Work in progress report - Cardiac general

Transpulmonary versus continuous thermodilution cardiac output after valvular and coronary artery surgery

Rose-Marieke B.G.E. Breukers¹, A.B. Johan Groeneveldb,*, Rob B.P. de Wildeb, Jos R.C. Jansenb

¹Department of Intensive Care and Institute for Cardiovascular Research, VU University Medical Center, Amsterdam, The Netherlands
²Department of Intensive Care, Leiden University Medical Center, Leiden, The Netherlands

Received 5 February 2009; received in revised form 30 March 2009; accepted 31 March 2009

Abstract

Residual left-sided valvular insufficiencies after valvular surgery may confound transpulmonary thermodilution cardiac output (COtp). We compared the technique with the continuous right-sided thermodilution technique (CCO) after valvular surgery (n=8) and coronary artery surgery (n=8). Patients with pulmonary and femoral artery catheters in the intensive care unit (ICU) were included. After valvular surgery, there was minimal aortic insufficiency in four patients and minimal to moderate mitral valve insufficiency in six. Five fluid loading steps (250 ml) were done in each patient. CCO and COtp were measured prior to and 15 min after each step. The cardiac output was lower after valvular than coronary artery surgery but responses to fluid loading steps were similar among surgery types and techniques. After valvular and coronary artery surgery, cardiac output was lower prior to responses than in non-responses to fluids, by either technique. After valvular surgery, COtp and CCO correlated (r=0.64, P<0.001, n=48) but fluid-induced changes did not. After coronary artery surgery, COtp and CCO correlated (r=0.81, P<0.001) and changes also did (r=0.55, P<0.001). At fluid-induced CCO increases >20%, the r for changes in cardiac output measured by both techniques was similar after valvular and coronary artery surgery. Thus, COtp and CCO were of similar value in predicting and monitoring fluid responses after both surgery types. This argues against left-sided valvular insufficiencies confounding COtp.

Keywords: Cardiac function; Heart valve; Hemodynamics; Mitral valve repair; Shock (circulatory)

1. Introduction

Fluid loading is a common therapeutic intervention after cardiac surgery and accurate cardiac output measurements are necessary to monitor fluid responses. The effect of cardiac output monitoring techniques on judging responses has rarely been addressed [1].

The transpulmonary and primarily left-sided thermodilution technique for cardiac output measurements (COtp) has been used to judge fluid responses [1]. However, the technique is sensitive to thermal loss, re-circulation or forward/backward movement of the thermal indicator, for instance in the presence of left-sided valvular insufficiencies and regurgitant blood flows [2–4]. Hillis et al. [2] showed that transpulmonary dye-dilution cardiac output underestimates right-sided thermodilation cardiac output in the presence of aortic and/or mitral valve insufficiency. In contrast, the COtp has been compared right-sided measurements and results appeared interchangeable, prior to or after coronary artery surgery and only rarely combined with valvular surgery [1, 3, 5, 6].

The continuous right-sided thermodilution technique for cardiac output measurements in the pulmonary artery (CCO) could be less suitable for monitoring fluid responses, because of relatively long response times and, as for the bolus technique, in the presence, perhaps, of tricuspid insufficiencies [1, 7]. Nevertheless, the CCO has been claimed to be an acceptable alternative to the bolus thermodilution in coronary artery surgery patients, sometimes combined with valvular surgery [1, 6, 8–13]. Also, in patients after valvular surgery, the techniques appeared comparable [10]. In the single comparison of COtp and CCO after fluid loading, Hofer et al. [1] found, prior to coronary artery surgery, that techniques were interchangeable. This does not exclude a difference after surgery when hemodynamic stability may be less, however [6, 10–13].

In the current study we evaluated COtp and CCO and their response to fluid loading separately after coronary artery and valvular surgery. The null hypothesis was that the value in predicting and monitoring fluid responses by COtp as compared to CCO does not differ between valvular and coronary artery surgery patients, in spite of residual left-sided valvular insufficiencies in the former.

