Comparison of pulmonary artery and aortic transpulmonary thermodilution for monitoring of cardiac output in patients with severe heart failure: Validation of a novel method*

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Objective: Hemodynamic monitoring with the pulmonary artery catheter is frequently used in the management of severe heart failure. For measurement of cardiac output (CO), transpulmonary thermodilution (TPTD) has recently been adopted into clinical practice as an alternative to pulmonary artery thermodilution. However, no data have been published on the comparability of the two methods in patients with severely reduced left ventricular function. Our objective was to evaluate the correlation between these two methods of CO determination in patients with severe left ventricular dysfunction.

Design: Prospective observational clinical study.

Setting: Cardiological intermediate care unit and medical intensive care unit of a university hospital.

Patients: Twenty-nine patients with left ventricular ejection fraction <35% and symptoms of heart failure (New York Heart Association class III–IV).

Despite ongoing debate regarding its safety and efficacy (1–10), hemodynamic monitoring with the pulmonary artery catheter (PAC) is frequently called for in the management of severe heart failure (11–13). Alternative methods of hemodynamic monitoring are therefore being evaluated (14). Transpulmonary thermodilution (TPTD) is now available for assessment of cardiac output (CO), stroke volume, and systemic vascular resistance without performing pulmonary artery catheterization (15). Previous clinical studies demonstrated good agreement between CO values measured by these two methods in patients during lung (16) or liver transplantation (17), after cardiac surgery (18), with burns (19), with critical illness (20), and even after rapid preload changes (21). However, no data have been published on the comparability of the two methods in patients with severely reduced left ventricular function. We therefore investigated the agreement between pulmonary artery thermodilution and TPTD results of CO measurement in patients with severe left ventricular systolic dysfunction and symptoms of heart failure.

Measurements and Main Results: The two methods of intermittent CO measurement were compared by simultaneously recording the results of pulmonary artery thermodilution and TPTD after injection of a cold saline bolus. Measurements were performed when clinically necessary. A total of 325 data pairs were analyzed. Mean CO of both methods was 4.4 L/min with a bias of 0.45 L/min (2 ± 1.20 L/min), resulting in a percentage error of 27.3%.

Conclusion: In patients with severely impaired left ventricular function, measurement of CO by TPTD provides valid results. (Crit Care Med 2009; 37:??–??)

Key Words: cardiac output; thermodilution; catheterization; Swan-Ganz; ventricular dysfunction; left; heart failure; congestive failure.

Materials and Methods

Study Design and Participants. This prospective observational study was approved by the institutional Ethical Committee. Written informed consent was obtained from patients or their next of kin. All patients referred to the intensive care or the cardiological intermediate care units of our university hospital for symptomatic heart failure (New York Heart Association class III–IV) were included in the study if they demonstrated severe left ventricular systolic dysfunction (left-ventricular ejection fraction <35%), and if invasive hemodynamic monitoring was considered by the attending physician to be necessary. Left-ventricular ejection fraction was evaluated by echocardiography using Simpson’s rule. Exclusion criteria were severe valvular disease, conditions precluding safe catheterization of the femoral artery (aortic aneurysm, severe peripheral arterial occlusive disease, femoral artery bypass graft, infection of the inguinal skin), coagulopathy (aPTT >50 sec, INR >1.5, platelets <50 Gpt/L), or age <18 yrs.

Cardiac Output Measurement. A 7.5-F PAC (VoLEF right-heart thermodilution catheter, Pulsion Medical Systems, Munich, Germany) was introduced via internal jugular or subclavian vein and a 5-P thermistor-tipped aortic catheter (Pulsiocath PV2015L20, Pulsion Medical Systems) via femoral artery. To facilitate simultaneous measurement with one bolus injection, CO values were computed with a PICCO Plus monitor for TPTD and a VoLEF monitor (an extension to the PICCO Plus for pulmonary artery thermodilution; both Pulsion Medical Systems), both using the modified Stewart-Hamilton equation (22). For measurements, 15 mL of cold (≤8°C) normal saline was injected via the proximal lumen of the PAC by the physician on duty at random points of the respiratory cycle. Injectate volume was increased to 20 mL for patients with a body surface area >2 m². For each method, data from three consecutive injections were averaged to obtain a pair of CO values. After
baseline, further measurements were performed at the attending physician’s discretion after changes in medication or deterioration of clinical status.

Statistical Analysis. To assess agreement between the two methods of measurement, Bland–Altman plots were used together with mean bias and limits of agreement (mean bias ± 2 SD) (23) as well as the percentage error (2 SD of bias/mean CO of both methods) (24). These statistics were calculated for the entire dataset and separately—to eliminate bias from repeated measurements and to specifically test agreement in the low range of CO—for subsets containing only the initial measurement, the minimal COpa or the maximal COpa of each patient.

