Overestimation of Pediatric Cardiac Output by Thermal Indicator Loss

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SUMMARY The accurate measurement of pediatric cardiac output by thermodilution requires that the quantity of cold indicator introduced into the central circulation be known. This study defines an important source of error in the correction factor for the amount of heat gained by small volumes of cold injectate during passage through pediatric catheter systems. This error may result in significant overestimation of cardiac output (as much as 59%) when blood at body temperature is withdrawn into the injection lumen of the pediatric catheter before the injection.

THERMODILUTION catheter systems, both adult and pediatric, should account for the amount of heat gained (C_T) by the cool injectate as it passes through a lumen of a catheter warmed to body temperature. The C_T factor is incorporated into the formula for cardiac output by thermodilution (see appendix) and a table of C_T values for various injectate volumes and temperatures is constructed that is specific for a given catheter type and size. Usually, injectate temperature, patient body temperature and C_T are entered as constants into a thermodilution cardiac computer.

A common method for measuring and computing C_T includes the volume of the catheter dead space as part of the total injectate volume. This method was first described and used with the adult #7F flow-directed thermodilution catheter and later with the smaller pediatric catheter systems. However, the dead space of the injection lumen of the adult #7F catheter is 0.8 ml (8% of a 10-ml injection), whereas in the smaller #5F pediatric catheter system the dead space is approximately 0.65 ml (65% of a 1-ml injection). This observation led to the investigation of the effect that temperature of the dead space fluid has on the C_T value supplied by the catheter manufacturer, because many investigators recommend prefilling the injection catheter with blood at body temperature* and others do not.1, 7-11

Materials and Methods

Two catheter systems (Edwards Laboratories) were studied. The first was a #5F, 60-cm, flow-directed catheter with four lumens: one for measuring pressure at the catheter tip, one for measuring pressure and injecting cool solution through an opening 15 cm proximal to the catheter tip, one for balloon inflation and one that contained lead wires to a thermistor. The second catheter system consisted of a #2F thermodilution catheter (designed to be inserted through the right ven-

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Received March 3, 1981; revision accepted May 1, 1981.

there was a rise in fluid temperature from exposure to air at ambient temperature. This stable reading was recorded as the average temperature of the delivered injectate (TID).

We determined (and subtracted from TID) the amount of heat gained by the injectate from the measurement apparatus itself (TK), i.e., the small plastic bag and thermistor. Before and after each set of CT measurements for a given catheter, injectate volume and temperature, an identical volume of injectate was directly introduced into the small plastic bag with a syringe at injectate temperature. The temperature of the directly delivered injectate (no catheter) was measured and recorded as TK. The largest TK was 0.8°C for the 1 ml, 0°C injectate and the variability of the TK measurements (before and after a given set of CT measurement) was less than 0.1°C.

CT was calculated from the formula

\[
CT = \frac{(TB - TID - TK)(TB - TI)}{
\}

where TID is the mean temperature of the injectate delivered for a given volume at the injection site (including the catheter and stopcock dead space), TK is the amount of heat gained by the injectate from the measurement apparatus, TB is the temperature of the water bath and TI is the temperature of the injectate just before injection.

CT measurements were performed with each catheter system at injectate temperatures of 0 ± 0.1°C (iced) and 24°C ± 0.5°C (room temperature). At 0°C, injectate volumes of 1, 2, 3 and 5 ml were collected and measured for the #5F catheter, and injectate volumes of 1, 2 and 5 ml for the #3.5F catheter. At 24°C temperature, injectate volumes of 1, 2 and 5 ml were collected and measured for each catheter.

Two series of CT measurements were made. In the first series, at each injectate volume and temperature, at least 5 CT determinations were performed by prefilling the dead space of the catheter to be tested with 1 ml of injectate (either 24°C or 0°C), waiting 20 seconds, and injecting as rapidly as possible. The delivered injectate volume was collected and its temperature measured. The fluid from prefilling was not collected in the small plastic bag, but was injected into the water bath.

In a second series, five more CT determinations were done with the catheter dead space prefilled with 1 ml of 37°C injectate. In this way, the effect on CT by prefilling the injection catheter dead space with body temperature fluid at 37°C or injectate temperature fluid before actual injection could be quantitated and compared to the CT value supplied by the manufacturer.

The following terms are used:

- CT(I) — the average of CT measurements with the catheter dead space prefilled with 1 ml injectate temperature fluid for a given volume and injectate temperature.
- CT(37) — the average of CT measurements with the catheter dead space prefilled with 1 ml of DSW at 37°C for a given volume and injectate temperature.
- CT(M) — the CT value supplied by the catheter manufacturer for a given volume and injectate temperature.

**Results**

The CT(I) determinations measured in this study agreed with the CT(M) values at almost all injectate volumes for the #3.5F and #5F catheter systems. The largest differences between CT(I) and CT(M) with the #3.5F catheter at 1- and 2-ml volumes of 0°C injectate, resulting in differences of 4.7% and 3.2%, respectively. All other CT(I) vs CT(M) differences were 1.2% or less (table 1).

