CROATIAN MEDICAL JOURNAL
CMJ

43(6):680-684,2002

CLINICAL SCIENCES

Measuring Cardiac Output during Dobutamine Infusion after Off-pump Coronary Artery Bypass: Comparison of Transesophageal Echo-Doppler and Thermodilution

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Aim. To compare transesophageal echo-Doppler with thermodilution method for measuring cardiac output during dobutamine infusion after off-pump coronary artery bypass.

Method. Using transesophageal echo-Doppler and thermodilution methods, we measured cardiac output in 30 patients after off-pump coronary artery bypass, immediately before and 5, 15, and 30 min after the introduction of continuous dobutamine infusion (3 μg/kg/min). Paired t-test and Bland-Altman analysis were used to compare the results obtained by two methods in this prospective study.

Results. Significant increase in cardiac output during dobutamine infusion was detected by both thermodilution (from 3.9 ± 1.0 to 4.6 ± 1.1 L/min; $p < 0.001$) and transesophageal echo-Doppler (from 3.8 ± 1.2 to 4.8 ± 1.4 L/min; $p < 0.001$). Initial measurement results of thermodilution and transesophageal echo-Doppler techniques showed clinically acceptable agreement, with a mean difference of only +0.09 L/min (95% confidence interval (CI), –0.42 to +0.61). Subsequently repeated measurements after 5, 15, and 30 min showed almost the same agreement between the methods. The highest mean difference between the initial and repeated measurements was found at 5 min after the introduction of dobutamine infusion (–0.29 L/min, 95% CI, –1.06 to +0.48).

Conclusion. Transesophageal echo-Doppler and thermodilution can be interchangeable as methods for measuring cardiac output after off-pump coronary artery bypass.

Key words: *cardiac output; catheterization, Swan-Ganz; coronary artery bypass; dobutamine; echocardiography, transesophageal; thermodilution*

Swan-Ganz catheter and thermodilution have been used to measure cardiac output, which allows us to determine oxygen delivery and to assess how fluid and vasoactive therapy are driven through the body (1,2). Right heart catheterization, however, may be associated with certain risks and costs (3), although some studies advocate it (4).

Transesophageal sonography-based hemodynamic monitoring has been proposed as an alternative to the Swan-Ganz catheterization because it is free of many potential serious risks that pulmonary artery catheterization carries (5). The popularity and safety of diagnostic Doppler echocardiography in clinical medicine have led to the application of this technique in cardiac output measuring. All of the sonography-based methods for cardiac output monitoring are based upon the Doppler principle, although each technique employs slightly different equipment and measures blood flow at a different site in the body. The evolution of Doppler techniques into practical clinical monitoring tools required an ultrasound transducer that could be positioned and secured in place for continuous monitoring without the need for physician to repeate adjustments or perform time-consuming measurements (6).

The use of transesophageal echo-Doppler in cardiac output monitoring is controversial. Some authors claimed that the new technique is at least as accurate as thermodilution, which is a standard clinical method (7,8), whereas others showed that it was not (9,10). Because there is no method for direct measurement of cardiac output, debates on the most accurate method are likely to continue in the future. So far, there have been no reports on the measurement of cardiac output by use of new esophageal Echo-Doppler Hemosonic 100 method in patients with coronary artery disease who underwent off-pump surgery.

Limitations of transesophageal sonography are usually encountered when the esophageal/aortic anatomy precludes a good sonography window, which occurs in about 15% of cases (11).

The aim of this study was to assess transesophageal echo-Doppler method for cardiac output measurement in comparison with thermodilution in pa-

tients receiving dobutamine infusion after off-pump coronary artery bypass.

