Title

The effects of the phases of ventilation on the thermodilution technique of cardiac output measurement in mechanically ventilated patients

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The Effects of the Phases of Ventilation on the Thermodilution Technique of Cardiac Output Measurement in Mechanically Ventilated Patients

by

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THESIS

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Abstract

Thermodilution cardiac output (CO) measurements are a routine part of the clinical management of postoperative cardiac surgical patients. However, researchers report that a limitation of the thermodilution technique is the variation in CO in association with the phases of ventilation. Yet, only minimal research has been conducted on patients receiving mechanical ventilation. For this reason, this study examined the effects of the phases of ventilation on thermodilution CO measurements in mechanically ventilated patients.

A quasi-experimental design was used to test the following hypothesis: Thermodilution CO values measured by timing the injection of the indicator at end-inspiration are significantly different from CO values measured by timing the injection of the indicator at end-expiration for postoperative cardiac surgical patients receiving mechanical ventilation. A convenience sample of twenty subjects, 17 men and 3 women, was selected from those patients having cardiac surgery at a large university-teaching hospital. Ages ranged from 49 to 77 years, with a mean age of 63 years. All subjects received continuous positive pressure ventilation (CPPV), consisting of intermittent mandatory ventilation (IMV) with 5 to 10 centimeters of water positive end-expiratory pressure (PEEP). CO measurements were

obtained by timing the injection of the thermal indicator at end-inspiration and end-expiration for each subject. A mean of three measurements was calculated at each phase of ventilation. The phase of ventilation in which the injection of the indicator occurred was examined using a paired t-test analysis. The results were found to be statistically significant with $p < .001$ and thus, the null hypothesis was rejected. Similar results were also obtained for cardiac index and systemic vascular resistance. The findings indicate that there is a significant difference in CO measurements when the indicator is injected at different times in the respiratory cycle. These results suggest that thermodilution CO determinations in cardiac surgical patients should be measured by timing the injection of the indicator with a specific point in the respiratory cycle. This would eliminate potential error in comparing sequential measurements when various personnel are performing the procedure.

Dedication

To my parents, Vincent and Violet Lachenmyer, without whom I would have been somebody else.

To my brothers and sisters, Sue, Butch, JoAnn, Bill, Jim, Laura, and Robert, who added much to my development.

And, in memory of Sam, who taught me about living and caring.

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Chapter I: Introduction

Identification of the Problem

Thermodilution cardiac output (CO) measurements are a routine part of the management of postoperative cardiac surgical patients in the intensive care unit (ICU). The thermodilution method consists of injecting an indicator of a known volume and temperature into the blood at one point and detecting the temperature change of the blood at another point downstream (Levett & Replogle, 1979). When a pulmonary artery (PA) catheter is used, the change in blood temperature is detected by a thermistor located on the distal tip of the catheter, and a temperature-time curve is recorded. Cardiac output is determined from the amount of heat dilution over time that occurred. An analog computer electronically integrates the temperature-time curve and digitally displays the calculated CO (Edwards Laboratories, 1979).

A stable PA blood temperature is necessary in order to detect the temperature change of the blood flowing past the thermistor after the injection of the indicator. The accuracy of the CO determination is affected by this stability of blood temperature between the injection and sampling sites during the measurement. Several researchers have reported a fluctuating baseline blood temperature with thermodilution curves that result from distinct changes in the PA temperature associated with the phases of ventilation (Armengol, Man, Balsys, & Wells, 1981; Ganz, Donoso, Marcus,

Forrester, & Swan, 1971; Olsson, Pool, Vandermoten, Varnauskas, & Wassen, 1970; Weisel, Berger, & Hechtman, 1975; Woods, Scott, & Harken, 1976). These variations in PA blood temperature have been attributed to a cooling effect caused by either the inhaled gas or the venous return of cooler peripheral blood to the pulmonary circulation (Afonso, Herrick, Youmans, Rowe, & Crumpton, 1962; Wessel, James, & Paul, 1966).

Theoretically then, factors influencing airway temperature and/or venous return, such as positive pressure ventilation, may alter the accuracy of the thermodilution method. Most cardiac surgical patients are mechanically ventilated postoperatively (Behrendt & Austen, 1976). Cardiac output measurements are frequently obtained to assess cardiac function and guide treatment modalities (Gilbert & Hew, 1979). Yet, minimal research has been done on these patients to examine the effects of timing the thermodilution injections at different points in the respiratory cycle on the accuracy of the CO determinations. The majority of studies reported in the literature are animal studies, and further exploration is needed in human subjects. For this reason, this study examined the effects of timing the injection of the indicator with the respiratory cycle on thermodilution CO measurements in postoperative cardiac surgical patients receiving mechanical ventilation.

Purpose of the Study

The purpose of this study was to examine the relationship between the timing of the thermodilution injection at two points in the respiratory cycle and CO measurements in patients receiving continuous positive pressure ventilation (CPPV).

Significance of the Problem

Rationale for CO Measurement

Impaired cardiac performance, manifested chiefly by a low CO, remains a significant cause of mortality and morbidity following cardiac surgical procedures (Kouchoukow, Sheppard, & Kirklin, 1977). Survival of the patient undergoing cardiac surgery is dependent on the continued maintenance of intracellular functional integrity (Litwak & Dack, 1982). Optimal postoperative recovery of the cardiac subsystem can be considered normal only when the CO is adequate for the metabolic needs of the organism as a whole (Kirklin & Kirklin, 1981). Thus, the goal of postoperative management of the patient subjected to a cardiac operation is the "implementation of therapeutic intervention that permits movement toward or maintenance of optimal steady-state conditions within the cell" (Litwak & Dack, 1982, p. 17).

Simultaneous changes in various physiological parameters make it difficult to interpret the hemodynamic status of the postoperative cardiac surgical patient

(Kohanna, Cunningham, Catinella, Adams, Nathan, & Pasternack, 1981). The direct measurement of CO is often necessary to accurately evaluate cardiac function and the hemodynamic status of the patient (Russell, Kouchoukos, & Karp, 1978). Guyton (1968) has stated that "CO is perhaps the single most important weather vane of functional effectiveness of the circulation."

Traditionally, blood pressure (BP) measurements have been used for the clinical assessment of cardiovascular (CV) performance (Jurado, 1982). Unfortunately, equating normal BP measurements with normal CV functioning leads to gross errors in clinical judgment. Ohm's law states that pressure (P) is the product of flow (F) and resistance (R); such that $P = F \times R$. For the CV subsystem, F is represented by CO and R is equal to vascular resistance. Resistance is not directly measurable, but can be derived from the relationship of $R = P/F$.

This formula demonstrates that a reduction in CO does not necessarily result in a corresponding drop in arterial pressure. Compensatory feedback mechanisms in both the autonomic nervous system and the endocrine system increase resistance when CO is decreased, thus maintaining BP (Swan & Ganz, 1980). Therefore the measurements of both BP and CO are necessary to accurately assess CV function (Russell et al., 1978).

Nursing Significance

Technological advancements in the past decade have led to the development of sophisticated hemodynamic monitoring procedures and equipment (Armstrong and Baigrie, 1979). The specialized techniques involved in hemodynamic monitoring require that the critical care nurse incorporate knowledge of physiological principles with technical expertise in order to provide quality care (Johanson, Dungca, Hoffmeister, and Wells, 1981).

One specialized monitoring technique is the measurement of CO. Cardiac output measurements are used to diagnose, select specific therapeutic measures, and assess the patient's response to therapy. In this investigator's practice, it is the responsibility of the nurse in the critical care setting to measure CO, evaluate the adequacy of the CO for the specific patient, and initiate changes in treatment as indicated based on standing physician orders.

Thermodilution is the method frequently used for measuring CO at the bedside because (a) the indicator has no demonstrable pharmacological effects, (b) the blood temperature change does not affect heart rate or rhythm, and (c) the thermodilution CO determination is a simple technical procedure (Swan, 1978). However, as previously mentioned, a limitation of the thermodilution technique is the occurrence of a fluctuating thermal baseline that results from distinct changes in the PA temperature related to respiratory cycling (Weisel, Berger, and Hechtman, 1975).

Research findings indicate that in the clinical setting, changes in PA blood temperature may represent a realistic degree of uncertainty in the absolute value of a CO determination (Woods et al., 1976). If CO is to be used in the management of patients, it must be obtained accurately (Sorensen, Bille-Brahe, and Engell, 1976). Thus it is clinically important to know if CO determinations are affected by timing the thermodilution injection at different points in the respiratory cycle during mechanical ventilation in order for critical care nurses to accurately measure CO and guide treatment modalities for postoperative cardiac surgical patients.

Hypothesis

The hypothesis for this study is: Thermodilution CO values measured by timing the injection of the indicator at end-inspiration will be significantly different from CO values measured by timing the injection of the indicator at end-expiration for postoperative cardiac surgical patients receiving CPPV.

Chapter II: Review of Literature

In the past decade, hemodynamic monitoring has become recognized as a necessary part of the clinical management of post-operative cardiac surgical patients. The bedside measurement of CO provides objective information about cardiac function. This chapter will review the related theories, literature, and research on the subject of thermodilution CO measurements.

Theoretical Background

Physiological Mechanisms of Cardiac Output

The primary function of the heart is to pump a sufficient quantity of blood to meet the needs of the tissues for oxygen and nutrients (Neville, 1971, p. 60). Cardiac output is the volume of blood pumped by the heart per minute, and reflects the ability of the heart as a pump. Cardiac output is the product of stroke volume (SV) and heart rate. Heart rate is the number of times per minute the heart contracts, and SV is the amount of blood ejected from the ventricle with each beat (Berne & Levy, 1981).