2. Patients and methods

2.1. Patients

Eight consecutive, mechanically ventilated patients undergoing elective valvular repair or replacement, and
eight after coronary artery surgery only, < 85 years of age, were included 2 h after arrival at the intensive care unit (ICU). Other inclusion criteria were a pulmonary artery occlusion pressure (PAOP) < 18 mmHg and central venous pressure (CVP) < 13 mmHg and a CCO < 8.0 l/min. The exclusion criteria were a life expectancy < 24 h, surgical bleeding 100 ml/h, clinical evidence for pulmonary edema, known aneurysms of thoracic or abdominal aorta and atrial fibrillation. All patients underwent hypothermic cardiopulmonary bypass. None of the patients had visible V waves on their CVP curve, arguing against hemodynamically significant tricuspid insufficiency. The Local Ethics Committee approved the study protocol and written informed consent was obtained preoperatively. In the six-month period of inclusion for this study, there were 21 eligible patients who had given informed consent; we excluded three coronary artery surgery patients because of premature discontinuation of fluid loading following fear of overloading, and two valvular surgery patients, before start of study, needing a re-thoracotomy because of bleeding and tamponade. Upon arrival in the ICU, patients were sedated. Patients were mechanically ventilated by volume-controlled ventilation with tidal volumes not exceeding 10 ml/kg and a positive end-expiratory pressure (PEEP) of 5 (15 patients) or 7 cm H2O (1 valvular surgery patient). Ventilation frequency was 10–13 breaths/min to maintain the arterial PCO2 in the normal range. Ventilator settings were not changed during the study. Doses of sedative and vasoactive agents were unaltered during the study in each patient. In sequential atrioventricular pacemaker-dependent patients after surgery, the pacemaker frequency was set at about 80 beats/min.

2.2. Measurements

A pulmonary artery catheter (8.5-Fr, CCO/VIP, Edwards Life Sciences, Irvine, CA, USA) had been preoperatively inserted via the internal jugular vein. This allowed CCO measurements via warm pulses by a thermal filament and transpulmonary pressure occlusion technique (PiCCO, Pulsion Medical Systems, Munich, Germany) and referenced to atmospheric pressure after calibrating and zeroing, at the midchest level, i.e. mean arterial pressure (MAP) and body temperature. In each patient, five consecutive fluid loading steps were done, by infusing 250 ml of colloid solution (Voluven®, Fresenius, Germany) in 15 min. Thirty minutes after start of each fluid loading step (and 15 min after completion), cardiac output was measured by the two methods, CCO preceding C0tp. For the latter, three injections of 20 ml of cold (<8 °C) normal saline via the CVP port of the pulmonary artery catheter were given and values were averaged. A transesophageal echocardiogram was obtained in valvular surgery patients after surgery and before fluid loading, and compared with preoperative echocardiograms (ECHOpac and Vivid 7, GE Healthcare, Milwaukee, WI, USA).

2.4. Statistical analysis

We expected cardiac output increases in 30–50% of the 40 steps. Responses and non-responses among steps for either technique were defined by an increase in cardiac output of >5% vs. ≤ 5% and ≥ 10% vs. <10%, per fluid loading step, to account for the volumes administered and the literature on fluid responsiveness. Generalized estimating equations, taking repeated measurements in the same patients into account, were used to evaluate changes in time, to evaluate values to predict and monitor fluid responses, and to study potential differences between surgery types and techniques herein. Partial correlation coefficients for absolute values and fluid-induced changes, with patient number as covariate to account for repeated measurements in the same patients, were calculated and compared after Z transformation. Bland–Altman analysis was used to calculate bias, precision (S.D.) and limits of agreement (bias ± 2 S.D.). Exact two-sided \( P > 0.001 \) are given and considered statistically significant when \(< 0.05 \) (ns = not significant). Data are summarized as mean ± standard deviation (S.D.), since they were normally distributed.

3. Results

3.1. Patient characteristics

In both groups mean age, gender and BMI were similar, but the EuroSCORE was higher in valvular surgery (Table 1). Of the valvular surgery patients, four had prior mitral insufficiency, one patient had mitral insufficiency and stenosis, one patient had mitral and aortic insufficiency and two patients had aortic stenosis. After surgery, six patients had some tricuspid insufficiency (grading from minimum to grade 2 out of 4) on echocardiography. In contrast, there was some residual aortic insufficiency (grading from minimum to grade 2 out of 4) in four patients and mitral valve insufficiency (grading from minimum to grade 2 out of 4) in six patients. Four valvular surgery and one coronary artery surgery patient were pacemaker-dependent.
Table 1
Patient characteristics

<table>
<thead>
<tr>
<th>Age, years</th>
<th>Gender, ♂/♀</th>
<th>BMI, kg/m²</th>
<th>Surgical procedure</th>
<th>Vasoactive drugs</th>
<th>EuroSCORE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Valvular surgery</td>
<td>65±12</td>
<td>6/2</td>
<td>26±4</td>
<td>MVP (5), MVR (1), AVP (2), AVR (1), TVP (1), CABG (2), Bentall-procedure (1), aortic re-construction (1)</td>
<td>Dobu (3), dopa (1), nor (1), enoximone (2)</td>
</tr>
<tr>
<td>Coronary artery surgery</td>
<td>68±9</td>
<td>6/2</td>
<td>29±3</td>
<td>CABG (2–5x)</td>
<td>Dobu (3), dopa (4), enoximone (1)</td>
</tr>
</tbody>
</table>