The difference measured between CT(37) and CT(M) was much greater at all injection volumes for both 24°C and 0°C injectate temperatures than at those measured between CT(I) and CT(M) (table 2). The largest differences were with the #5F catheter: 0°C injectate at volumes of 1 and 2 ml, 59.1% and 25.9% respectively; and 24°C injectate at volumes of 1 and 2 ml, 29.0% and 18.6%, respectively.

The difference between the values for CT(I) and CT(37) with each catheter, injectate volume and temperature were tested for statistical significance. The #3.5F catheter, 0°C injectate at 2 ml volume gave the only value that was not significant (p < 0.20); the difference was significant at 5 ml (p < 0.05). All other comparisons of CT(I) and CT(37) were significant (p < 0.01).

**Discussion**

Thermodilution can be performed by withdrawing blood at body temperature either before or after the injection.1-7 Goodyer et al.8 and Fronke and Ganz9 recommended withdrawing blood at body temperature before injection so as to avoid mixing of the injectate with fluid at some unknown temperature intermediate between body temperature and that of the previous injection. For a specific injection catheter in a body at constant temperature, the amount of heat gained for a given injectate volume can only be con-
constant if the initial conditions, i.e., the temperature and volume of the dead space of the injection catheter, are the same for each determination.

Ganz and Swan described the variability of $C_T$ for the adult #7F flow-directed thermodilution catheter. They reported that $C_T$ was relatively constant (within 3%) for injection rate (2-4 ml/sec), body temperature (35-39°C) and intravascular catheter length (25-45 cm). Only $C_T$ at 0°C with a 10-ml injectate volume was measured, and it was not stated whether the catheter dead space was prefilled with 0°C or 37°C D5W. They did, however, recommend withdrawing blood at body temperature after the injection of cold indicator.

Meisner et al. described withdrawing blood at body temperature after injection to minimize a cooling effect (which prolongs the downslope of the descending limb of the thermodilution curve) from the cold injectate remaining in the catheter lumen. The errors introduced by this cooling effect were small; nevertheless, Meisner et al. recommended warm withdrawal of blood after injection to improve accuracy. However, if cardiac output measurements were done in duplicate or triplicate using the catheters and $C_T(M)$ in this study, and following the recommendation of Meisner et al., the second and third determinations would overestimate $Q$ by the percent difference listed in table 2.

Large, significant differences occur between $C_T(37)$ and $C_T(M)$, differences that do not exist between $C_T(I)$ and $C_T(M)$ when the injection rate, body temperature, injectate temperature and catheter immersion length are held constant. This difference between $C_T(37)$ and $C_T(M)$ increases as injectate volume and temperature decrease for each catheter. $C_T(M)$ and $C_T(I)$ were determined by a similar technique, i.e., when $C_T$ was measured by the manufacturer, the injection lumen was prefilled with injectate temperature fluid as this is a simpler and faster technique to perform in the laboratory.

The overestimation of cardiac output from using $C_T(M)$ and prefilling the catheter with blood at body temperature for all measured injectate temperatures and volumes with #5F and the #3.5F catheters is listed in table 2. For example, if a #F catheter similar to the one used in this study was inserted into a pediatric patient, an injectate volume of 2 ml, 0°C D5W used and $C_T(M) = 0.729$ are entered as constants into a cardiac output computer. If the injection catheter is prefilled with blood at body temperature and the injectate then delivered within 20 seconds, the

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**Table 1. Catheter Dead Space Prefilled with 1 Milliliter of D5W at 0°C or 24°C**

<table>
<thead>
<tr>
<th>Catheter</th>
<th>Vol</th>
<th>$T_I$</th>
<th>n</th>
<th>$C_T(I)$</th>
<th>SD</th>
<th>$C_T(M)$</th>
<th>%Diff.</th>
</tr>
</thead>
<tbody>
<tr>
<td>#3.5F</td>
<td>1.0</td>
<td>0</td>
<td>6</td>
<td>0.804</td>
<td>0.010</td>
<td>0.842</td>
<td>4.7</td>
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<td>prefilled</td>
<td>2.0</td>
<td>0</td>
<td>5</td>
<td>0.867</td>
<td>0.013</td>
<td>0.895</td>
<td>3.2</td>
</tr>
<tr>
<td>0°C D5W</td>
<td>5.0</td>
<td>0</td>
<td>5</td>
<td>0.916</td>
<td>0.004</td>
<td>0.927</td>
<td>1.2</td>
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<tr>
<td>#5F</td>
<td>1.0</td>
<td>0</td>
<td>7</td>
<td>0.571</td>
<td>0.012</td>
<td>0.571</td>
<td>0.0</td>
</tr>
<tr>
<td>prefilled</td>
<td>2.0</td>
<td>0</td>
<td>8</td>
<td>0.735</td>
<td>0.009</td>
<td>0.729</td>
<td>-0.8</td>
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<tr>
<td>0°C D5W</td>
<td>3.0</td>
<td>0</td>
<td>5</td>
<td>0.786</td>
<td>0.003</td>
<td>0.792</td>
<td>0.8</td>
</tr>
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<td>#3.5F</td>
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<td>24</td>
<td>6</td>
<td>0.895</td>
<td>0.017</td>
<td>0.901</td>
<td>0.7</td>
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<tr>
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<td>24</td>
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<td>0.933</td>
<td>0.010</td>
<td>0.934</td>
<td>0.1</td>
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<tr>
<td>24°C D5W</td>
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<td>24</td>
<td>5</td>
<td>0.948</td>
<td>0.008</td>
<td>0.956</td>
<td>0.8</td>
</tr>
</tbody>
</table>