As proposed by Critchley and Critchley (24) for the comparison of CO measurement techniques, a percentage error of 30% or less was defined to signal acceptable agreement.

RESULTS
Between October 2003 and May 2005, 185 patients admitted for severe heart failure were screened for eligibility and 29 were enrolled in the study. Baseline data and underlying diseases along with baseline hemodynamic parameters obtained by PAC are presented in Table 1.

Table 1. Baseline patient characteristics and underlying diseases; baseline hemodynamic parameters obtained by pulmonary artery catheter

<table>
<thead>
<tr>
<th>Sex, n (%)</th>
<th>Male</th>
<th>Female</th>
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<tbody>
<tr>
<td></td>
<td>19 (66)</td>
<td>10 (34)</td>
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<tr>
<td>Age, mean ± sd (yrs)</td>
<td>60 ± 11</td>
<td>60 ± 11</td>
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<tr>
<td>Ejection fraction, mean ± sd (%)</td>
<td>22 ± 6</td>
<td>22 ± 6</td>
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<tr>
<td>Mechanically ventilated, n (%)</td>
<td>6 (21)</td>
<td>6 (21)</td>
</tr>
<tr>
<td>Underlying heart disease, n (%)</td>
<td>16 (55)</td>
<td>11 (38)</td>
</tr>
<tr>
<td>Ischemic cardiomyopathy</td>
<td>11 (38)</td>
<td>11 (38)</td>
</tr>
<tr>
<td>Dilated cardiomyopathy</td>
<td>1 (3.5)</td>
<td>1 (3.5)</td>
</tr>
<tr>
<td>Toxic cardiomyopathy</td>
<td>1 (3.5)</td>
<td>1 (3.5)</td>
</tr>
<tr>
<td>Hypertensive heart disease</td>
<td>9 (31)</td>
<td>9 (31)</td>
</tr>
<tr>
<td>Stage of heart failure, n (%)</td>
<td>20 (69)</td>
<td>9 (31)</td>
</tr>
<tr>
<td>New York Heart Association class III</td>
<td>20 (69)</td>
<td>9 (31)</td>
</tr>
<tr>
<td>New York Heart Association class IV</td>
<td>9 (31)</td>
<td>9 (31)</td>
</tr>
<tr>
<td>Baseline hemodynamic parameters (measured by pulmonary artery catheter), mean ± sd</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cardiac output (COpa) (L/min)</td>
<td>4.0 ± 1.3</td>
<td>4.0 ± 1.3</td>
</tr>
<tr>
<td>Cardiac index (CIpa) (L/min/m²)</td>
<td>2.1 ± 0.7</td>
<td>2.1 ± 0.7</td>
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<tr>
<td>Central venous pressure (mm Hg)</td>
<td>12 ± 6</td>
<td>12 ± 6</td>
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<tr>
<td>Systolic pulmonary artery pressure (mm Hg)</td>
<td>49 ± 15</td>
<td>49 ± 15</td>
</tr>
<tr>
<td>Diastolic pulmonary artery pressure (mm Hg)</td>
<td>26 ± 10</td>
<td>26 ± 10</td>
</tr>
<tr>
<td>Mean pulmonary artery pressure (mm Hg)</td>
<td>34 ± 12</td>
<td>34 ± 12</td>
</tr>
<tr>
<td>Pulmonary capillary wedge pressure (mm Hg)</td>
<td>17 ± 9</td>
<td>17 ± 9</td>
</tr>
<tr>
<td>Systemic vascular resistance index (dyne*cm²/m²)</td>
<td>2855 ± 824</td>
<td>2855 ± 824</td>
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COpa, cardiac output measured by pulmonary artery thermodilution.

Figure 1. Scatter plot of cardiac output measured by pulmonary artery thermodilution (COpa) vs. transpulmonary thermodilution (COtp). (A) all measurements (n = 325), (B) each patient’s initial measurement (n = 29), (C) each patient’s minimal COpa and corresponding COtp (n = 29), and (D) each patient’s maximal COpa and corresponding COtp (n = 29).

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with this method in various groups of patients (14, 16–21, 25–28). However, the present study is the first that compares both methods in patients with severe left ventricular dysfunction and heart failure.

In the present study, the level of agreement between CO values measured by TPTD and those measured by PAC is within the range of the above-mentioned previous studies and fulfils the criteria of acceptance as published by Critchley and Critchley (24). This agreement could be confirmed even in the analysis of the individual patients’ minimal CO, which corresponded to an average cardiac index of only 2.0 ± 0.7 L/min.

Compared with PAC measurement, TPTD resulted in a consistent but small overestimation of CO, which had likewise been found by the majority of other authors (16–20).