Stroke volume is determined by three factors: (a) preload, the end-diastolic stretch of the muscle fiber, or the ventricular end-diastolic volume, (b) afterload, ventricular wall tension and the resistance to ventricular ejection by the blood pressure in the aorta, and (c) myocardial contractility, the inotropic state of the cardiac

muscle to change its force of contraction independent of preload and afterload (Gilbert & Hew, 1979). Stroke volume is directly related to preload and myocardial contractility, and inversely related to afterload (Jurado & Osborn, 1982).

Preload is dependent on venous return, or the volume of blood returning to the heart with each heart beat. The relationship between preload and CO can be described by the Frank-Starling law of the heart (Berne & Levy, 1981). Briefly stated, Starling found that fiber length increased as ventricular end-diastolic volume (EDV) increased. This increase in volume and fiber length results in a greater stroke volume, and therefore CO is increased (Haas, 1979; Woods, 1976). Clinically, EDV is difficult to determine, so ventricular end-diastolic pressure (EDP) is commonly used instead. The Starling effect is also responsible for the equality of outputs of the two ventricles and for the changes in CO that occur with respiration (Ross, 1982).

Afterload is the resistance against which the ventricles must contract (Ross, 1982). For the left side of the heart, systemic vascular resistance (SVR) is used clinically to measure afterload. Elevation of SVR increases ventricular systolic pressure and decreases SV by opposing ejection. Conversely, the reduction of afterload results in an increase in SV since the impedance to blood flow is decreased.

Myocardial contractility, the third component of SV, is the inotropic state of the cardiac muscle. Contractility is

the ability of the cardiac muscle to shorten and/or develop tension, independently of preload and afterload (Bond, 1982). Contractility can be described as the velocity of muscle shortening (Gilbert & Hew, 1979). Several factors affect contractility. These include the sympathetic nervous system, catecholamines, acid-base balance, oxygen, and a number of drugs.

Hemodynamic Monitoring

Hemodynamic monitoring enables the clinician to assess cardiac function in relationship to the Starling mechanism. Pulmonary Artery thermistor catheters are used for bedside determinations of pulmonary capillary wedge (PCW) pressure and CO. Systemic vascular resistance can then be calculated from CO, mean arterial pressure (MAP), and right atrial pressure (RAP). Contractility can be indirectly assessed when the other determinants of SV are known. Repeated measurements of these variables permits the construction of left ventricular (LV) function curves (Weisel, Vito, Dennis, Berger, & Hechtman, 1975).

Left ventricular function curves provide dynamic descriptions of myocardial performance and are used to guide specific treatments to obtain optimal CO in postoperative cardiac surgical patients. Cardiac output can be improved by directing therapy to the specific variable or variables that need changing: maximizing preload, reducing afterload, increasing contractility, or optimizing heart rate (Buckberg, 1977). Since the function of the heart is to

deliver oxygenated blood to the tissues to meet their metabolic requirements, CO becomes a significant and valuable measurement because it provides a direct assessment of the transport function of the circulation (Ross, 1982).

Measurement of Cardiac Output

In clinical situations, CO in humans is usually measured by indirect methods. Two major methods are reported in the literature: (a) the Fick method, which utilizes the relationship between oxygen consumption and arterial venous oxygen concentration, and (b) the indicator dilution method which utilizes a relationship between volume, concentration, and time (Pugh, 1979). Indicator dilution methods commonly used consist of dye-dilution CO measurements and thermodilution CO measurements.

The Thermodilution Technique

Indicator-dilution methods are based on the principle that if a known amount of indicator is injected into an inlet of a system through which fluid is flowing at F milliliters/second, and complete mixing of the indicator and fluid takes place in that system, then flow through the system can be calculated by continuous measurement of the concentration of the indicator in an outlet of the system (Runciman, Ilsley, & Roberts, 1981). Flow is calculated from the amount of indicator injected, the passage time of the indicator, and the average concentration of the indicator during this time. To ensure accuracy of the CO measurements, the method requires that there is (a) complete

mixing of the indicator and blood before the sampling site is reached, and (b) no loss of the indicator during the measurement.

The thermodilution method uses the indicator-dilution principle to calculate CO, and depends on the induction of a change in heat content of the blood when a cold solution is used as the indicator (Jurado, 1982). When using a PA thermistor catheter, the thermal indicator is injected into the central venous blood flow, mixed in the right ventricle, and the concentration of the indicator is sampled in the PA (Levett & Replogle, 1979). The concentration is equal to the temperature change of the blood.

Commercially available CO computers record the blood temperature change as a temperature-time curve and derive CO by the Stewart-Hamilton indicator-dilution formula modified for the thermal indicator. The following equation is the result (Edwards Laboratories, 1979; Ross, 1982):

$$C.O. = \frac{K\ (T_B - T_i)\ V_i\ (60)\ (C_T)}{\int_0^{\infty} T_B\ (t)\ dt}$$

where:

C.O. = cardiac output in liters/minute

K = density factor: The ratio of the specific heat times the specific gravity of the injectate to the specific heat times the specific gravity of the blood.

T_B = blood temperature

T_i = injectate temperature

V_i = injectate volume

60 = seconds/minute

C_T = correction factor for the warming of the injectate as it passes through the catheter

T_B (t) dt = change in blood temperature as a function of time.

The accuracy of the CO determination depends on the accuracy of the initial blood and injectate temperatures and the stability of the blood temperature between the injection and sampling sites during the measurement (Wessel, James, & Paul, 1966). Fluctuations in blood temperature represent physiological "noise" to the thermistor and effect the curve of the blood temperature change over time (Woods, Scott, & Harken, 1976). Woods et al.,(1976) calculated CO values of 1.4, 1.7 and 1.9 liters/minute by integrating the same thermodilution curve using three different baseline temperatures varying by 0.011 to 0.023 degrees Centigrade (°C). They demonstrated that the accuracy of the calculated CO is affected by changes in blood temperature.

Effects of Mechanical Ventilation on the Cardiovascular System

Mechanical ventilation consisting of intermittent positive pressure ventilation (IPPV) with positive end-expiratory pressure (PEEP) is referred to as continuous positive pressure ventilation (CPPV). Following cardiac surgery, most patients require mechanical ventilation during the first postoperative night (Behrendt & Austen, 1976).

One mode of positive pressure ventilation commonly used is intermittent mandatory ventilation (IMV). Positive end-expiratory pressure is used postoperatively to reverse alveolar collapse resulting from decreased lung expansion during cardiac surgery. The main concern in applying PEEP is that it decreases cardiac output as a consequence of decreased venous return and increased pulmonary vascular resistance (PVR) due to increased intrathoracic pressure (Harper, 1981).

Normally, intrathoracic pressure is negative during spontaneous respiration, especially during inspiration, thus facilitating venous return to the heart (Wade, 1982). During IPPV intrathoracic pressure is positive during inspiration, impairing venous return and CO (Braun, Cheney, & Lochnen, 1980; Cournand, Motley, Werko, & Richards, 1948). The lowest intrathoracic pressure occurs at the end of expiration when airway pressure equals atmospheric pressure. Thus, during mechanical ventilation, venous return is enhanced in the expiratory phase of the respiratory cycle, which is the opposite of the blood flow pattern with spontaneous respirations (Whitcomb, 1982). With the addition of PEEP, intrathoracic pressure remains positive throughout the ventilatory cycle and exaggerates the hemodynamic alterations caused by mechanical ventilation. Airway pressure never reaches atmospheric pressure, and venous return is hampered throughout the ventilatory cycle.

Research has shown that the effects of PEEP on CO are dependent on several factors: the intravascular volume status, the level of end-expiratory pressure applied, the compliance of the lung, and the functional residual capacity at the time PEEP was applied (Hopewell & Murray, 1982). Van Trigt, Spray, Pasque, Peyton, Pellom, Christion, Fagracus and Wechsler (1981) demonstrated in 16 patients undergoing coronary artery bypass grafting that PEEP equal to or greater than 10 centimeters (cm) of water significantly reduced CO. The decreased CO was due to decreased left-ventricular volume from impaired venous return.

Angerpointer, Farnsworth, and Williams (1977) evaluated the circulatory effects of PEEP in 11 postoperative cardiac surgical patients using phasic aortic blood flow measurements and high-fidelity pressure recordings to calculate CO. Positive end-expiratory pressure was applied in 5 cm of water increments to 15 cm water. A consistent trend of depression of cardiac performance was observed with each increment of PEEP in all subjects. The results showed that SV, CO, peak aortic blood flow, arterial BP and peak LV power were decreased at all levels of PEEP. At 15 cm water PEEP CO was reduced by 15 percent. These authors suggest that PEEP levels greater than 10 cm water should be used with caution after cardiac operations.

Research on the Thermodilution Technique

Historical Perspectives

The thermodilution technique was introduced by Fegler in 1953 (Fegler, 1954; Fegler, 1957). His initial studies in dogs showed good reproducibility of CO values with the thermodilution method, as well as agreement between the thermodilution method and the direct Fick procedure and the dye-dilution method. However, the routine use of the thermodilution technique in the clinical setting did not occur until 1971 when Swan and Ganz developed a flow-directed PA thermistor catheter (Ganz et al., 1971; Pugh, 1979). They demonstrated that the thermodilution technique was an accurate and reproducible technique for determining CO in man (Ganz et al., 1971; Forrester, Ganz, Diamond, McHugh, Chonette, & Swan, 1972; Swan & Ganz, 1980). Since that time, the thermodilution method has become widely used in the clinical setting. It also has been extensively studied since it was first introduced almost 30 years ago.

