Clinical Evaluation of Esophageal Doppler Cardiac Output Measurement during General Anesthesia

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We evaluate the accuracy of cardiac output measurement with esophageal Doppler ultrasonography (ECO). A total of 71 simultaneous measurements of esophageal Doppler and thermodilution cardiac output were compared in 16 patients undergoing general anesthesia in the supine position. ECO was determined easily with minimal experience, and significantly correlated with thermodilution cardiac output (TDCO) measurement ($P < 0.001$). The regression equation obtained was $Y = 0.983X + 0.019$, and the correlation coefficient was 0.935. Furthermore, ECO was more reproducible than TDCO. However, ECO is not able to assess CO accurately in either lateral or prone position and after cardiopulmonary bypass in open heart surgery. Our results suggest that the esophageal Doppler technique allows a noninvasive and continuous cardiac output monitoring in patients during general anesthesia, and that it is more useful in patients for whom invasive monitoring is considered inappropriate. However, further improvement in this technique will be necessary for its routine use in clinical anesthesia. (Key words: cardiac output, esophageal Doppler ultrasonography, thermodilution)

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The ability to determine cardiac output (CO) and related derived hemodynamic variables improves patient's care during anesthesia. The currently available method to obtain CO during anesthesia is themodilution flow measurement which requires placement of a pulmonary artery (PA) catheter in the central veins. As it is invasive and associated with thromboembolic, infectious, and traumatic complications[1–3], an alternative method of measuring CO have been required.

Doppler ultrasonography is a noninvasive alternative that has been shown to correlate well with thermodilution cardiac output (TDCO) measurement[4–7]. Early Doppler CO measurement required repeated positioning and holding probe, and it was troublesome during anesthesia. However, a Doppler ultrasonic probe was incorporated into a standard esophageal stethoscope, and this enables us to monitor Doppler signals from the descending aortic blood flow. In this study, we compared CO measurement made by esophageal Doppler ultrasonography with that made by standard thermodilution method during general anesthesia.

Methods

The patients were 16 (7 males and 9 females) adults scheduled for elective surgery at the central operating room of Hokkaido University Hospital. The mean age was 48.8

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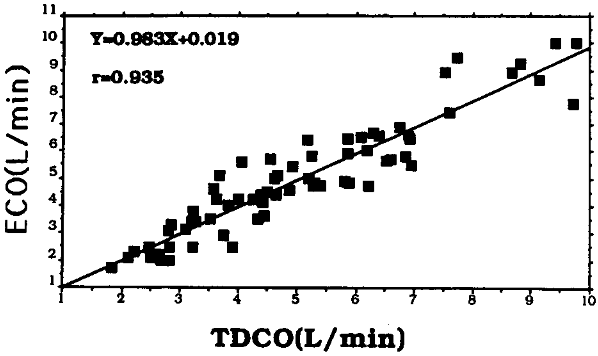

Fig. 1. Esophageal Doppler cardiac output (ECO) vs thermodilution cardiac output (TDCO) (n = 71). The correlation is significant ($P < 0.001$).

(range 25–63) years. After the routine preoperative assessment, all patients were found to require both an intra-arterial catheter and a Swan-Ganz pulmonary artery catheter during anesthesia and surgery. All patients whose surgical position was not supine were excluded. Informed consent was obtained from each patient at the time of pre-anesthesia visit.

After induction of anesthesia, placement of a PA catheter and insertion of an esophageal Doppler probe were made together with direct arterial blood pressure and ECG monitoring.

Ultrasonography Technique

The device utilized in this study was ACCUCOM®, (Datascope, Inc USA). Three steps are required to initiate continuous monitoring of CO. The first is a calculation of cross-sectional area of ascending aortic diameter (CSA). The diameter is determined from a nomogram contained in the monitor, based on age, sex, height, and weight. The CSA is automatically calculated from the aortic diameter. The second is insertion of the esophageal Doppler probe and adjustment for optimal Doppler signal. This provides descending aortic blood velocity (DAV). The final step is one time measurement of ascending aortic blood velocity (ABV) via Doppler ultrasound from the suprasternal notch and the ACCUCOM® computes CO. After the suprasternal CO measurement is done, the ACCUCOM® automatically computes the calibration factor K (K = CO/DAV). Then ACCUCOM® automatically and continuously computes CO from K factor and continuously measured DAV: CO = K*DAV.

