THE EFFECTS OF THE RESPIRATORY CYCLE BY MECHANICAL VENTILATION ON CARDIAC OUTPUT MEASURED USING THE THERMODILUTION METHOD

JUNICHI TAJIRI, M.D., HIROTADA KATSUYA, M.D., KAZUFUMI OKAMOTO, M.D.
KENJI URATA, M.D., AND TATSUO SATO, M.D.*

The feasibility of the thermodilution technique to measure cardiac output (CO) during positive pressure ventilation was assessed in 12 critically ill patients. An indicator (5 ml of 5% glucose in cold water) was injected at the mid and end of the inspiratory and expiratory phases of mechanical ventilation to see the effects of the respiratory cycle on thermodilution data. The 36 measurements at mid-inspiration yielded the smallest coefficient of variation (CV), 2.7%. The CV of 36 randomly selected measurements was 6.0%. CO at end-inspiration gave the highest value ($p < 0.05$). These data suggested that one major disadvantage of the thermodilution method, the need for repeated measurement to minimize the variation in data, could be overcome by timing the injection according to a certain phase of mechanical ventilation.

IN the bolus-injection thermodilution method to determine cardiac output (CO), repeated measurements are necessary to minimize the variation in data. This variation is caused by (1) non-uniform performance of the thermal indicator technique, (2) errors in signal production and processing in the catheter-computer system,¹ and (3) changes in right ventricular output which may vary during positive pressure ventilation due to cyclic changes in venous return² and right ventricular afterload.³

Attempts have been made to evaluate the effect of positive pressure ventilation on CO measurement using the thermodilution method, but most of them have been done in dogs, not in men. The authors, therefore, evaluated a varia-

tion in cardiac output data in relation to the respiratory cycle during mechanical ventilation in critically ill patients.

PATIENTS & METHODS

Twelve critically ill patients (9 males and 3 females, age ranging from 17 to 76) were studied. All patients were under mechanical ventilation with tidal volume of 10–15 ml/kg, and I:E ratio of 1:3–4 (CV 2000 or Servo 900B Ventilator). Respiratory frequency was set between 12–15 times/min. To minimize the effect of transpulmonary pressure, peak inspiratory pressure (PIP) was kept between 20–25 mmHg. A 7F thermodilution catheter was introduced through the right external jugular vein or right basilic vein into the pulmonary artery, and its thermister lead was connected to a cardiac output computer (Cardiac Output Computer 9520, Edwards Corporation). Electrocardiogram (ECG), heart rate, aortic, pulmonary arterial, and pulmonary artery

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Intensive Care Unit of Kumamoto University Hospital. * Third Department of Internal Medicine of Kumamoto University Medical School.

Mailing address: Junichi Tajiri, M.D., Third Department of Internal Medicine, Kumamoto University Medical School, 1-1-1 Honjo, Kumamoto 860, Japan

Fig.1. Bolus-injection technique.

Fig.2. Mean $\dot{Q}$ values after bolus injections at mid-(#1) and end-inspiration (#2) and at mid-(#3) and end-expiration (#4). For each series of four injection, the data were calculated as percentages of #2.

occlusion pressures were simultaneously recorded. The movement of chest wall was observed and the injection of cooled glucose solution was done either at the mid- or end- of the inspiratory or of the expiratory phase.

CO measurement: Five percent glucose solution and syringes were cooled in water with ice and salt. The temperature of the cooling water was kept below 1°C . After the stabilization of the circulation, the determination of CO were done rapidly. Five ml of cooled 5% glucose solution ($0-1^{\circ}\text{C}$) was injected as an indicator, manually within approximately one second, at mid- and end-inspiration, and mid- and end-expiration (Fig. 1). Immediately after 2 preliminary injections of 5 ml of the indicator to "cool" the catheter, at least 3 repeated injections were made in each phase. To avoid non-uniform performance of the technique, only one of the authors (J.T.) injected the indicator throughout the study. A paired Student's t-test was used to

TABLE I VARIATION IN DATA OF EACH SERIES

Point of the respiratory cycle	Coefficient of variation (CV)
randomly selected ($n = 36$)	6.0%
mid-inspiration ($n = 36$)	2.7%
end-inspiration ($n = 36$)	3.0%
mid-expiration ($n = 36$)	3.3%
end-expiration ($n = 36$)	4.5%

analyse the results.

RESULTS

For each series of four injections, cardiac output were expressed as percentages of the values obtained at the end-inspiration, to avoid inter-subject variation in the absolute values. Of 144 cardiac output measurements, 36 made at mid-inspiration had the smallest coefficient of variation (CV), 2.7%. The CV of 36 randomly selected measurements was 6.0% (Table I). Mean values of each series are shown in Fig. 2. Cardiac output at end-inspiration gave the highest CO value ($p < 0.05$).

DISCUSSION

There have been several studies related to cardiac output measurement using the thermol-dilution technique during mechanical ventilation.⁴⁻⁶ They have already pointed out that the respiratory cycle influenced greatly the cardiac output data. Variation in cardiac output data may reflect real changes in cardiac output within the respiratory cycle and in pulmonary blood temperature.⁷

Our study demonstrated that CO measured at end-inspiration was the highest value ($p < 0.05$). Our results in man agreed with those of Armen-gol et al., who showed that CO at end-inspiration was the highest in dogs.⁴

However, they did not mention the reason why CO measurement at end-inspiration was the highest value. Though the reason is as yet not clear, it may be speculated as follows; At end inspiration of mechanical ventilation the superior and inferior caval veins are depressed due to the compression of the inflated lungs. Furthermore,

a downward movement of diaphragm stretches the inferior caval vein and blood in the vein is squeezed into the right heart. These mechanical effects will cause increase in venous return and in pulmonary arterial flow.

The CV of CO measurement at mid and end inspiration and mid expiration was 2.7%, 3.0% and 3.3%, respectively. But the CV of CO measurement at end expiration was 4.5%.

It would be desirable to confirm our results with other methods of CO determination, but there is no other practical method available for bed-side measurement of CO at each phase of respiration. One major disadvantage of the thermodilution method is the need for repeated measurements to minimize variation in data. However, this could be overcome by timing the injection during mechanical ventilation.

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