Pulmonary Artery Temperature Changes

A major variable affecting the accuracy and reproducibility of the thermodilution technique is the changes in PA blood temperature associated with certain conditions of ventilation (Weil, 1977). In his initial experiments Fegler (1957) observed variations in central venous blood temperature in association with respiratory activity which he attributed to intermittent inspiratory cooling of the right heart by the overlying lung tissue. If

temperature variation was large, an error was introduced into the CO calculations. Therefore, Fegler rejected those thermodilution curves that had exaggerated distortion due to variations in blood temperature.

Afonso et al., (1962) studied the thermal variations in the blood temperature of the superior vena cava (SVC) and the inferior vena cava (IVC) and the PA in anesthetized dogs during spontaneous respirations. Studies were done with inspired air at a room temperature of 72 degrees Fahrenheit (°F) and at 100° F. Rhythmical thermal fluctuations in these vessels correlated highly with the respiratory rate. The amplitude of the thermal changes was variable, but thermal changes of larger amplitude were associated with deeper respirations of longer duration and more forcible efforts. In addition, thermal variations disappeared during apnea induced by hyperventilation. These authors attributed the thermal variations in PA blood to changes in flow and blood temperature in the SVC and IVC during respiration.

A later study by Wessel, James, and Paul (1966) supported the work of Afonso et al. (1962). They examined the effects of respiration on blood temperature in dogs breathing spontaneously and with volume ventilators. Inspired air varied from temperatures of 20.5 - 22° C. to 60° C. Periodic temperature changes of the blood in association with the respiratory frequency was observed in all dogs. The most common pattern in the PA resulted in a

rapid temperature fall beginning in the IVC during mid or end inspiration, followed by a gradual return to base-line temperature, and a stable temperature during expiratory pause. Their data suggest that increased alveolar ventilation and airflow results in temperature differences between the PA and aorta due to heat exchange with the blood in the pulmonary vascular bed.

Respiratory Activity and the Thermodilution Technique

In 1971, Wessel, Paul, James, and Grahn studied the efficacy of room temperature injectate as a thermal indicator in dogs to: (a) measure CO from multiple sampling sites, (b) compare simultaneous thermal and dye-dilution CO determinations, (c) compare CO obtained by alternating iced and room temperature injectate; (d) evaluate non-indicator blood temperature changes, and (e) examine the effect of thermistor position within the blood stream on thermodilution curves. Twenty-four mongrel dogs were anesthetized with pentobarbital and ventilated with humidified 99.9 percent oxygen and a volume-controlled respirator.

Instrument and operator errors were minimized by using digital computer analysis in the integration of dilution curve areas. Indicator injections were done manually. All thermal dilution curves were recorded under conditions which minimized respiratory variations of blood temperature, either during apnea or by using rapid ventilator rates. Under these conditions, respiratory blood temperature

changes rarely exceeded 0.011° C in the PA. During spontaneous deep breathing the most prevalent pattern of respiratory changes resulted in an overestimation of the thermal curve due to a transient decrease in blood temperature with each inspiration, and therefore, an overestimation of CO.

The largest changes in blood temperature occurred during respiratory efforts against a closed respiratory valve, diaphragmatic respiratory efforts in open-chest animals, sudden onset of panting or shivering, or slow cyclic variations of blood pressure. Blood temperature changes during quiet spontaneous respiration were usually too small to affect thermodilution curves. These authors concluded that thermodilution CO measurements may not be feasible during conditions that increase respiratory intrathoracic pressure changes such as asynchronous spontaneous respiratory efforts in ventilated patients or automatically cycled deep breaths during mechanical ventilation. The findings of this study in regards to non-indicator blood temperature changes are consistent with the findings of Afonso et al. (1962).

Woods et al. (1976) evaluated the use of a PA thermistor catheter for PA pressure and thermodilution CO measurements in dogs during IPPV, PEEP, and apnea. They observed fluctuations in PA temperature which occurred at a frequency equal to the respiratory rate. The magnitude of these fluctuations varied with ventilatory pattern,

respiratory rate, and level of anesthesia among animals, and was not seen during apnea. Irregular PA temperature variations of 0.080 to 0.110° C were produced in lightly anesthetized animals with asynchronous breathing against the ventilator. Deeply anesthetized animals breathing spontaneously produced variations as large as 0.076° C. After a thoracotomy was done, irregular fluctuations in PA temperature of 0.021 to 0.034° C were observed. Temperature variation during IPPV and PEEP ranged from 0.031 to 0.086° C.

The PA temperature was relatively warm at end-expiration during spontaneous ventilation and was relatively cool at end-expiration during positive pressure ventilation. This reversal of temperature resulted in an overestimation of CO during IPPV and PEEP. Apnea was associated with the most stable PA temperature.

Successive measurements of CO deviated from one another by as much as 14 percent if injection of the thermal indicator was out of phase by one half a respiratory cycle. However, successive measurements deviated by only 0 to 6.7 percent if the indicator was injected at the same point in the ventilatory cycle. These investigators suggest that systematic injection of the indicator at the same point in the respiratory cycle can achieve relative accuracy for comparing sequential measurements of CO.

The findings of this study (Woods et al., 1976) are consistent with the observations of other researchers on the

thermodilution technique (Wessel et al., 1971). However, the lack of information for specific procedures makes it difficult to draw conclusions that are applicable to the clinical setting. These authors do not specify a particular phase in the ventilatory cycle to time injection of the indicator with, only that this should be done to minimize error in CO calculations. Also, the timing procedures for the injection of the thermal indicator is not described. Thus, it is difficult to determine how these investigators decided that end-expiration produced a positive error in CO determinations.

Armengol et al. (1981) also evaluated the fluctuations in CO in relation to the respiratory cycle during artificial ventilation in dogs. Their study investigated the need for repeated measurements of CO when using the thermodilution technique in order to ensure reproducibility of the data. Their protocol involved the injection of iced 5 percent dextrose in water at mid and end inspiration and expiration, and after 4 seconds of apnea. Timing of the injection of the indicator was determined by the ventilator's "drive-cam." Measurements were made during IPPV and PEEP.

Their data showed that sequential CO measurements taken at end-inspiration varied by only 5.1 percent and usually gave the highest CO. The maximal and minimal CO were significantly different in 15 of 17 experiments ($p < 0.05$ to 0.001). The authors concluded that the need for repeated measurements to minimize variation in data with the

thermodilution technique could be avoided by timing the injections of the thermal indicator with the respiratory cycle. Thus, these findings support the work of Woods et al. (1976).

This study controlled for internal validity by the subjects being their own controls. However, each dog received a minimum of 24 injections of 5 cubic centimeters (cc) of fluid for a total of 120 cc per dog. Each dog averaged 18 kilograms (kg). This amount of volume could affect the CO values obtained and invalidate the findings. Also, the sample consisted of six dogs, and is not generalizable to the human population. These authors do not describe specific procedures for timing the injection of the indicator, thus, this study could not be reproduced.

Jansen, Schreuder, Bogaard, Van Rooyen, and Versprille (1981) investigated the error in thermodilution CO measurements during different phases of the respiratory cycle, in pigs receiving mechanical ventilation with PEEP. Cardiac output was measured on both the left and right side of the heart during different levels of PEEP. The purpose of the study was to determine the most appropriate moment in the respiratory cycle for injection of the thermal indicator.

Thermodilution CO measurements were made with automatic injections of 0.9 percent room temperature saline. Injections were timed by dividing the ventilatory cycle into percentages from zero to 100 percent. Thermodilution

measurements were performed at all even percentages of the ventilatory cycle, for a total of 50 measurements per subject. A mean CO value was calculated from all 50 measurements.

These investigators found that if the injection of the thermal indicator was not timed with the respiratory cycle, differences in CO values up to 40 percent and 70 percent occurred for the left and right side of the heart respectively. They attribute the larger variations on the right side to changes in regional venous inflow and therefore, probably due to a continuous redistribution of different heat contents. These authors concluded that random measurements of thermodilution CO during IPPV and CPPV can be very unreliable. Their data demonstrated that the mean of a large series of thermodilution CO measurements evenly distributed over the respiratory cycle correlated well with the mean Fick CO.

This study reported much larger errors in CO determinations than other research studies. The accuracy of their results is questionable since only 0.5 cc of room temperature injectate was used to obtain the CO measurements. The authors conclude that the mean of several CO measurements evenly spaced throughout the respiratory cycle is more accurate than random measurements when using the thermodilution technique. The feasibility of their conclusions in the clinical setting has to be questioned. The need for multiple CO measurements to obtain an accurate

mean value is not practical for the cardiac surgical patient.

Snyder and Powner (1982) examined phasic variation in CO in dogs and in one patient being evaluated for brain death. The purposes of this study were: (a) to observe the relation between thermodilution CO values and the ventilation cycle, and (b) to define a practical method of determining a mean CO using the thermodilution technique in patients. A quasi-experimental repeated measures design was used for data collection. Ten dogs weighing 15-23 kg were anesthetized, paralyzed, and ventilated via endotracheal tubes with volume ventilators at a frequency of 10 insufflations per minute.

Thermodilution CO measurements were obtained at sequential seconds within the six second ventilatory cycle. The first CO measurement was initiated with peak airway pressure, and subsequent measurements were initiated at each second of the ventilation cycle at one minute intervals. Thermodilution CO measurements used both room temperature and iced saline injectate. Dye-dilution CO measurements were performed in a similar manner, except that injections occurred at five minute intervals. Thermodilution CO measurements required 12-30 minutes for collection and dye-dilution required 60 minutes. A mean CO was calculated using all values obtained during a six second ventilation cycle. The "flow variation" was calculated by subtracting the lowest CO value during one second of the ventilation

cycle from the highest CO value during that same cycle.