Thermodilution Technique

TDCO was measured in patients with 7.5-F PA catheters (American Edwards) in place. Thermal indicator was a 5-ml of iced 5% dextrose solution. The injection was made at end-expiration of the patient's respiratory cycle. American Edwards SAT-1® CO computer was used in this series of study.

When TDCO was compared with simultaneous esophageal Doppler cardiac output (ECO), measurements were repeated at least two times as rapidly as possible. Isolated single measurements of TDCO or ECO were not included for analysis and less than two measurements of TDCO or ECO were not included for analysis of coefficient of variation (CV) for each epoch.

Statistics

All values were expressed as the mean ± the standard deviation of the mean. Average of thermodilution and esophageal Doppler cardiac ouput values within each epoch are used as the data points for a simple liner regression analysis and CV. The Student's t test and the paired t test were used for the statistical analysis. A probability value of $P < 0.05$ was considered statistically significant.

Results

A total of 71 paired measurement of average CO by esophageal Doppler and by thermodilution were obtained in 16 patients. The mean value of ECO was 4.94 ± 2.1 (range from 1.7–10.0) ℓ/min, whereas that of TDCO was 5.0 ± 1.9 (rang from 1.8–9.8) ℓ/min. As shown in figure 1, ECO was significantly

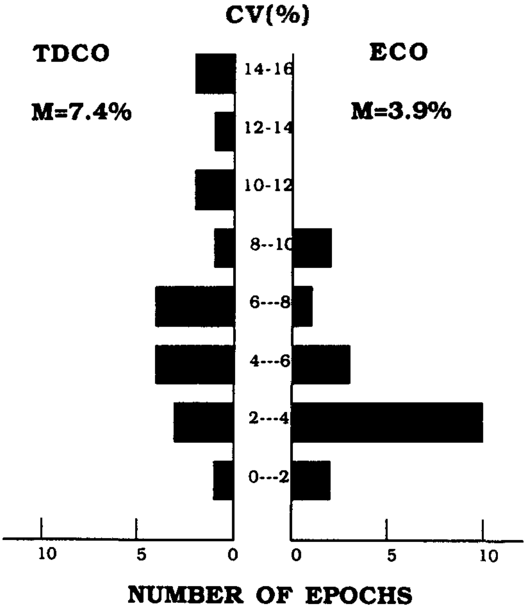

Fig. 2. Within epoch variability of thermodilution cardiac output (TDCO) vs esophageal Doppler cardiac output (ECO). ECO was more reproducible than TDCO ($P < 0.05$). M, mean coefficient of variation (CV).

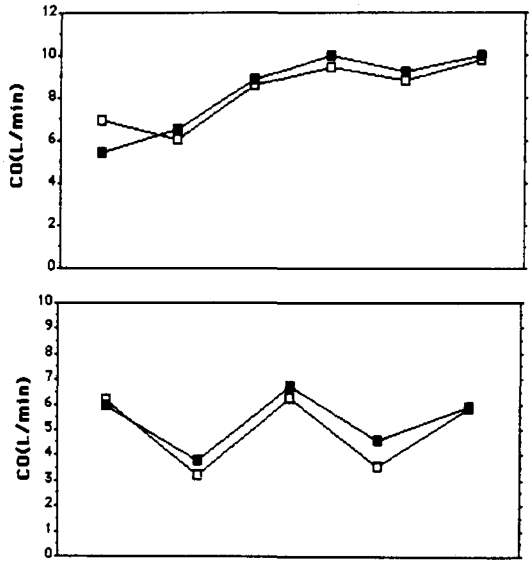

Fig. 3. Esophageal Doppler cardiac output (ECO) and thermodilution cardiac output (TDCO) values for each epoch recorded in two different patients. ■: ECO, □: TDCO, CO: cardiac output.

correlated with TDCO ($P < 0.001$). The regression equation obtained is Y = 0.983X + 0.019, and the correlation coefficient or r value was 0.935.