Abbreviations: $T_I$ = injectate temperature; $C_T(I)$ = average amount of heat gained in study prefilling catheter with 1 ml of D5W at 0°C or 24°C; $C_T(M)$ = average amount of heat gained as value determined by manufacturer; %Diff = ($C_T(M)$ - $C_T(I))/C_T(I)$.

**Table 2. Catheter Dead Space Prefilled with 1 Milliliter of D5W at 37°C**

<table>
<thead>
<tr>
<th>Catheter</th>
<th>Vol</th>
<th>$T_I$</th>
<th>n</th>
<th>$C_T(37)$</th>
<th>SD</th>
<th>$C_T(M)$</th>
<th>%Diff.</th>
</tr>
</thead>
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<td>#3.5F</td>
<td>1.0</td>
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<td>0.001</td>
<td>0.927</td>
<td>1.8</td>
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<td>15</td>
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<td>0.022</td>
<td>0.571</td>
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<td>0</td>
<td>6</td>
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<td>0.012</td>
<td>0.729</td>
<td>25.9</td>
</tr>
<tr>
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<td>3.0</td>
<td>0</td>
<td>5</td>
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<td>0.004</td>
<td>0.792</td>
<td>11.6</td>
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<tr>
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<td>5.0</td>
<td>0</td>
<td>5</td>
<td>0.780</td>
<td>0.003</td>
<td>0.835</td>
<td>7.1</td>
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<td>24</td>
<td>5</td>
<td>0.860</td>
<td>0.015</td>
<td>0.901</td>
<td>4.8</td>
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<td>5</td>
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<td>0.006</td>
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<td>4.2</td>
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<td>24</td>
<td>5</td>
<td>0.927</td>
<td>0.012</td>
<td>0.956</td>
<td>3.1</td>
</tr>
<tr>
<td>#5F</td>
<td>1.0</td>
<td>24</td>
<td>6</td>
<td>0.668</td>
<td>0.020</td>
<td>0.862</td>
<td>29.0</td>
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<td>6</td>
<td>0.774</td>
<td>0.010</td>
<td>0.918</td>
<td>18.6</td>
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<tr>
<td></td>
<td>5.0</td>
<td>24</td>
<td>5</td>
<td>0.886</td>
<td>0.008</td>
<td>0.949</td>
<td>7.1</td>
</tr>
</tbody>
</table>

Abbreviations: $T_I$ = injectate temperature; $C_T(37)$ = average amount of heat gained in study prefilling catheter with 1 ml of D5W at 37°C; $C_T(M)$ = amount of heat gained determined by manufacturer; %Diff = ($C_T(M)$ - $C_T(37))/C_T(37)$.
value calculated by a cardiac output computer will overestimate \( Q \) by 25.9%. This error will be reproducible in a series as long as the catheter is prefilled with blood at body temperature before each determination. Many of the errors are in a range that would be clinically important in management of the pediatric patient as well as statistically significant in small animal research.

Requirements for the accurate measurements of thermodilution cardiac output in the pediatric patient for the two catheter systems used in this study are: (1) Preaspiration of blood at body temperature should not be done. (2) The catheter lumen should be filled with 1 ml of the injectate temperature fluid, and after a 20-second delay, the desired volume of injectate should be injected as rapidly as possible. (3) Do not withdraw blood at body temperature after the injection. (4) Use the values for \( C_T \) supplied by the catheter manufacturer. (Catheters by other manufacturers may yield different results.) (5) Serial cardiac output determinations may be repeated as soon as the temperature baseline is stable and 20 seconds has passed, as the injection lumen is prefilled with injectate temperature fluid from the previous injection. The above injection technique provides the precise delivery of a known amount of thermal indicator, is clinically easy to perform and repeat, and improves the accuracy and reproducibility of pediatric cardiac output measurements.

Acknowledgment
The authors gratefully acknowledge and thank Patricia Hirt for her excellent typing and proofreading of this manuscript.

References

Appendix

\[
Q = \frac{1.08 (T_n - T_t) V C_T 60}{\int \Delta T_n(t) dt}
\]

where \( Q \) = cardiac output (l/min); \( T_n, T_t \) = temperature of blood and injectate (°C); \( V \) = volume of the injectate (l); \( C_T \) = correction for the amount of heat gained by injectate during injection; 1.08 = correction for the specific heat and gravity of blood and injectate; \( \int \Delta T_n(t) dt \) = integral of the resultant temperature-time curve (°C • sec); 60 = factor for conversion of l/sec to l/min.
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Circulation. 1982;65:380-383
doi: 10.1161/01.CIR.65.2.380

Circulation is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
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Print ISSN: 0009-7322. Online ISSN: 1524-4539

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