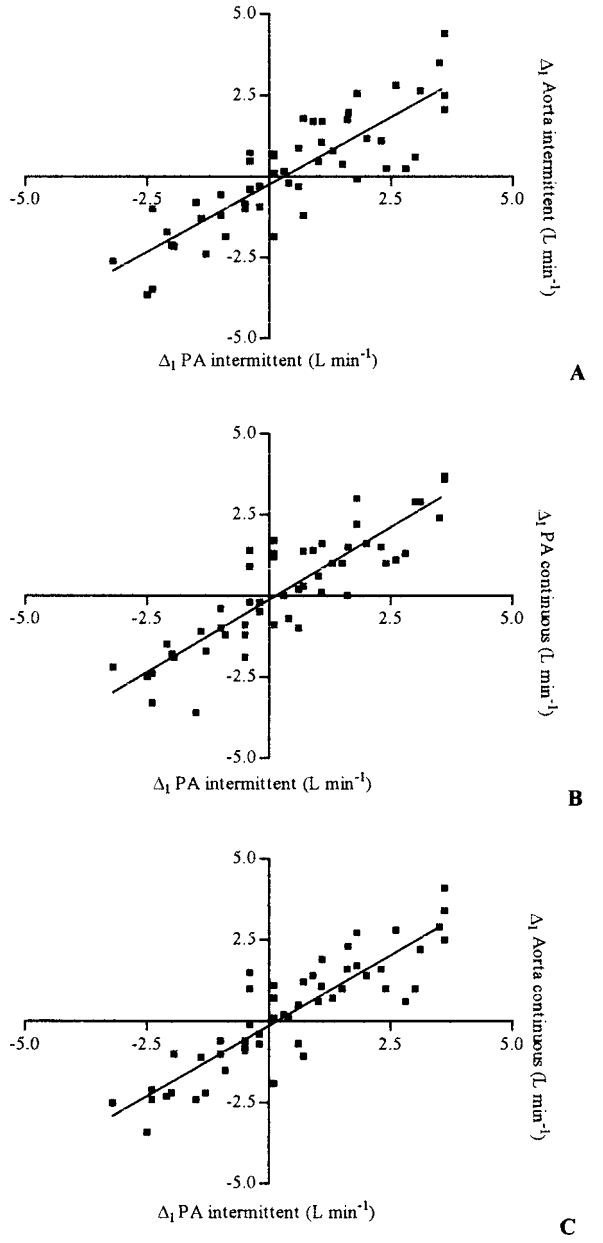

FIGURE 2 Linear regression analysis of differences (Δ) in cardiac output between the study phases (Δ_1 = Lung 1-Before incision) A): Aorta intermittent *vs* PA intermittent (y = 0.8328 × -0.2491 r^2 = 0.73, $P < 0.0001$); B): PA intermittent *vs* PA continuous (y = 0.8935 × -0.123 r^2 = 0.78, $P < 0.0001$); C): PA intermittent *vs* Aorta continuous (y = 0.8668 × -0.1354 r^2 = 0.78, $P < 0.0001$).

respectively for (a) Aorta intermittent *vs* PA intermittent, (b) PA intermittent *vs* PA continuous, (c) PA intermittent *vs* Aorta continuous:

Δ_2: a: y = 0.845 × +0.2555 r^2 = 0.74, $P < 0.0001$); b: y = 0.7838 × +0.2935 r^2 = 0.79, $P < 0.0001$); c: y = 0.869 × +0.05568 r^2 = 0.76, $P < 0.0001$).

Δ_3: a: y = 0.7803 × -0.6214 r^2 = 0.79, $P < 0.0001$); b: y = 0.8039 × -0.1866 r^2 = 0.85, $P < 0.0001$); c: y = 0.8381 × -0.3396 r^2 = 0.81, $P < 0.0001$);

Δ_4: a: y = 0.7284 × +0.1171 r^2 = 0.62, $P < 0.0001$); b: y = 0.925 × -0.2409 r^2 = 0.75, $P < 0.0001$); c: y = 0.8564 × +0.07373 r^2 = 0.78, $P < 0.0001$);

Δ_5: a: (y = 0.7763 × +0.1443 r^2 = 0.68, $P < 0.0001$); b: (y = 0.9105 × +0.2979 r^2 = 0.78, $P < 0.0001$); c: (y = 0.8556 × +0.177 r^2 = 0.79, $P < 0.0001$).

Discussion

The performance of the PiCCO System was excellent either when used for transpulmonary thermodilution intermittent technique or as pulse contour CO monitoring, and accuracy and precision were similar to those previously observed.[1,3–6] The Vigilance system for PA continuous monitoring showed a level of agreement and precision similar to those previously reported in the literature.[1,7–10] 2SD of bias tended to increase (i.e., precision decreased) after the first reperfusion and during the second cross-clamping phases (Rep 1 and at Lung 2 phases) but the difference was not statistically significant.

The analysis of studies comparing different methods is cumbersome when the accuracy and precision of the reference method is uncertain, because of the inability to discriminate between errors induced by the technique under investigation and errors related to the reference method. Our results indicate that the transpulmonary thermodilution technique and the pulmonary artery thermodilution method can be used interchangeably, even if the validation of methods prior to their use as references is advisable to define and exclude technical and operator induced measurement errors.

Few studies so far evaluated the performance of the PiCCO system for both continuous and bolus thermodilution as compared to a third technique.[1,3–6] In the population studied, no clinically relevant disagreement between techniques was observed for the majority of measurements. We analyzed the data as bias and 2SD. Clinicians can expect Aorta intermittent measurements to be within approximately ± 1.5 $L \cdot min^{-1}$ or less of PA intermittent 95% of the time in these particular clinical conditions.

In conclusion, we confirm that Aorta intermittent, Aorta Continuous and PA continuous measurements agree with the current clinical standard PA intermittent CO measurement. Continuous CO can be monitored either by pulse contour analysis or by PAC in patients during lung transplant surgery.

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