Within-epoch variability of ECO was compared to that of TDCO by examining the CV for each epoch (fig. 2). Analyzing 18 epochs in 5 patients, the mean CV for ECO was 3.9 ± 2.5%, while that for TDCO was 7.3 ± 4.2%. The difference between these CVs was significant, with ECO being the more reproducible ($P < 0.05$).

Inspection of epoch by epoch TDCO/ECO plots for each individual patient revealed a small difference between TDCO and ECO (fig. 3). However, calibration errors for individual patients often changed after cardiopulmonary bypass (fig. 4A) or after rotating a surgical table (fig. 4B).

There was no complication attributable to the use of the ACCUCOM®.

Discussion

Although it has been pointed out of sev-

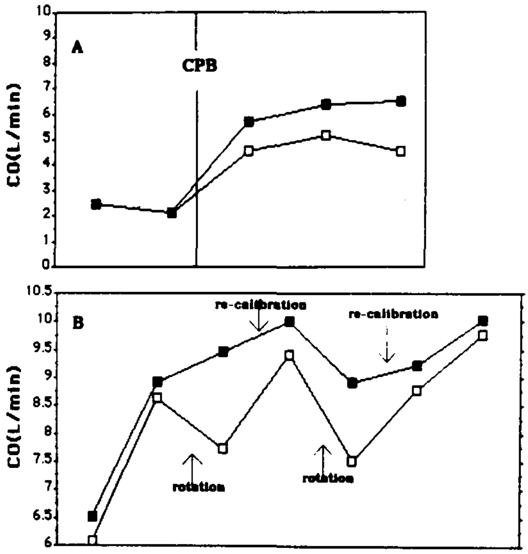

Fig. 4. The effect of cardiopulmonary bypass (A) and rotation of a surgical table (B) on esophageal Doppler cardiac output (ECO) and thermodilution cardiac output (TDCO). ■: ECO, □: TDCO, CO: cardiac output.

eral theoretical problems in the CO measurement by Doppler ultrasonography[8,9], this study revealed that CO measurement by esophageal Doppler ultrasonography provide a good assessment of CO of patients during general anesthesia. It is supported strongly by the high correlation coefficient value of 0.935, which is in agreement with the value of other investigators[10,11].

Compared with TDCO, ECO has the following several merits. First, it is able to monitor CO continuously and noninvasively without the need for repeated measurement procedures by the operator. Second, it is more reproducible than TDCO. Third, it is more easy to operate than TDCO with minimal experience. However, there are several demerits in the ECO. First, it is not able to assess CO accurately in all but supine position because the position of the esophageal Doppler probe is changed in lateral or prone positions and because it is not able to detect adequate amount of signals. Second, as shown in figure 4A, in open heart surgery, the calibration error was greatly altered upon emergence from cardiopulmonary bypass. The reason for this may be that manipulation of the heart and mediastinum during bypass often deviate the position between esophageal probe and the descending aorta, and/or that the distribution of blood flow between aortic arch vessels and descending aort may be altered during CPB and rapid rewarming. This is partly supported by the fact that the radial artery pressure does not accurately reflect central artery pressure immediately after the CPB[12].

The ACCUCOM® device has own demerits. First, the esophageal probe is too large for use in children and it distresses the adults when they are alert. Second, it does not work during an electrocautery.

Finally, the question should be answered whether the isolated CO values or trends are clinically valuable in the absence of cardiac filling pressure. CO and cardiac filling pressure are available simultaneously with the use of PA catheter, and permit calculation of vascular resistance and other related variables which enable us to evaluate hemodynamic changes and therapeutic effects during anesthesia. Therefore, further evaluations should be necessary to utilize CO values and trends alone in helping patient care during anesthesia.

In conclusion, we have shown that esophageal Doppler ultrasonography is a reliable, noninvasive method that allows continuous measurements of CO during general anesthesia. ECO has greater reproducibility than TDCO. Further investigations should address the utility of CO values or trends alone in helping the patient care. Further improvement of this device would be required.

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