Overestimation of low cardiac output measured by thermodilution

J. P. Tournadre, D. Chassard and R. Muchada

Summary
We have investigated the influence of a cold water bolus (CWB) injection on overestimation of cardiac output (CO) in low CO states in anaesthetized dogs. CO was measured using three methods: (1) thermodilution (TD), (2) electromagnetic (EM) flow meter placed on the pulmonary artery and (3) transoesophageal echo-Doppler (OD) placed on the descending aorta. Measurements of CO were obtained before (steady state) and after induction of a low CO state with thiopentone 5 mg kg\textsuperscript{-1} i.v. After CWB injection, mean CO measured by EM and OD increased by 26% and 27%, respectively \((P < 0.05)\) during steady state, and by 85% and 75% \((P < 0.05)\) during the low CO state. This transient increase was produced by an increase in stroke volume, while heart rate did not change. Frank Starling’s law may explain this variation by a sudden increase in preload produced by CWB injection. These results indicate that thermodilution overestimated CO during low CO states when CWB injection was used. (Br. J. Anaesth. 1997; 79: 514–516).

Key words

Several methods have been used to measure cardiac output (CO) in humans. The thermodilution method (TD), described initially by Fegler,\textsuperscript{1} has been used for 20 yr since its development with the catheter described by Swan and Ganz.\textsuperscript{2} Several studies have demonstrated good overall agreement between TD and other methods estimating CO. However, several studies have shown that the TD method overestimates CO in the low range.\textsuperscript{3–5} This was explained by heat loss during measurement.\textsuperscript{3}

In our clinical anaesthetic practice, we observed in patients in whom CO was recorded simultaneously by TD and transoesophageal echo-Doppler (OD), an increase in CO measured by OD, immediately after injection of an iced water bolus. Therefore, this study was designed to investigate the effect of an iced temperature injectate on CO measured by TD, OD and by an electromagnetic (EM) flow meter placed on the pulmonary artery of anaesthetized dogs during normal and low CO states.

Materials and methods
After approval from our institutional Animal and Care Committee, six dogs (weight 18 (SD 5) kg) were anaesthetized with thiopentone 5 mg kg\textsuperscript{-1}, vecuronium 0.08 mg kg\textsuperscript{-1} and phenoperidine 0.015 mg kg\textsuperscript{-1}. The trachea was intubated and the lungs ventilated mechanically (Bird Mark 8, Products Corporation, Palm Springs, CA, USA) at an \(P_{\text{ET}}\) of 1, ventilatory frequency 20 bpm and tidal volume 10 ml kg\textsuperscript{-1}. Anaesthesia was maintained with phenoperidine 0.02 mg kg\textsuperscript{-1} h\textsuperscript{-1} and vecuronium 0.04 mg kg h\textsuperscript{-1}.

A Swan–Ganz catheter was inserted into the pulmonary artery via the right external jugular vein under x-ray control (7F diameter, Edwards Laboratories, Irvine, CA, USA). Thermodilution CO was measured using triplicate injections of 5 ml of 5% dextrose at \(2^\circ\text{C}\) (cold water bolus (CWB)) during end-expiration.

A 12-mm EM flow probe (In Vivo Metric, Healsburg, CA, USA) was placed around the pulmonary trunk via a left-sided thoracotomy. Pulmonary blood flow (PBF) was measured continuously with an EM blood flow meter (FM 501, Carolina Medical Electronics, King, NC, USA).

A special echo-Doppler probe, described previously,\textsuperscript{6} was used to measure aortic blood flow (ABF) using a transoesophageal echo-Doppler (OD) ultrasound method (Dynemo 3000, Sometec, Paris, France). ABF, PBF, ECG and heart rate (HR) were recorded simultaneously and continuously before, during and after CWB injection.

Measurements were made with both continuous methods (PBF, ABF) after 15 min of steady state following surgical preparations and were repeated after injection of thiopentone 5 mg kg\textsuperscript{-1} i.v. to obtain a low CO state.

Instantaneous blood flow variations were measured by EM flow meter and OD methods during CWB injection. These measures were integrated by planimetry to calculate the average stroke volume (SV) on seven cardiac cycles. These

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were identical to cycles sampled during inscription of the TD curve. Data are expressed as mean (SD) and were compared by Wilcoxon's test between the two states and by one-way analysis of variance (ANOVA) for haemodynamic data obtained by the different methods. Results were considered statistically significant at *P*<0.05.

**Results**

Results are summarized in table 1.

In all cases injection of thiopentone 5 mg kg⁻¹ produced a decrease in HR and SV. For all measurement techniques there was a decline in CO after thiopentone (*P*<0.05). HR remained unchanged throughout the course of injection of the CWB using the TD method. CO values obtained by TD were higher than those obtained by the two other methods (*P*<0.05). The differences recorded with the other methods were more important during low CO states.