A Mann-Whitney U-Test was used for data analysis. The results showed that flow variation varied with inflation pressure, but not with tidal volume or PEEP. Mean variations in thermodilution CO using iced versus room temperature saline were not significantly different. Flow variation was less or absent with dye-dilution CO. Measurements initiated at peak airway pressure yielded CO values that were 96-129 percent of the corresponding mean CO during that ventilation pattern.

These authors conclude that initiation of thermodilution CO measurements at a particular moment of the ventilation cycle does not reliably determine absolute or even relative changes in average CO. They suggest that thermodilution CO measurements in mechanically ventilated patients should include at least three determinations initiated at evenly spaced intervals during the ventilation cycle.

As with the other studies, the effects of multiple treatments is a threat to internal validity (Campbell & Stanley, 1963). Each dog received a minimum of 126 cc of fluid which is a large amount of volume for a 15-23 kg animal. In addition, internal validity is threatened by the lack of randomization and the time element for data collection. Cardiac output can vary normally over a 60 minute period, and variations obtained in the experiment may reflect physiological changes and not the effects of the

interventions. As the authors mention, this would be a technically demanding exercise in the clinical setting. The mean CO value of wide variations might reflect an accurate CO or it might reflect artifact. Reproducibility of values would have to be confirmed.

Most of the research on thermodilution in man has involved the comparison of the thermodilution technique to another technique such as dye-dilution or Fick to determine the accuracy of the thermodilution CO value. Several researchers in reporting their data have mentioned cyclic variations in baseline temperatures during mechanical ventilation and the need to maintain a quiet, steady state of respiration while doing the measurements (Fischer, Benis, Jurado, Seely, Teirstein, & Litwak; 1978, Olsson et al., 1970; Sorensen et al., 1976).

In a clinical study by Olsson et al. (1970), CO by thermodilution was measured at rest in 11 patients during spontaneous respirations. The purpose of this study was to test the thermodilution technique using a dual thermistor pulmonary artery catheter and to compare the results of thermodilution with those of dye-dilution CO measurements. Results showed a correlation coefficient of 0.98 between thermodilution and dye-dilution.

During the study, the researchers observed variations in PA blood temperature associated with the respiratory rate. Some temperature variations were as large as the thermodilution curves. Thus, these investigators

recommended that patients refrain from unnecessary movements and avoid deep breaths during CO measurements to obtain reproducibility and precision of the thermodilution method.

Sorensen et al. (1976) compared thermodilution CO measurements and dye-dilution cardiac output measurements at low output states. They also observed PA temperature variations with the respiratory rate. To control for this, the ventilator was stopped and the animals were apneic during indicator injection.

Summary

This chapter has discussed the physiology of cardiac output and mechanical ventilation, and the principle of the thermodilution method. Related literature and research has been reviewed and critiqued. Several studies on the thermodilution method have been discussed. These studies demonstrate the controversy over the reliability of the method in the clinical setting. The major concern with the method is the changes in PA blood temperature with respiration during mechanical ventilation. Woods et al. (1976) and Armengol et al. (1981) advocate timing of the thermal indicator with the respiratory phase to enhance reproducibility of data. However, later studies by Jansen et al. (1981) and Snyder and Powner (1982) suggest that using one phase of ventilation is inaccurate and that a mean CO should be determined by timing measurements at evenly spaced intervals during one ventilatory cycle. All of these

studies used animals and have some threats to validity, as previously discussed. Based on the results of the animal studies discussed, and the existence of similar observations in man, a protocol was developed to examine the relationship between the phases of ventilation and thermodilution CO measurements in postoperative cardiac surgical patients on mechanical ventilation.

Chapter III: Methodology

This study investigated the relationship between CO determinations measured by timing the injection of the indicator at two different phases of ventilation in subjects receiving artificial ventilation, using the thermodilution technique. A quasi-experimental design was used to examine this relationship.

The Research Hypothesis

The null hypothesis for this study was: There is no difference between thermodilution CO values measured by timing the indicator injection at end-inspiration when compared to CO values measured by timing the indicator injection at end-expiration for patients receiving CPPV.

Experimental Variables

The dependent variable was the mean cardiac output value. The independent variable was the timing of the injection of the indicator with the phase of ventilation: (a) end-inspiration and (b) end-expiration.

Definition of Terms

1. Cardiac output: The number, in liters/minute, that appeared on the digital readout of the CO computer after injection of the thermal indicator for each individual measurement. Cardiac output was measured by injecting the thermal indicator at those points in the respiratory cycle specified to be end-inspiration and end-expiration.

2. Thermal indicator: A 0.9 percent saline solution at room temperatures of 22-25 degrees centigrade. Ten cc of indicator was used for each CO measurement.

3. Mean cardiac output: The mean of the three CO values obtained at each of the two points in the respiratory cycle. Each subject had a mean CO calculated at end-inspiration and at end-expiration.

4. Mechanical ventilation: All subjects received CPPV consisting of IMV with PEEP. All subjects were without spontaneous respiratory activity.

5. End-inspiration: The point at which peak inspiratory pressure (PIP) was reached and inspiration was terminated by the ventilator, and measured by visual observation of the pressure gauge of the ventilator.

6. End-expiration: The point in the ventilator cycle where exhalation of tidal volume was completed, and measured by visual observation of the bellows spirometer of the ventilator.

Research Design

A quasi-experimental repeated measures design was used to test the hypothesis. The study evaluated two experimental treatments. Each subject received both treatments in order to achieve experimental control. The experimental treatments consisted of measuring CO using the thermodilution method, by timing the injection of the indicator during (a) end-inspiration and (b) end-expiration.

Timing of the injection of the indicator for the first CO measurement for each subject began at end-inspiration or end-expiration in an alternating fashion. This was to control for the effect of the sequence of the CO measurements. The phase of ventilation for injection of the indicator for the first subject was selected by the flip of a coin. For this study, CO measurements for subject one began at end-expiration. Cardiac output measurements for subsequent subjects began at end-inspiration or end-expiration in alternating order.

Setting

Data were collected from subjects admitted to the cardiovascular intensive care unit (CVICU) of a 650-bed university teaching hospital in the San Francisco Bay Area. The CVICU is a 25-bed unit. Cardiovascular surgical patients are admitted to the CVICU directly from the operating room. All patients are intubated and are placed on mechanical ventilators. Artificial ventilation in this unit consists of IMV with PEEP. The usual ventilator parameters are: (a) respiratory rates of 6 to 10, (b) tidal volumes approximately 15 cc per kg, (c) fractional inspired oxygen (F_iO_2) of .40 to .70, (d) PEEP of a minimum of five cm of water pressure, and (e) inspiratory to expiratory (I:E) ratio of 1:2.

The measurement of CO using the thermodilution technique by nurses is a standard procedure in the CVICU at this hospital. Patients with thermodilution PA catheters in

place routinely have CO determinations measured every two to four hours as indicated by their hemodynamic status. The surgeons write standing orders so that the nurses can institute appropriate changes in the patient's treatment plan based on the CO measurement. Treatment modalities consist of giving volume replacement, adjusting the infusion rate of a vasoactive and/or inotropic medication, and adjusting ventilator settings.

Sample

A convenience sample of twenty subjects, male and female, was selected from those patients admitted for cardiac surgery. Criteria for eligibility of patients to be in the study were:

- consent
- 18 years of age or older
- able to speak, read, and write the English language
- scheduled for cardiac surgery

Informed consent was obtained from potential subjects on the night before their surgery (See Appendix A for the Consent Form). Of those that consented, patients were included in the study who:

- were less than 48 hours post cardiac surgery
- had a quadruple-lumen PA thermistor catheter in place
- were receiving IMV with 5 to 10 cm PEEP
- were receiving intravenous infusions at less than 150 ml/hr for the past two hours

- had a drug regime constant for the past 30 minutes and had not received diuretics for the past two hours
- had chest tube losses totaling less than 100 ml/hr for the past two hours

Sample Characteristics

The study sample consisted of 20 subjects, 17 men and 3 women, who met the criteria for inclusion in the study. Their ages ranged from 49 to 77 years, with a mean age of 63 years. All of the subjects underwent one of the following surgical procedures: (a) mitral valve replacement (MVR), (b) aortic valve replacement (AVR), (c) both mitral and aortic valve replacements, (d) coronary artery bypass grafts (CABG), and (e) CABG with MVR or AVR. Individual surgical procedures for each subject are listed in Table 1. Two subjects (numbers 9 and 18) were on the intra-aortic balloon pump (IABP). Vital signs for each subject obtained at the time of data collection are shown in Table 2.

