Measuring Cardiac Output: Intermittent Bolus Thermodilution Method

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Q What are the physiological principles underlying the intermittent bolus thermodilution (TDCO) method of determining cardiac output?

The TDCO method is the one clinicians use most often to measure cardiac output. It is based on the principles of dilution. A known quantity of an indicator (ie, a contrast agent) is injected into the bloodstream. Blood flow and blood volume are calculated by measuring the concentration of the indicator downstream at a distal arterial site at selected times. The TDCO method uses a cold solution to create a thermal deficit as a variant of the indicator-dilution method. A bolus of sterile solution (ie, the injectate) that is colder than the patient’s blood is injected into the proximal port of a pulmonary artery catheter located in the right atrium. In the atrium, the injectate mixes with the blood and passes through the tricuspid valve into the right ventricle. A thermistor within the catheter senses the change in blood temperature as the blood passes the catheter tip located in the pulmonary artery.1 A curve that shows the change in temperature over time is calculated by a computer and converted into a measurement of cardiac output. Cardiac output is inversely proportional to the area under the curve.

The normal cardiac output curve has a rapid smooth upstroke and a gradual downstroke (Figure 1). A small area under the curve indicates a high cardiac output. The faster blood flows through the heart, the earlier the peak and sharper the drop, because the catheter senses temperature change over a short period. A low cardiac output results in a larger area under the curve. When blood flows slowly (low cardiac output), the area under the curve (temperature change over time) is greater because the catheter senses changes in temperature over a longer period. The curves vary according to the patient’s clinical condition and according to deviations in technique (Figure 2).

Concerns about contamination of prefilled syringes of injectate and...
warming of injectate due to handling led to the design of closed delivery systems (Figure 3). The closed system is designated for use with a pulmonary artery catheter and a cardiac output computer or with iced and room-temperature injectate. The closed system also incorporates a flow-through temperature probe that measures the temperature of the injectate near the site of injection. The obvious advantages are that closed systems do not require preparation of individual syringes, eliminate inefficiencies, and reduce multiple entries into a sterile system.

Q: How accurate is the TDCO method?

The accuracy of the method is related to how closely the observed signal (ie, measurement of cardiac output) matches an accepted standard value. Forrester et al found a correlation coefficient of 0.993 between a mechanical pump with a known flow and TDCO measurements. In other studies with flowmeters, correlation coefficients were 0.97 to 1.0. Other researchers have used the direct Fick method as the gold standard for measurement of cardiac output. The Fick principle states that the amount of a substance taken up by the body per unit of time is equal to the arterial level of the substance minus the venous level of the substance multiplied by the flow. Cardiac output can be calculated by the Fick method by dividing the amount of oxygen consumed by the body by the arterial-venous oxygen difference. Numerous studies have addressed the correlation between the direct Fick method and the TDCO method. In all but 2 studies, the correlations between values obtained with the 2 methods

Figure 2 A, Variations in the normal cardiac output curve seen in certain clinical conditions. B, Abnormal cardiac output curves that will produce an erroneous cardiac output value.

were 0.91 to 0.98. The TDCO method is an acceptable substitute for the Fick method or the indicator-dilution method.

Many of the derived hemodynamic indexes and the clinical therapies for critically ill patients depend on accurate measurement of cardiac output. Critical care nurses routinely use the TDCO method to measure cardiac output in critically ill patients and are responsible for the accuracy and analysis of the obtained values. Several technical considerations must be understood in order to minimize the potential for error. These include the position of the pulmonary artery catheter, volume and temperature of the injectate, the phase in the respiratory cycle for administration of the injectate, the patient’s body position, effects of concomitant intravenous infusions, and the effect of positive end-expiratory pressure. Even under ideal circumstances, TDCO measurements have a 10% error.17,18

Q: Is the continuous cardiac output (CCO) method as accurate as the TDCO method?

Clinical studies have also compared the accuracy of the CCO and the TDCO methods. These studies are synthesized and critiqued in the “Annotated Bibliography” section of the research-based protocol on measurement of cardiac output.19 Although the studies report good correlations (0.84 to 0.94) between measurements obtained with the 2 methods, comparisons between CCO and TDCO values have intrinsic methodological issues. The TDCO method itself is not a gold standard for measurement of cardiac output. Under ideal circumstances, TDCO measurements have a 10% error rate related to operator error, temperature transduction, and instrument inaccuracies. Studies that compare values obtained with the CCO method with values obtained with an inaccurate gold standard such as the TDCO method may lead to erroneous estimation of the accuracy of the CCO device. Further studies are necessary to compare CCO values with more precise measurement of cardiac output (such as those obtained by using the Fick or the indicator-dilution method) in a variety of critically ill patients. Such confirmatory studies are necessary to verify the accuracy of CCO technology.

