Title: MAJOR ERRORS IN THERMODILUTION MEASUREMENT OF CARDIAC OUTPUT CAUSED BY RAPID VOLUME INFUSION

Authors: R. C. Wetzel, M.D. and T. W. Latson, M.D.

Affiliation: Department of Anesthesiology/Critical Care Medicine, The Johns Hopkins Medical Institutions, Baltimore, Maryland 21205

Introduction. Cardiac output measurement by thermodilution is commonplace in the anesthetic management of patients with severe cardiovascular disease. Under stable conditions the accuracy of such measurements is suitable for clinical application. Previous reports have described the effects of respiration, low cardiac output, and injectate volume and temperature on the accuracy of these measurements. One of the assumptions made in the calculation of cardiac output by this technique is that the background temperature of the blood returning to the heart is stable. This assumption may be incorrect during intermittent rapid volume infusion, and the potential error incurred could theoretically be quite large.

Methods. We prospectively studied seven patients undergoing cardiac surgery who had Swan-Ganz thermodilution pulmonary artery catheters for routine operative management. This study was approved by the Joint Hospital Committee of Clinical Investigations. Following chest closure but prior to skin closure, during periods of hemodynamic stability, a series of thermodilution cardiac output measurements were made during alternating control and infusion conditions. Both room temperature and warmed (diverted through a blood warmer) fluids were infused. The volume and rate of infusion was not precisely controlled, but simulated the clinical situation of rapid volume supplementation by a "squeeze-bulb" incorporated into the intravenous line. The approximate volume delivered by one compression of the bulb was 30-45 mls. For measurements made during infusions, three to five compressions of the bulb were made starting just prior to the injection of the iced saline used for the thermodilution measurement (total administered volume was approximately 90 to 150 ml). This volume was administered through a 14 or 16 gauge peripheral intravenous catheter located in the wrist or forearm. Thermodilution measurements were made by injecting 10 ml of iced saline via the central venous port of an Edwards Swan-Ganz thermodilution pulmonary artery catheter in the standard fashion using a LYONS (E/M) cardiac output computer with simultaneous recording of the thermodilution curve. Each test measurement was compared to the mean of the control measurement made immediately before and after. Results are mean ± S.D.

Results. With cold infusion, cardiac output measurements were incorrect by 30-80%. The mean of the control measurement was 5.85 ± 1.1 l/m versus 3.35 ± 1.53 l/m during infusion ($p < .001$, by paired Students t-test) (see Figure). For warm infusions, the range of percent reduction was 20 to 40% with the mean of the control measurement being 4.82 ± .97 l/m versus 4.02 ± .92 l/m during infusion ($p < .001$).

Discussion. Our results demonstrate large, clinically significant errors in thermodilution cardiac output measurements during rapid volume infusion through a peripheral vein. The equation for determination of cardiac output by the thermodilution technique is:

$$CO = k \times (Ti - Tbs) / \int (T(t) - Tbs)\, dt$$

where Ti is the injectate temperature, Tbs is the reference baseline blood temperature, T(t) is the temperature measured at the catheter tip as a function of time, and k is a constant which takes into account the heat capacity of the injectate solution and blood, the volume of the injectate, and an estimate of heat "loss" to external sources. The denominator is equal to the area under the temperature curve, and the trailing edge of this curve is usually approximated by an exponential fit based on the initial part (60-70%) of the decay in this curve. In these calculations, Tbs is assumed constant. Variations in Tbs may affect the calculation, with errors occurring not only in the numerator and denominator of the basic equation, but also from improper exponential extrapolation of the curve. This error in the cardiac output determination will depend on both the magnitude and timing of fluctuations in Tbs. Fluctuations in Tbs during infusion will vary between patients depending on size, temperature, cardiac output, and location of infusion site. The predominant effect observed with this infusion protocol was an increase in the area of the thermodilution temperature curve, which resulted in a decrease in the calculated cardiac output. Although such an effect is easily predicted from the theoretical basis by which the measurement is derived, the magnitude of error incurred has not been previously described. Awareness of this effect is necessary to avoid misleading results which may lead to errors in patient management.