All subjects were mechanically ventilated with the Bennett MA 1 volume set ventilator. They all received intermittent mandatory ventilation with 5 to 10 cm of PEEP. Table 3 lists individual subject ventilator settings for tidal volume, PEEP, PIP, and IMV rate. The mean PEEP value was 7.25 cm of water. The tidal volumes ranged from 900 to 1400 cc with a mean of 1115 cc. The cc per kg ranged from 9 to 17 cc/kg with a mean of 14. The mean PIP was 32 cm of water pressure and the mean IMV rate was 7.4 breaths per

Table 1

Individual Subject Data: Age, Sex, Surgical Procedure, EKG Rhythm, and Hemodynamic Medications

Subject No.	Age	Sex	Surgical Procedure*	EKG Rhythm*	Hemodynamic Medications*
1	58	male	MVR	V-paced	dopamine @ 8 mcq/kg/min SNP @ 2.7 mcq/kg/min NTG @ 1.5 mcq/kg/min lidocaine @ 2 mg/min isoproterenol @ 1 mcq/min
2	59	female	CABG	sinus	dopamine @ 2.8 mcq/kg/min SNP @ 0.8 mcq/kg/min NTG @ 0.5 mcq/kg/min
3	65	male	CABG & AVR	sinus	SNP @ 2.1 mcq/kg/min
4	51	male	CABG	sinus	SNP 0.7 mcq/kg/min lidocaine @ 2 mg/min
5	71	male	CABG	sinus	lidocaine @ 2 mg/min NTG @ 0.4 mcq/kg/min
6	51	male	AVR	sinus	epinephrine @ 8 mcq/min dopamine @ 8 mcq/kg/min lidocaine @ 1 mg/min
7	58	male	AVR	sinus	SNP @ 1 mcq/kg/min
8	66	male	AVR	sinus	dopamine @ 5.4 mcq/kg/min
9	58	female	CABG & IABP	sinus	NTG @ 0.5 mcq/kg/min SNP @ 1.2 mcq/kg/min
10	77	male	CABG	A-V paced	SNP @ 4.2 mcq/kg/min lidocaine @ 2 mg/min
11	54	male	CABG	A-paced	dopamine @ 4.7 mcq/kg/min SNP @ 1.8 mcq/kg/min NTG @ 1.1 mcq/kg/min lidocaine @ 2 mg/min epinephrine @ 1.7 mcq/min
12	54	male	CABG	A-paced	dopamine @ 5.1 mcq/kg/min SNP @ 1.1 mcq/kg/min lidocaine @ 2 mg/min

Table 1, continued

Subject No.	Age	Sex	Surgical Procedure*	EKG Rhythm*	Hemodynamic Medications*
13	77	male	AVR & CABG	sinus	NTG @ 1.2 mcq/kg/min dopamine @ 4 mcq/kg/min lidocaine @ 3 mg/min SNP @ 0.2 mcq/kg/min
14	49	male	CABG	A-paced	SNP @ 0.5 mcq/kg/min
15	77	male	AVR & CABG	sinus	dopamine @ 3.2 mcq/kg/min
16	70	male	AVR	sinus tachy-cardia	SNP @ 6.2 mcq/kg/min dopamine @ 4.1 mcq/kg/min trimethaphan @ 0.4 mg/min
17	72	male	MVR	A-paced	SNP @ 1 mcq/kg/min lidocaine @ 2 mg/min dopamine @ 2.5 mcq/kg/min
18	51	female	CABG & IABP	V-paced	SNP @ 1.7 mcq/kg/min NTG @ 0.7 mcq/kg/min lidocaine @ 2 mg/min dopamine @ 3.9 mcq/kg/min
19	65	male	AVR & MVR	sinus	lidocaine @ 1 mg/min dopamine @ 2.6 mcq/kg/min SNP @ 0.5 mcq/kg/min epinephrine @ 1 mcq/min
20	70	male	CABG	sinus	lidocaine @ 3 mg/min SNP @ 0.4 mcq/kg/min dopamine @ 4.4 mcq/kg/min

* MVR = mitral valve replacement, CABG = coronary artery bypass grafts, AVR = aortic valve replacement, IABP = intra aortic balloon pump; EKG = electrocardiogram; V = ventricular, A-V = atrial-ventricular sequential pacing, A= atrial; dopamine = dopamine hydrochloride, SNP = sodium nitroprusside, NTG = nitroglycerin, lidocaine = lidocaine hydrochloride, isoproterenol = isoproterenol hydrochloride, epinephrine = epinephrine hydrochloride, trimethaphan = trimethaphan camsylate; mcq = micrograms, kg = kilograms, min = minutes; mg = milligrams.

Table 2

Individual Subject Vital Signs

Subject No.	HR	MAP	RAP	PAD	Temperature °C	BSA M^2
		mm Hg				
1	100	71	13	22	36.2	1.75
2	92	74	14	16	37.7	2.08
3	84	72	13	16	38.3	1.86
4	84	72	7	12	37.7	2.00
5	95	70	12	17	38.0	1.98
6	104	64	18	26	37.9	1.88
7	94	68	11	14	37.3	1.84
8	100	65	9	24	39.0	2.09
9	102	84	9	16	36.9	2.06
10	104	65	10	16	37.0	1.72
11	107	67	17	19	37.3	1.83
12	107	77	10	13	37.9	1.83
13	90	78	15	22	36.6	2.02
14	92	69	15	18	37.6	2.44
15	82	94	12	22	37.1	2.02
16	108	76	12	12	35.9	2.03
17	101	75	7	15	37.5	1.80
18	111	75	20	30	38.5	1.68
19	92	74	11	21	37.0	1.96
20	90	62	12	15	37.5	1.85

HR = heart rate, MAP = mean arterial pressure, RAP = right atrial pressure, PAD = pulmonary artery diastolic pressure, mm Hg = millimeters of mercury, °C = degrees centigrade, BSA = body surface area, M^2 = square meters.

Table 3

Individual Subject Ventilator Settings

Subject No.	Tidal Volume		PEEP cm of H_2O	PIP cm of H_2O	IMV Rate/ minute
	cc	cc/kg			
1	1000	15	7.5	30	9
2	1300	14	5.0	32	6
3	1200	15	5.0	26	6
4	1000	12	7.5	30	6
5	1200	16	5.0	25	10
6	1200	16	7.5	55	10
7	1200	15	7.5	35	6
8	1300	15	10.0	35	10
9	900	12	5.0	30	7
10	900	14	10.0	32	6
11	1100	15	10.0	32	8
12	1100	15	7.5	26	8
13	1400	17	7.5	32	6
14	1200	9	10.0	44	8
15	1200	15	5.0	35	6
16	900	14	5.0	26	8
17	1000	14	10.0	28	6
18	900	13	5.0	30	8
19	1200	15	10.0	32	8
20	1100	15	5.0	24	6
mean	1115	14	7.3	32	7.4

kg = kilograms, cm = centimeters, H_2O = water, cc = cubic centimeters, PEEP = positive end-expiratory pressure, PIP = peak inspiratory pressure, IMV = intermittent mandatory ventilation

minute. Airway temperature was maintained at 35-37° C. for all subjects, as measured by a temperature probe placed at the connection to the endotracheal tube.

Experimental Protocol

Instruments

The following instruments were used for data collection.

1. Medical Chart. The medical chart was reviewed to obtain descriptive data regarding the subject's age, sex, height, weight, type of surgery, vital signs, ventilator settings, and medications. Subject weight and height was taken from the preoperative check list. At this setting, patients are weighed the morning of their surgery. Height is obtained at the time of admission in this hospital. Ventilator settings in the CVICU are recorded by Respiratory Therapists, and are checked every hour for postoperative intubated patients. Vital signs were measured by the investigator. Dosages of drug infusions were calculated by the investigator, based on drug concentration, infusion rate, and subject weight.

2. A 7 French Swan-Ganz Pulmonary Artery Thermistor Catheter (Model 93A-131-7F). This catheter is a quadruple lumen design with a balloon at the distal end. Lumen one is the distal lumen, and terminates at the tip of the catheter. Lumen two is the proximal lumen and terminates 30 cm from the tip. Lumen three contains the thermistor wires which

terminate 4 cm from the tip of the catheter. The fourth lumen allows for inflation and passive deflation of the balloon. The distal and proximal lumens of the catheter for each subject were connected to transducers in order to monitor both right atrial pressure and pulmonary artery pressure. When the distal lumen of the catheter is in the pulmonary artery, the proximal lumen is located in the right atrium (Forrester et al., 1972).

Correct position of the catheter was verified by an undamped pulmonary artery pressure trace and the ability to obtain a pulmonary capillary wedge pressure by injecting 1-1.5 cc of air in the balloon lumen of the catheter (Woods, 1976). Positioning of this catheter is determined by an appropriate PA waveform, and fluoroscopy is not necessary (Woods & Grose, 1982). Use of the Swan-Ganz catheter (Model 93A-131-7F) has shown that thermistor variability would account for less than 0.2 percent of variation between cardiac output measurements (Runciman et al., 1981).

3. Hewlett-Packard Monitor (Model 7826B) with oscilloscope, strip-chart recorder, and quartz transducer (Model 7120-7662). Each subject had two pressure transducers, one for MAP and one for both PA and RAP. Both transducers were positioned at the phlebostatic level at the mid axillary line and the fourth intercostal space. The transducers and the strip chart recorder were simultaneously zeroed and calibrated for each subject. The transducers were zeroed to atmospheric pressure by opening the

transducer to air and obtaining a zero pressure on the digital display of the monitor. Calibration was performed electronically by use of the built-in mechanisms of the monitor. In this setting, transducers and pressure modules are calibrated once a week with a mercury manometer.

4. Edwards Cardiac Output Computer (Model 9520A). The "self-test" procedure recommended by Edwards Laboratories (1979) was performed prior to data collection for each subject to ensure proper functioning of the equipment. In this setting, the CO computer is serviced once a month by the Biomedical Instrumentation Department. Two variables need to be known for the calculation of CO, the volume of injectate and the temperature of the injectate. The volume of injectate was measured by the investigator as 10 cc for each CO determination. Plastic 12 cc disposable syringes were used. The temperature of the injectate is continuously monitored by an injectate probe when using the Model 9520A CO computer. Once the volume and injectate temperature are known, the appropriate computation constant is entered into the computer (Edwards Laboratories, 1979).

After injection of the indicator, the temperature of the indicator-blood mixture is sensed by the distal thermistor in the catheter. The resulting time-temperature curve is amplified and integrated in the computer. Integration is automatically terminated when the curve returns to 30 percent of its peak. If the computer does not sense a thermal dilution curve within 12 seconds or if the

thermal dilution curve does not fall to 30 percent of its peak value within 72 seconds the computer will automatically reset (Edwards Laboratories, 1979). Research has shown that variations between cardiac output measurements attributable to computer error is less than two percent (Runciman et al., 1981).