MVP, mitral valve plasty; MVR, mitral valve replacement; AVP, aortic valve plasty; AVR, aortic valve replacement; TVP, tricuspid valve plasty; CABG, coronary artery bypass graft; Dobu, dobutamine; Dopa, dopamine; Nor, nor-epinephrine. Mean±s.D., or number, where appropriate.

3.2. Effect of fluid loading

Table 2 shows hemodynamics prior to and after the last fluid loading step. Table 3 shows that, for the 40 fluid loading steps involved in this study, the cardiac output was indeed lower after valvular than coronary artery surgery (P=0.049 for COTp and P=0.015 for CCO). In responses, the baseline cardiac output was generally lower than in non-responses but increases were similar, regardless of surgery types and techniques. Fluid responses/non-responses (>5%, ≤5%) were fairly concordant among cardiac output measurement techniques (62%, ns, for valvular surgery and 68%, P=0.010 for coronary artery surgery).

3.3. Relation between COs

Prior to, during and after fluid loading after coronary artery and valvular surgery, COTp and CCO correlated at r=0.81 (P<0.001, n=48) and r=0.64 (P<0.001, n=48), respectively. After valvular surgery, fluid-induced changes of COTp and CCO did not correlate (r=0.26, ns, n=40), whereas fluid-induced changes of COtp and CCO correlated after coronary artery surgery (r=0.55, P<0.001, n=40). When arbitrarily selecting observations (n=34) at CCO increases of <20%, the correlation was 0.75 (P<0.001) for absolute values and 0.38 (P=0.030) for fluid-induced changes after valvular surgery. When arbitrarily selecting observations (n=35) with increases in CCO of <20%, the r was 0.84 (P<0.001) for absolute values and 0.58 (P<0.001) for fluid-induced changes after coronary artery surgery (ns vs. r after valvular surgery).

3.4. Bland–Altman analysis (Fig. 1)

After valvular surgery, the bias of the COtp as compared to CCO was 0.94 l/min (precision 0.74 l/min), so that the limits of agreement were 0.54–2.42 l/min (2 S.D./mean cardiac output of 5.8 l/min equals 25%). After coronary artery surgery, the bias was 1.00 l/min (precision 0.94 l/min), so that the limits of agreement were 0.88–2.88 l/min (2 S.D./mean cardiac output of 6.9 l/min equals 27%).

4. Discussion

This study suggests that, even though cardiac output is lower after valvular than coronary artery surgery, the overestimation of CCO by COtp is comparable, and COtp and CCO are of similar value in predicting and monitoring (relatively small) fluid responses after both surgery types. This argues against residual left-sided valvular insufficiency confounding transpulmonary thermodilution.

We chose to compare COtp and CCO, since both may be less affected by respiratory variations of stroke volume in mechanically ventilated patients than the bolus thermodilution technique. The precision and thus limits of agreement of cardiac output measurements, which were similar after valvular and coronary artery surgery, were within 30%, the value proposed to be associated with clinically acceptable errors [15]. The positive bias of COtp vs. pulmonary artery thermodilution cardiac output, often observed before, can be attributed to thermal loss [1, 3–6]. The comparability of the bias irrespective of surgery types argues against thermal loss induced by residual valvular insufficiencies, but we cannot exclude that forward/backward flows had partly masked greater thermal loss and higher bias, expected at lower cardiac output [4], after valvular surgery. Even though increases in cardiac output with fluid loading were comparable among techniques, irrespective of surgery type, there was a tendency for underestimation of relatively high (fluid-induced changes

MAP, mean arterial pressure; GEDV, global end-diastolic volume; COtp, transpulmonary cardiac output; CCO, continuous cardiac output; temp, body temperature. For after vs. before: **P=0.002, ***P<0.001 (and P=0.040 vs. valvular surgery), ****P=0.002, *****P=0.009 (and P=0.024 vs. valvular surgery). Mean±s.D., or number, where appropriate.
Coronary artery surgery
the dashed line the limits of agreement
CCO, l
in
Fig. 1. Bland–Altman plot of difference between transpulmonary (COTp) and continuous cardiac output (CCO) vs. their mean; (a) after valvular surgery and (b) after coronary artery surgery. The solid line indicates the bias and the dashed line the limits of agreement (bias ± 2 S.D.).