This difference has been ascribed to a transient reduction in heart rate by cold injection (29, 30). In addition, TPTD is assumed to be more susceptible to unaccounted loss of thermal indicator than is pulmonary artery thermodilution (22), although the significance of this mechanism may be arguable (31). However, the difference between COtp and COpa has been found by most authors to be tolerable for clinical use.

In 14 measurements, only COpa, but not COtp, could be determined. It is conceivable that the transpulmonary transit time of the indicator bolus had been excessively long owing to reduced left ventricular function or to intraventricular recirculation of the indicator bolus as a result of ventricular dilation. Detailed analysis did indeed reveal a significant

Table 2. Results of Bland–Altman analysis and mean cardiac index (CI)

<table>
<thead>
<tr>
<th></th>
<th>CI (Mean ± SD, L/min/m²)</th>
<th>Mean CO (L/min)</th>
<th>Bias COtp–COpa (L/min)</th>
<th>2 SD (L/min)</th>
<th>Error (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>All measurements (n = 325)</td>
<td>2.3 ± 0.6</td>
<td>4.4</td>
<td>0.45</td>
<td>1.20</td>
<td>27.3</td>
</tr>
<tr>
<td>Initial measurement (n = 29)</td>
<td>2.3 ± 0.7</td>
<td>4.3</td>
<td>0.38</td>
<td>1.16</td>
<td>26.9</td>
</tr>
<tr>
<td>Minimal COpa (n = 29)</td>
<td>2.0 ± 0.7</td>
<td>3.8</td>
<td>0.39</td>
<td>1.13</td>
<td>29.8</td>
</tr>
<tr>
<td>Maximal COpa (n = 29)</td>
<td>2.9 ± 0.7</td>
<td>5.5</td>
<td>0.58</td>
<td>1.51</td>
<td>27.4</td>
</tr>
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</table>

CO, cardiac output; COpa, CO measured by pulmonary artery thermodilution; COtp, CO measured by TPTD.

Figure 2. Bland–Altman plot of cardiac output measurements by pulmonary artery thermodilution (COpa) and by transpulmonary thermodilution (COtp). Solid lines indicate mean bias, dotted lines show 2 SD limits of agreement. (A) all measurements (n = 325), (B) each patient’s initial measurement (n = 29), (C) each patient’s minimal COpa and corresponding COtp (n = 29), and (D) each patient’s maximal COpa and corresponding COtp (n = 29).
association of missing CO<sub>Tp</sub> values with longer transit times and lower CO<sub>Tp</sub>. However, prediction of failure of TPTD to yield results did not seem possible because TPTD results could still be obtained in the majority of even the very low CO values. Altogether, missing values of CO<sub>Tp</sub> appeared in <5% of measurements and, accordingly, are of minor importance.

A Less Invasive Alternative to Pulmonary Artery Catheterization. Several studies had cast doubt on the safety of PAC use (1, 3, 32–34). More recently, increased mortality attributable to PAC use could not be verified but neither have benefits from its use been demonstrated (6, 7, 9, 10).

TPTD requires a central venous catheter, but in many patients with severe heart failure who require invasive hemodynamic monitoring, a central venous catheter would in any case be obligatory. Although it is a common practice to use superior vena cava access, recent data suggest that a femoral venous catheter, which may be inserted with lower risk in certain patients, may be used instead (35). Insertion of the thermistor-tipped catheter into a central artery, however, is still a prerequisite to TPTD and cannot be substituted by a peripheral arterial catheter (36).

In addition to CO measurement, assessment of volume status is a major concern of hemodynamic monitoring. TPTD provides parameters for volume-status evaluation that under certain circumstances rival pulmonary artery occlusion pressure measured by PAC (37–40). Although it has not been proven that TPTD produces fewer complications or greater benefit than PAC use, many authors on the whole believe that TPTD is less invasive. The present study was clearly not designed to address safety issues.

Limitations. Accuracy of pulmonary artery thermodilution measurements may have been enhanced if the single cold injections had been evenly distributed throughout the ventilatory cycle (41, 42) or timed at a specific point in the respiratory cycle (14). However, this seemed hardly feasible in these predominantly spontaneously breathing patients with manifest heart failure and severe left ventricular systolic dysfunction.

Follow-up measurements in individual patients were performed according to clinical necessity only. Repeated measurements after defined interventions would have added interesting information but were beyond the scope of this observational study.

CONCLUSIONS

This study demonstrates that CO determination by TPTD is reliable and agrees well with the results from pulmonary artery thermodilution in patients with severe left ventricular dysfunction. Results from previous studies with other severely ill patients are confirmed and extended to this particular group for whom the potentially less invasive monitoring technique may represent a welcome alternative.

ACKNOWLEDGMENTS

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