![Figure 1](image)

**Figure 1** Effect of a cold water bolus (iced temperature) injection on stroke volume measured in the descending aorta and pulmonary artery in a dog with a low cardiac output.

**Table 1** Mean (SD) pulmonary blood flow (PBF), aortic blood flow (ABF) and cardiac output (CO) (measured by the thermodilution method) at steady state and after injection of thiopentone 5 mg kg⁻¹ (low CO state). *P*<0.05 vs before injection of the cold water bolus (CWB); †*P*<0.05 vs steady state

<table>
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<tr>
<th></th>
<th>Steady state</th>
<th>Low CO state</th>
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<tr>
<td>HR (beat min⁻¹)</td>
<td>137 (22)</td>
<td>120 (19)†</td>
</tr>
<tr>
<td>PBF (ml min⁻¹)</td>
<td>1583 (253)</td>
<td>1086 (297)†</td>
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<tr>
<td>Before CWB</td>
<td>1988 (430)*</td>
<td>2035 (378)*</td>
</tr>
<tr>
<td>After CWB</td>
<td>1382 (294)</td>
<td>947 (287)†</td>
</tr>
<tr>
<td>ABF (ml min⁻¹)</td>
<td>1722 (391)*</td>
<td>1682 (281)*</td>
</tr>
<tr>
<td>OD (ml min⁻¹)</td>
<td>2067 (466)</td>
<td>1847 (315)†</td>
</tr>
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</table>

CWB injection induced significant increases in PBF and ABF (*P*<0.05) (fig. 1). These increases were found in the two states but were proportionally more important during the low CO state.

Differences between the results of TD and those of pulmonary flow meter and aortic OD obtained after injection of CWB were not statistically significant. After CWB injection, CO, measured using EM and OD, increased by 26% and 27%, respectively, during steady state (*P*<0.05), and by 85% and 75% during low CO state (*P*<0.05).

**Discussion**

Data from previous studies showed that the TD method overestimated measurement of CO in patients with low CO states. This could explain the weak correlation between measurements by TD and other methods, such as the Fick method, during low CO conditions. Data from previous studies found a good correlation between TD and other methods under these conditions. Our study did not evaluate this phenomenon during high output states as previous studies found a good correlation between TD and other methods under these conditions.

In the course of the two CO states evaluated in our study (steady and low CO state), TD overestimated CO values compared with EM flow meter and OD (note that these two methods are performed in two different anatomical sites, the pulmonary artery and descending aorta, respectively). This was more significant in the presence of a low CO state. ABF was lower by 13–17% compared with PBF under all conditions. This can be explained by the fact that measurements at this level of the aorta do not take into account blood flow to the upper extremities, head, bronchial tubes and cardiac areas.

The increase in aortic flow was lower than that of pulmonary flow (75% and 85%, respectively, *P*<0.05) during the low CO state. This may reflect a septal shift in response to substantial increases in right ventricular end-diastolic volume that might transiently decrease left ventricular end-diastolic volume because of the restrictive effects of the pericardium. Thus aortic flow would be lower than pulmonary flow.

We found that CO, when measured by EM or OD, increased in all cases after administration of CWB injection. This transient increase was produced by an increase in SV over several cardiac cycles, while HR remained unchanged. During rapid injection of CWB into the right atrium, a transient increase in CO could increase SV by increasing preload. Frank Starling's law may explain this variation by a sudden increase in preload after CWB injection. This also explains why the phenomenon is more significant at low compared with normal CO states.

The increase in SV after injection of the CWB occurred without a change in HR. This may have resulted from the use of thiopentone. Its effect on the autonomic nervous system prevents the sinus bradycardia caused by CWB injection described by Harris and colleagues and Nishikawa and Dohi under similar conditions. Because CO = SV × HR, a...
decrease in HR may balance the increase in SV. This may explain the good correlation between CO determination with TD and other methods, even in low CO states. However, when HR is unchanged, especially in low CO states, the transient increase in SV could be responsible for discrepancies between TD and other methods of measurement of CO.

With the TD method, CO output is measured in the course of the first cardiac cycles after injection of the CWB. We found that SV increased after injection of the CWB compared with basal values. Thus the calculated output is overestimated. It is remarkable to note that when we measured outputs by EM and OD after CWB injection, we found values close to those obtained by TD during steady state or low CO. One can therefore estimate by EM and OD after CWB injection, we found remarkable to note that when we measured outputs

We used iced temperature injectates rather than room temperature injectates, as first described by Swan and Ganz. To eliminate the influence of temperature induced by cardiac reflexes, a study should be performed under the same conditions.

Accurate measurement of CO is an important goal in the management of anaesthetized or critically ill patients with compromised cardiac function. Our findings showed that thermodilution overestimated CO during low CO states when iced temperature injectates were used. This suggests that other non-invasive methods are necessary to determine CO in patients with low output states.

Acknowledgements

We thank Dr Fraser and Ilmars Lidums (Adelaide, Australia) for help in the preparation of the manuscript.

References