5. Bennett MA I Ventilator with a bellows spirometer for measuring exhaled volume, and a pressure gauge for measuring peak inspiratory pressure. The Bennett MA I is a gas-powered, volume-cycled ventilator (Kirk & Mackeen, 1978). Peak inspiratory pressure is the pressure required to deliver the preset tidal volume. Inspiration ends when the pre-set volume limit is reached. The spirometer displays tidal volume (Puritan-Bennett, 1975). The spirometer fills during each expiration and maintains its filled position during the expiratory pause. The compressibility factor of the bellows is variable with each tidal volume set (McPherson, 1981). The Bennett spirometer measures an accurate volume within plus or minus 100 cc (Puritan-Bennett, 1976).

6. Protractor. A protractor was used to achieve accuracy in determining the angle of the backrest.

7. Digital Time-Elapse Clock. A stopwatch was used to time the rate of injection of the indicator and the interval between successive cardiac output measurements. Edwards Laboratories (1979) recommends that injection of the thermal indicator should not be slower than 10 cc in four seconds.

Manual injections have been shown to be as reproducible and reliable as automatic injections of the thermal indicator (Nelson & Houtchens, 1982). Research has shown that error due to procedural variation would contribute to less than two percent variation between CO measurements (Runciman et al., 1981).

Specific Procedures

Access to subjects was provided by the Clinical Nursing Coordinator of the CVICU, the Medical Director of the CVICU, and the university staff cardiovascular surgeons. Approval for the study was obtained from the Committee on Human Research at the University of California, San Francisco and from the Medical Committee for the Use of Human Subjects in Research at the hospital where the study was conducted.

The procedures involved in data collection for this study are a routine part of patient care in the CVICU. Each subject received only 30 cc of fluid more than he/she normally would have received in his/her routine care. The subjects were not at increased risk as there is no documentation in the literature that an extra 30 cc of fluid to an adult patient is associated with adverse effects.

1. All subjects were positioned supine with their backrests at 20 degree angles, verified with a protractor. Subjects were placed on their backs, and the investigator used a protractor that was placed on the bedframe to position the backrest at a 20 degree angle.

2. Data were collected when the subject had been at rest for a 15 minute period prior to data collection. Rest was defined as no turning, no endotracheal suctioning, and no chest tube stripping for 15 minutes prior to data collection and during data collection.

3. All subjects had 7F Swan-Ganz PA catheter in position at the time of the study. Subject transducers and the CO computer were zeroed and calibrated as described.

4. Measurement of caridac output. Cardiac output was measured three times by the thermodilution method for each treatment, so that each subject had three CO measurements timed at end-inspiration and three CO measurements timed at end-expiration, for a total of six CO measurements per subject.

5. Each CO measurement consisted of the injection of 10 cc of a 0.9 percent saline solution (NS), for a total of 60 cc of fluid per subject. Injectate temperatures ranged from 22.0 to 24.5° C. Central blood temperatures for subjects ranged from 35.9 to 39.0° C, with a mean temperature of 37.4° C (see Table 2).

6. Injection of the indicator was done manually by the investigator and took two to four seconds to complete. The six CO determinations for each subject were measured at the rate of one per minute. The CO displayed on the digital readout of the CO computer was read and recorded by the primary investigator. The time to obtain the six CO measurements for each subject was never more than eight

minutes. Total subject time for data collection, including positioning and calibration of the equipment was never more than 30 minutes.

7. At the time of data collection, each subject's medical chart was reviewed for the following data: the type of surgery, vital signs, medications, ventilator settings, age, sex, height, and weight. Vital signs included heart rate (HR), mean arterial pressure (MAP), right atrial pressure (RAP), PA diastolic pressure (PAD), pulmonary capillary wedge pressure (PCW), and central blood temperature from the PA catheter (see Appendix B for sample data collection tool). Vital signs were recorded by the investigator after calibration of the equipment and prior to the measurement of the six CO determinations.

8. Subject confidentiality and anonymity was protected by coding the data with a number assigned to each subject at the time informed consent was obtained. The code sheet and the signed consent forms were locked in the investigator's file.

Limitations of the Study

The following limitations of this study need to be noted:

1. The sample size is small, and focused on a specific setting. Also, a convenience sample, and not a probability sample, was used. Therefore, generalizability of the findings may be limited.

2. The data focus strictly on differences in CO values measured at different points in the respiratory cycle, and not on direction of change or accuracy of one value over another value.

3. Individual subject conditions, such as medications, age, ventilator settings, body temperature, hemodynamic parameters, or presence of other diseases in the body, are not controlled for in this study. This problem may be mitigated somewhat by the fact that each subject was his/her own control.

4. The primary investigator obtained consent from all of the subjects and was responsible for all data collection. Therefore, selection bias and instrumentation are threats to internal validity of this study.

Summary

This chapter has described the research design, the study population, the experimental protocol, and the instruments used in data collection. Limitations of the study also were presented.

Chapter IV: Results

Data were analyzed to determine whether to accept or reject the null hypothesis. The sample was composed of 20 postoperative cardiac surgical patients. A paired t-test was used to analyze the data. The level of significance for rejecting the null hypothesis was pre-set at $\alpha = .05$.

Findings

CO Measurement

Three CO measurements by the thermodilution technique were obtained by timing the injection of the thermal indicator at end-inspiration and at end-expiration. A mean of the three CO measurements obtained at each phase of ventilation was calculated. Table 4 lists all six CO determinations for each subject and the mean CO for each phase of ventilation. Mean CO values at end-inspiration ranged from 2.97 to 9.84 liters/minute, with a mean of 6.17 liters/minute. At end-expiration, mean CO values ranged from 2.80 to 9.44 liters/minute, with a mean of 5.24 liters/minute. Individual mean CO values and the differences for the two phases of ventilation are shown in Table 5. The differences were calculated as the CO value at end-inspiration minus the CO value at end-expiration. The range of differences in CO values was from 0.09 to 2.54 liters/minute. Cardiac output determinations measured at end-inspiration were higher than those measured at end-

Table 4

Individual Cardiac Output Values Obtained at End-inspiration and End-expiration

Subject No.	End-inspiration				End-expiration			
	Cardiac Output				Cardiac Output			
	1	2	3	Mean	1	2	3	Mean
1	4.46	4.12	4.13	4.24	3.51	3.68	3.70	3.63
2	9.92	9.50	10.10	9.84	7.57	7.58	7.55	7.57
3	6.30	7.05	6.75	6.70	4.77	4.42	4.47	4.55
4	5.69	6.60	5.80	6.03	4.04	4.10	3.83	3.99
5	3.79	3.80	4.04	3.88	5.56	4.34	4.40	4.77
6	6.69	6.14	5.83	6.22	5.10	5.62	5.67	5.46
7	7.20	7.00	6.97	7.06	6.04	5.60	6.00	5.88
8	6.68	6.45	7.18	6.77	4.60	6.76	7.47	6.28
9	5.11	5.07	5.11	5.10	4.33	4.46	4.50	4.43
10	4.19	3.67	3.79	3.88	3.13	2.97	2.90	3.00
11	6.61	7.32	6.90	6.94	5.90	5.78	6.13	5.94
12	6.61	6.33	5.85	6.26	5.53	5.31	5.51	5.45
13	4.93	5.84	5.36	5.38	3.91	4.31	4.00	4.07
14	8.33	7.52	8.85	8.23	5.64	5.24	6.18	5.69
15	6.11	5.89	6.08	6.03	4.85	4.33	4.88	4.69
16	6.50	6.66	6.43	6.53	6.21	6.48	6.21	6.30
17	8.17	9.77	9.37	9.10	7.66	10.07	10.59	9.44
18	3.21	2.96	2.76	2.98	2.98	2.69	2.73	2.80
19	4.85	5.39	5.19	5.14	5.57	4.38	5.19	5.05
20	7.40	7.06	7.01	7.18	5.62	6.19	5.66	5.82

Note. Cardiac output values in liters/minute.

Table 5

Mean Cardiac Output Measurements at End-inspiration and End-expiration and Differences for Each Subject

Subject No.	Cardiac Output end-inspiration	Cardiac Output end-expiration	Change
1	4.24	3.63	0.61
2*	9.84	7.57	2.27
3*	6.70	4.55	2.15
4*	6.03	3.99	2.04
5	3.88	4.77	-0.89
6	6.22	5.46	0.76
7*	7.06	5.88	1.18
8	6.77	6.28	0.49
9	5.10	4.43	0.67
10	3.88	3.00	0.88
11*	6.94	5.94	1.00
12	6.26	5.45	0.81
13*	5.38	4.07	1.31
14*	8.23	5.69	2.54
15*	6.03	4.69	1.34
16	6.53	6.30	0.23
17	9.10	9.44	-0.34
18	2.98	2.80	0.18
19	5.14	5.05	0.09
20*	7.16	5.82	1.34
Mean	6.17	5.24	0.93
S.D.+	1.73	1.54	

Significance $p < .001$ with $t = 4.74$

Note. Cardiac output values in liters/minute
+ standard deviation
* Change in CO of 1.0 liters/minute due to a change in the phase of ventilation the thermal indicator was injected

expiration except for in subject numbers 5 and 17. For these two subjects, CO values at end-expiration were the largest. The mean CO values calculated at the two phases of ventilation were analyzed with a paired t-test to determine if CO measurements obtained by timing indicator injection at end-inspiration were significantly different from CO measurements at end-expiration. The results were found to be statistically significant with $p < .001$ (Table 5). Thus, the null hypothesis for this study was rejected.