Fig. 1. Bland–Altman plot of difference between transpulmonary (COTp) and continuous cardiac output (CCO) vs. their mean; (a) after valvular surgery and (b) after coronary artery surgery. The solid line indicates the bias and the dashed line the limits of agreement (bias ± 2 S.D.).

Table 3
Responses (R) and non-responses (NR) among fluid loading steps, defined by 5% and ≤ 5%, and ≥ 10% and < 10% increase in cardiac output

<table>
<thead>
<tr>
<th></th>
<th>Valvular surgery</th>
<th>Coronary artery surgery</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>R (&gt;5%)</td>
<td>P-value</td>
</tr>
<tr>
<td></td>
<td>NR (≤5%)</td>
<td></td>
</tr>
<tr>
<td>COTp, l/min</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Before</td>
<td>n=14</td>
<td>n=26</td>
</tr>
<tr>
<td></td>
<td>5.9 ± 0.6</td>
<td>6.5 ± 0.9</td>
</tr>
<tr>
<td></td>
<td>After</td>
<td>6.6 ± 0.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6.3 ± 0.8</td>
</tr>
<tr>
<td>CCO, l/min</td>
<td>n=19</td>
<td>n=21</td>
</tr>
<tr>
<td>Before</td>
<td>5.1 ± 0.8</td>
<td>5.4 ± 0.8</td>
</tr>
<tr>
<td></td>
<td>After</td>
<td>5.9 ± 0.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5.1 ± 0.7</td>
</tr>
<tr>
<td></td>
<td>R (≥10%)</td>
<td>NR (&lt;10%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>COTp, l/min</td>
<td>n=9</td>
<td>n=31</td>
</tr>
<tr>
<td>Before</td>
<td>6.0 ± 0.4</td>
<td>6.4 ± 0.9</td>
</tr>
<tr>
<td></td>
<td>After</td>
<td>6.9 ± 0.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6.3 ± 0.8</td>
</tr>
<tr>
<td>CCO, l/min</td>
<td>n=11</td>
<td>n=29</td>
</tr>
<tr>
<td>Before</td>
<td>5.0 ± 0.9</td>
<td>5.4 ± 0.7</td>
</tr>
<tr>
<td></td>
<td>After</td>
<td>6.2 ± 1.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5.2 ± 0.7</td>
</tr>
</tbody>
</table>

COTp, transpulmonary cardiac output; CCO, continuous cardiac output. Mean ± S.D.

in) cardiac output by COTp vs. CCO after valvular surgery, thereby decreasing the correlation of changes after valvular vs. that after coronary artery surgery. This explains, in part, why correlation coefficients for changes seemed less different between surgery types at relatively low fluid-induced increases. The tendency argues for forward/backward flows so that an effect of residual left-sided valvular insufficiencies on COTp measurements cannot be completely excluded [2]. Hence, a larger number of study patients might have better revealed such a small effect. In any case, the high reproducibility of CCO and similar fluid-induced changes among techniques upon fluid loading steps argue in favor of the 15 min used in this study to reach a new steady state in CCO, as done before [7]. Also, none of the patients had hemodynamically important tricuspid insufficiency, that could confound right-sided thermodilution. Rapid re-warming in the first 45 min after hypothermic cardiopulmonary bypass possibly confounding the CCO [8, 12] is also not a likely source of error in our study. Indeed, the CCO technique is attractive to monitor fluid responses without the necessity of injections and calibrations as for pulse contour methods, which, in addition, may be confounded by aortic valve abnormalities [1, 6, 10, 13]. The COTp can be favored, however, if considered less invasive than the CCO. Otherwise, the relatively low cardiac output after valvular vs. coronary artery surgery may have been caused by more severe left ventricular dysfunction, as suggested by the lower cardiac output at similar GEDV. Apparently, dysfunction did not hamper similar fluid loading responses as after coronary artery surgery.

In conclusion, our data suggest that COTp and CCO are of similar value in predicting and monitoring (relatively small) cardiac output fluid responses after valvular and coronary artery surgery, in spite of lower cardiac output after valvular surgery but comparable overestimation by COTp. Hence, residual left-sided valvular insufficiency may not confound assessment of COTp and its response to fluid loading after valvular surgery.

References


[8] Böttiger BW, Soder M, Rauch H, Böhrer H, Motsch J, Bauer H, Martin E. Semi-continuous versus injectate cardiac output measurement in inten-