Other methodological problems limit the generalizability of these studies to other critically ill populations. The majority of the studies were done during periods of hemodynamic stability in patients who had had coronary artery bypass graft surgery. Many of these studies used small sample sizes (N = 12 to 35) and multiple observations. Therefore,
Q: What is the procedure for obtaining a TDCO measurement?

For accurate TDCO curves, the signal-to-noise ratio must be adequate for the cardiac output monitor to sense a change in temperature over time. The signal is the temperature difference between the injectate and the patient’s blood; the noise is the cycling variation in blood temperature. The difference between the temperature of the injectate and the temperature of the patient’s blood should be 10°C.2 Theoretically, 10 mL of iced injectate produces a greater signal-to-noise ratio than does 10 mL of room-temperature injectate or smaller volumes (eg, 5 mL) of either iced or room-temperature injectate. Use of room-temperature injectate or smaller volumes of injectate may decrease the temperature difference (signal) and may yield erroneous values for cardiac output. In most normothermic patients, 5 mL of iced injectate can be used if fluid restriction is warranted. Before using a smaller volume, clinicians must verify that the values obtained with the smaller volume are comparable to values obtained with a larger volume.

- To ensure the validity and reliability of the measurement, check the following:
  - position of the pulmonary artery catheter,
  - computation constant,
  - catheter size,
  - temperature of the injectate,
  - volume of injectate, 10 mL (or 5 mL if iced), and

measurements within each study were not completely independent of one another. For example, if a subject in a study had some characteristic that led to errors in measurement, multiple measurements in that subject would lead to overrepresentation and possibly negative bias in the results. Using larger sample sizes and limiting the number of data points per patient would control for this possible variation. Power analysis was not used to determine appropriate sample size (see the “Annotated Bibliography” in the protocol19 for more details). Rigorous studies that control for the issues just described are needed in critically ill patients to establish the accuracy of newer technologies of noninvasive measurements of cardiac output.
– patient’s body position.
  • Use appropriate TDCO technique:
    – Inject 10 mL within 4 seconds; 5 mL, within 2 seconds.
    – Administer the injectate when the patient is at end-expiration.
    – Obtain 3 measurements.
    – Assess the cardiac output curve.
    – Average values that are within 10% of the median value.
    – Starting at baseline, a normal cardiac output curve has a smooth rapid upstroke and a gradual downstroke.

Q: What further research on measurement of cardiac output is needed?

Although many research studies have been done on measurement of cardiac output and on newer methods, additional investigation and replication are needed. Further research is needed to do the following:
  • Describe chronobiological fluctuations in cardiac output.
  • Determine the validity and reliability of noninvasive methods of measuring cardiac output, such as Doppler flow imaging and echocardiography and thoracic electric bioimpedence, in various populations of critically ill patients.
  • Determine the validity and reliability of values obtained by using the CCO method in various populations of critically ill patients.
  • Determine the effect on clinical outcomes and cost of using CCO versus TDCO methods in critically ill patients.
  • Replicate studies with iced and room-temperature injectate in subgroups of critically ill patients, such as patients who have low ejection fraction, low cardiac output, high cardiac output, or hypothermia.
  • Replicate studies with small volumes of injectate in subgroups of critically ill patients, such as patients who have low ejection fraction, low cardiac output, high cardiac output, or hypothermia.
  • Replicate studies comparing the accuracy of closed system of injectate delivery with the accuracy of using prefilled syringes in subgroups of critically ill patients.
  • Replicate studies in patients with cardiac conditions in which the TDCO method is considered less accurate but for which cardiac output and other hemodynamic measurements are used, such as valvular disease (tricuspid regurgitation), dysrhythmias, and dilated heart chambers with increased ventricular dimensions.
  • Replicate studies of the effects of the patient’s body position on TDCO measurements in critically ill patients.

References

Note
This article was first published in Critical Care Nurse April 2000.