Derived Hemodynamic Parameters

Cardiac Index. Cardiac output values do not take into account the needs of the individual's tissues according to actual body size (Schroeder & Daily, 1976). A more specific measurement is the cardiac index (CI), which is the CO per square meter (M^2) of body surface area (BSA). For this reason, CI was calculated using the mean CO values for each phase of ventilation to determine whether controlling for BSA would alter the significance of the findings for this study.

Body surface area was determined from each subject's height and weight using the DuBois nomogram (DuBois, 1936). Table 6 lists individual mean CI values at end-inspiration and at end-expiration and their differences. As with CO, mean CI was higher at end-inspiration, except for subjects number 5 and 17. Mean CI values at end-inspiration ranged from 1.77 to 5.06 liters/minute/M^2, with a mean of 3.20 liters/minute/M^2. At end-expiration, mean CI values ranged

Table 6

Mean Cardiac Index Values at End-inspiration and End-expiration and Differences for Each Subject

Subject No.	Cardiac Index end-inspiration	Cardiac Index end-expiration	Change
1	2.42	2.07	0.35
2*	4.73	3.64	1.09
3*	3.60	2.45	1.15
4*	3.02	2.00	1.02
5	1.96	2.41	-0.45
6	3.31	2.91	0.40
7*	3.84	3.20	0.64
8	3.24	3.00	0.24
9	2.47	2.15	0.32
10*	2.26	1.74	0.52
11*	3.79	3.24	0.55
12	3.42	2.98	0.44
13*	2.66	2.02	0.64
14*	3.37	2.33	1.04
15*	2.98	2.32	0.66
16	3.57	3.44	0.13
17	5.06	5.23	-0.17
18	1.77	1.67	0.10
19	2.62	2.58	0.04
20*	3.87	3.15	0.72
mean	3.20	2.73	0.47
S.D.+	0.85	0.83	

significance $p < .001$ with $t = 4.95$

Note. Cardiac index values in liters/minute/M^2.
+ standard deviation
* change in cardiac index of 0.5 liters/minute/M^2 due to a change in the phase of ventilation the thermal indicator was injected.

from 1.67 to 5.24 liters/minute/M^2, with a mean of 2.73 liters/minute/M^2. The differences in mean CI at the two phases of ventilation ranged from 0.04 to 1.15 liters/minute/M^2.

These data were subjected to a paired t-test analysis to determine if CI values calculated at different times in the respiratory cycle were significantly different. As with the analysis of CO data, differences in CI values obtained at end-inspiration and end-expiration were found to be statistically significant with $p < .001$ (Table 6).

Systemic Vascular Resistance. Since CO is the expression of several variables, determination of those variables enables clinicians to guide therapy to specific needs. One of the variables affecting CO is afterload. In clinical practice, the closest approximation of afterload is the calculation of systemic vascular resistance, where resistance = pressure gradient/flow. Clinically, the formula is:

$$SVR = \frac{(MAP - RAP) \times 80}{CO}$$

where:

SVR = systemic vascular resistance

MAP = mean arterial pressure

RAP = right atrial pressure

80 = conversion factor to express the value in dynes/(seconds·cm-5).

Cardiac output is inversely related to afterload. Systemic vascular resistance might account for the differences in CO measurements that were obtained. Thus, SVR was calculated at end-inspiration and end-expiration using the mean CO values for each phase of ventilation. MAP and RAP were the same for both SVR calculations.

Table 7 lists individual mean SVR values and the differences for end-inspiration and end-expiration. Mean SVR values at end-inspiration ranged from 360 to 1478 dynes/(seconds·cm^{-5}), with a mean of 823. At end-expiration, mean SVR values ranged from 410 to 1571 dynes/(seconds·cm^{-5}), with a mean of 970. Systemic vascular resistance values calculated at end-inspiration were usually lower than values at end-expiration except for subjects number 5 and 17. The differences in mean SVR values ranged from 19 to 441 dynes/(seconds·cm^{-5}). A paired t-test analysis showed a significant difference between SVR values calculated at end-inspiration and end-expiration with $p < .001$ (Table 7).

Summary

The results of CO values measured at end-inspiration compared to CO values measured at end-expiration were found to be statistically significant at the $p < .001$ level of significance. Therefore, the null hypothesis for this study was rejected. Similar results were also obtained for hemodynamic parameters calculated using the CO measurement.

Table 7

Mean Systemic Vascular Resistance (SVR) at End-inspiration and End-expiration and Differences for Each Subject

Patient No.	SVR end-inspiration	SVR end-expiration	Change
1	1095	1278	-183
2	488	634	-146
3	704	1037	-333
4	862	1303	-441
5	1197	973	224
6	360	410	-50
7	646	776	-130
8	662	714	-52
9	1177	1354	-177
10	1133	1467	-334
11	576	674	-98
12	856	983	-127
13	937	1237	-300
14	525	760	-235
15	1088	1399	-311
16	539	559	-20
17	598	576	22
18	1478	1571	-93
19	980	999	-19
20	559	687	-128
mean	823	970	-147
S.D.+	301	347	

significance $p < .001$ with $t = -4.31$

Note. SVR in dynes/(seconds·cm^{-5}).
+ standard deviation

Differences in CI and SVR in relation to the phases of ventilation were found to be statistically significant ($p < .001$).

Chapter V: Discussion, Conclusions, and Recommendations

Discussion of Results

The null hypothesis for this study was: There is no difference between thermodilution CO values measured by timing the indicator injection at end-inspiration when compared to CO values measured by timing the indicator injection at end-expiration for patients receiving CPPV. Analysis of the data demonstrated that the differences between these two experimental treatments were statistically significant. Thus, the null hypothesis was rejected.

Variation in CO with Phase of Ventilation

Mean thermodilution CO measurements at end-inspiration were larger than mean CO measurements at end-expiration in 18 of the 20 subjects (see Table 4). One explanation for this could be the way in which the measurements were obtained. End-inspiration was operationalized for this study as the point when PIP was achieved, by visual observation of the pressure gauge of the ventilator. This means that the injection of the thermal indicator occurred just as intrathoracic pressure was the most positive. The ventilator ends inspiration as soon as the pre-set volume is delivered. Normal expiration begins immediately after active inspiration (Puritan-Bennett, 1975), and airway pressure returns to the level of end-expiratory pressure. Since venous return is facilitated during expiration for mechanically ventilated patients (Wade, 1982; Witcomb, 1982)

systemic venous return should be increased during this period. Theoretically then, CO might be greater if measured at this point in the ventilatory cycle.

On the other hand, end-expiration was operationalized for this study as the point when return of exhaled volume was completed, by visual observation of the bellows spirometer by the investigator. Thus, the subject's airway pressure was stabilized at the level of end-expiratory pressure. Use of this point for injection of the thermal indicator would find the subject's introthoracic pressure in a steady state. Therefore, there should not be significant changes in venous return at this time. These changes in pulmonary mechanics during mechanical ventilation are a possible explanation for why the mean CO at end-inspiration would be greater than the mean CO at end-expiration.

Afonso et al. (1962) and Wessel, James, and Paul (1966) demonstrated that changes in flow in the SVC and the IVC during respiration attributed to thermal variations in PA blood temperature. PA blood temperature was cooler at mid or end-inspiration and returned to base-line temperature during expiration. Woods et al. (1976) state that this cooling of PA blood temperature results in an overestimation of CO. Therefore, increased venous return occurring at the point used in the present study for end-inspiration could have caused a cooling of the PA blood temperature. This would also explain the results of a higher CO at end-inspiration.

However, the cooler PA blood temperatures in Woods et al. (1976) study were obtained at end-expiration. This is the opposite of the findings of the present study. The exact method of timing indicator injections for the study of Woods et al. is not known. Differences in reference points for timing could account for the reversal of the findings for the present study and the findings for Woods et al. (1976).

Armengol et al. (1981) also found CO values at end-inspiration to be higher. They state that the variation between measurements is less at end-inspiration. The present study did not demonstrate that CO measurements are more reproducible when timed with one phase of ventilation versus the other phase of ventilation.

Two subjects, numbers 5 and 17, had a reversal of this condition. For both subjects, mean CO was highest at end-expiration. Both subjects began their series of CO measurements at end-expiration, as did eight other subjects. There are no differences found in the descriptive characteristics of those two subjects when compared to the other 18 subjects that would account for this reversal in outcome of CO values. No correlation between hemodynamic parameters and ventilator settings and these two subjects' CO values can be found.

In reviewing the six individual CO measurements (see Table 3), subject number 17 had the largest variation between successive CO determinations. Both the first and

the fourth CO measurements for this subject were significantly lower than subsequent CO measurements. Also, this subject had above average CO measurements. These findings make it difficult to draw any conclusions about the reason for the change in CO from end-inspiration to end-expiration for this subject.

Range of Variation in CO Measurements

Differences in CO values ranged from 0.09 to 2.54 liters/minute (see Table 5). In subject numbers 2, 3, 4, 7, 11, 13, 14, 15, and 20 there was greater than a 1.0 liter/minute difference between the mean CO value measured at end-inspiration and the mean CO value measured at end-expiration. These variations in CO measurements ranged from 14 percent to 51 percent for these nine subjects. The literature on the thermodilution technique reports that a greater than 10 percent variation in CO determinations is clinically significant (Weil, 1977).

This possible range of variation in CO measurements can be used to demonstrate clinical significance of the findings. Using a CO for 5.0 liters/minute, measurements of 4.3 liters/minute or 5.7 liters/minute could be obtained with a 14 percent variation, or measurements of 2.45 liters/minute or 7.55 liters/minute could be obtained with a 51 percent variation in measurements. In each of these cases, therapeutic interventions would vary greatly depending on the CO measurement used to represent the hemodynamic status of the patient.

This range of variation between successive CO measurements is similar to those reported by other authors. Woods et al. (1976) reported deviations of 14 percent when injection of the thermal indicator occurred at different points in the ventilator cycle. Jansen et al. (1981) demonstrated differences in CO values up to 70 percent and Snyder and Powner (1982) obtained up to 29 percent differences in CO values when timing of the thermal indicator varied with the ventilatory cycle. Thus, the results of the present study are consistent with those of other researchers.

Conclusions and Recommendations

Implications for Nursing

In many critical care settings it is the responsibility of the nurse to obtain and record CO measurements. The critical care nurse also has the responsibility of interpreting the CO and other derived parameters and relating the data to the clinical picture of the patient. The CO and related hemodynamic measurements provide a dynamic description of myocardial performance (Weisel, Vito, Dennis, Berger, & Hechtman, 1975). Thus, fluid, drug, and respirator therapies can be directed to the specific area of need to best optimize the CO and therefore, tissue perfusion.

A major goal of treatment for the patient undergoing cardiac surgery is the improvement of myocardial function (Weisel, Berger, Hechtman, 1975). Serial CO determinations offer more information about patient response to therapy than single, isolated measurements. Depending on the institution, nursing staff change every 8, 10, or 12 hours, so that in a 24 hour period there would be a minimum of two persons performing the thermodilution technique if CO measurements were indicated.

The findings for this study demonstrate the need for standardized procedures for thermodilution CO measurements. The magnitude of error that can occur with inconsistencies in the technique could lead to inappropriate clinical interventions. Potentially, this could cause an unnecessary increase in cardiac work and/or myocardial and other tissue damage secondary to an inadequate CO for tissue perfusion. Therefore, timing of the injection of the thermal indicator should be consistent with one phase of ventilation.

The most recent research on the thermodilution technique (Snyder and Powner, 1982) reports that the use of one point in the ventilatory cycle for timing the thermal injection is unreliable for determining absolute or even relative changes in CO. These authors suggest that at least three CO determinations should be made by timing the indicator injection at evenly spaced intervals throughout the ventilatory cycle. The thermodilution CO could then be a mean value of CO over a full respiratory cycle. This

would be a difficult procedure to standardize in the clinical setting. Consistency of techniques between persons obtaining the measurements would be difficult to validate.

This author recommends that end-inspiration be used to time indicator injections. The reasons for this are: (a) it is an easier point to measure, and (b) research has shown that CO values obtained at end-inspiration are more reproducible (Armengol et al., 1981). The potential problem with timing the injection of the thermal indicator with end-inspiration is that the calculated CO value might be an over-estimation of true CO because of changes in venous return. However, as documented in the literature, sequential measurements of CO are more informative than single measurements, so this problem would be minimized if trends in CO were followed rather than absolute values.

Future Areas of Research

A limitation of this study is that the hypothesis focused only on differences in CO values and not on the accuracy of one value over the other if a difference did exist. Since statistical analysis was significant for the differences in CO measured at end-inspiration compared to the CO measured at end-expiration, two areas of research need to be considered.

1. Replication of the current study using subjects spontaneously breathing instead of those receiving mechanical ventilation. Simultaneous Fick CO measurements could be performed in order to determine accuracy, if

differences in CO occur during inspiration and expiration for subjects having spontaneous respirations.

2. Exact duplication of the current study with the addition of simultaneous dye-dilution CO measurements. Thermodilution and dye-dilution values could then be analyzed to determine whether thermodilution CO measurements at end-inspiration or at end-expiration have the closest correlation with dye-dilution, and thus the most accuracy.

3. Another limitation of this study was the effects of selection bias and the experimental variables. The primary investigator did all of the sampling and data collection. Suggestions for obtaining better control of extraneous variables for future research are: (a) having a second investigator, (b) use of a strip chart recorder to document the thermodilution curve wave form, (c) including the measurement of pulmonary vascular resistance in addition to SVR, (d) use of an automatic injector for the thermal indicator, or establish intrarater reliability for manual injections of the indicator, and (e) random assignment of the experimental treatments.

Summary

This study demonstrated that in the clinical setting variations in thermodilution CO measurements can occur if the injection of the indicator is timed at different points in the respiratory cycle for patients receiving mechanical ventilation. The implications for nursing practice and

education were discussed, and recommendations were made. Areas for future research were presented.

Appendix A

STANFORD UNIVERSITY HOSPITAL
CONSENT TO BE A RESEARCH SUBJECT

EXPERIMENTAL SUBJECT'S BILL OF RIGHTS

Persons who participate in a medical experiment are entitled to certain rights. These rights include but are not limited to the subject's right to: be informed of the nature and purpose of the experiment; be given an explanation of the procedures to be followed in the medical experiment, and any drug or device to be utilized; be given a description of any attendant discomforts and risks reasonably to be expected, if applicable; be given a disclosure of any appropriate alternatives, drugs, or devices that might be advantageous to the subject, their relative risks and benefits; be informed of the avenues of medical treatment, if any, available to the subject after the experiment if complications should arise; be given an opportunity to ask any questions concerning the experiment or the procedures involved; be instructed that consent to participate in the medical experiment may be withdrawn at any time and the subject may discontinue participation without prejudice; be given a copy of the signed and dated consent form; and be given the opportunity to decide to consent or not to consent to a medical experiment without the intervention of any element of force, fraud, deceit, duress, coercion or undue influence on the subject's decision.

INFORMED CONSENT

You are invited to participate in a study of the effects of the phases of breathing during artificial ventilation on measuring the pumping action of the heart. I hope to learn whether taking this measurement when you inhale or when you exhale affects the accuracy of the measurement. You were selected as a possible participant in this study because you are having cardiac surgery and cardiac surgery patients often have a catheter inserted that allows for post-operative measurement of how much blood their heart is pumping. If you return to the intensive care unit after your surgery with this catheter in place, you will be able to participate in this study. If you return to the intensive care unit without this catheter, you will not be included in the study.

If you decide to participate in this study, the following will happen:

PROCEDURES:
1. Ordinarily, when measurements of heart function are done, they are not timed with the phases of breathing. For purposes of this study, 3 measurements will be taken when you inhale, and 3 will be taken when you exhale.

2. Usually only 3 measurements are done at one time, but for this study you will have 6 measurements done. In order to do this measurement, 10 ml. of a saline (saltwater solution) is injected into the catheter. Thus, because of the 3 extra measurements, you will be getting a total of 2 oz. (60 ml.) of fluid injected instead of the 1 oz. (30 ml.) you would receive for the 3 standard measurements.

3. These measurements will be done at your bedside in the intensive care unit (ICU). Ms. Judi Lachenmyer, a registered nurse in the ICU and a graduate student at the University of California, San Francisco, will do the measurements. I have obtained permission from your physician and the head nurse of the ICU to do this study.

4. The procedures will take a maximum of 30 minutes and will not interfere with your routine care.

5. Ms. Lachenmyer, R.N. will also obtain information regarding your medical history from your medical chart.

RISKS/DISCOMFORTS: To the knowledge of this investigator the additional 30 ml. (1 oz.) of fluid injected into you through the catheter for this study will not cause any side effects.

BENEFITS: There will be no direct benefit to you from being in this study. However, it is hoped that the results of the study will show whether one way of measuring heart function is better than the other. This may benefit future patients like you who need these measurements.

Any data that may be published in scientific journals will not reveal your identity. In the interest of public safety, patient information will be provided to Federal and regulatory agencies as required.

Your decision whether or not to participate will not prejudice you or your medical care. If you decide to participate, you are free to withdraw your consent and to discontinue participation at any time without prejudice to you or effect on your medical care.

If you have any questions, I expect you to ask me. If you have any additional questions, Ms. lachenmyer, at 497-6081, will be happy to answer them.

In the event of physical injury that arises solely out of the negligence of the Stanford University Medical Center or its staff in this study, reimbursement for expenses incurred for necessary medical treatment and hospitalization is available. For further information, please call 497-5244 or write the Medical Center Committee for the Protection of Human Subjects at 851 Welch Road, Room 115, Palo Alto, California, 94304. In addition, if you are not satisfied with the manner in which this study is being conducted, you may report any complaints to the same telephone number and address.

YOUR SIGNATURE INDICATES THAT YOU HAVE READ AND UNDERSTAND THE ABOVE INFORMATION, THAT YOU HAVE DISCUSSED THIS STUDY WITH THE PRINCIPAL INVESTIGATOR, AND THAT YOU HAVE DECIDED TO PARTICIPATE BASED ON THE INFORMATION PROVIDED. A COPY OF THIS FORM IS AVAILABLE TO YOU UPON REQUEST.

_____ _____

Signature Date

_____

Signature of Investigator

Code number _____

Appendix B

DATA COLLECTION TOOL

AGE _____

SEX _____

HEIGHT _____

WEIGHT _____

BSA _____

SURGERY _____

_____

CATH DATA:

RA _____

RV _____

PA _____

PCW _____

LA _____

LV _____

AO _____

CO _____

CI _____

EF _____

VENTILATOR SETTINGS:

FIO_2 _____

RATE _____

VT _____

PEEP _____

PIP _____

MODE _____

VITAL SIGNS:

HR ____, EKG _____

MAP _____

RA/CVP _____

PAD _____

PCW _____

CORE TEMP _____

MEDICATIONS

_____

_____

_____

_____

_____

CO MEASUREMENTS:

INSPIRATION	EXPIRATION
1. _____ 2. _____ 3. _____	1. _____ 2. _____ 3. _____
mean CO _____ CI _____ SVR _____	mean CO _____ CI _____
Injectate temp _____	SVR _____

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