Patients and Methods

Patients

Thirty patients with coronary artery disease and the cardiac anesthesia risk evaluation score 1 (12), left ventricle ejection fraction more than 40%, and no evidence of myocardial infarction or diabetes in medical history were included in the prospective study between December 1, 2001, and February 10, 2002. There were 23 men aged between 37 and 71 years (median age 57) and 7 women aged between 45 and 64 years (median age 53). All the patients were treated at our institution within the study period. Median body surface area was 2 m^2 (range 1.7-2.4 m^2) in men and 1.8 m^2 (range 1.7-2.0 m^2) in women. The number of aorto-coronary bypasses per patient after the surgery ranged between 1 and 4 (median 3).

The study was approved by the Hospital Ethical Committee. Before entering the study, all the patients had signed an informed consent form. After undergoing an off-pump coronary artery bypass surgery, they were all administered dobutamine infusion (Dobutrex, Lilly, Giessen, Germany) and their cardiac output was measured by both transesophageal echo-Doppler and thermodilution method. The exclusion criteria were a damaged esophagus, irradiated mediastinum, and intracardiac shunt, but none of our patients met those criteria.

Anesthesia

All patients were premedicated with 10 mg morphine IM (Morphine Merck®, Merck KgaA, Darmstadt, Germany) 1 h before surgery. General anesthesia was induced with 0.1 mg/kg midazolam (Dormicum® F. Hoffman-La Roche Ltd., Basel, Switzerland), 25 μg/kg alfentanil (Rapifen® Janssen Pharmaceutica, Beerse, Belgium), and 0.5 mg/kg IV atracurium (Tracrium®, The Wellcome Foundation Ltd., London, UK). After orotracheal intubation, the lungs were mechanically ventilated (tidal volume 12 mL/kg, ventilatory frequency 12/min) (Cato, Dräger, Lübeck, Germany). Anesthesia was maintained with a nitrous-oxide mixture (60% oxygen and 40% nitrous oxide) and isoflurane (Forane®, Abbott Laboratories S.A., Abbott Park, IL, USA) (1-1.3 minimal alveolar concentration).

Hemodynamic Monitoring

After the collateral circulation was examined using Allen test (13), a catheter (Arrow International, Reading, PA, USA) was inserted into the left radial artery at the angle of 30-40° to the plane of the wrist, to measure direct intra-arterial blood pressure. Seldinger's technique (14) was applied for the central venous approach and the introduction of a 5-lumen Swan-Ganz catheter 7.5 Fr (Arrow International) into the internal jugular vein. Heart rate, arterial and central venous pressure values, and the progression of the catheter through the jugular vein into a pulmonary artery branch could be seen on a monitor (Hewlett Packard Viridia CMS; Böblingen, Germany) as well as the changes in pulmonary arterial pressure curve and values. The Swan-Ganz catheter was fixed after being placed into the pulmonary capillary wedge position, usually 50-60 cm from the internal jugular vein puncture site. A transducer (Peter von Berg, Kirchseeon, Germany) was used for transforming mechanical energy into electrical voltage.

After the surgery and before inotropic dobutamine infusion support, cardiac output was measured simultaneously by both thermodilution and transesophageal echo-Doppler. After this initial measurements, dobutamine infusion of 3 μg/kg/min was administered (Perfusor fm B/Braun; Braun Melsungen, Melsungen, Germany) and the simultaneous measurements of cardiac output by both methods repeated at 5, 15, and 30 min after the introduction of dobutamine infusion. Other hemodynamic parameters, such as mean arterial pressure, central venous pressure, mean pulmonary arterial pressure, pulmonary capillary wedge pressure, and heart rate were measured by Swan-Ganz catheter immediately after the assessment of cardiac output.

Thermodilution

Thermodilution with pulmonary artery catheter is currently the method of choice for measuring cardiac output in the clinical setting. By this technique, multiple cardiac output measurements can be obtained at intervals, using an inert indicator. A bolus of cold fluid is injected into the right atrium, and the resulting temperature change is detected by the thermistor in the pulmonary artery. Thermodilution cardiac output measurement cannot be reliably used in adult or pediatric patients with intracardiac shunts (6,15). During the patient's exhalation, an indicator (10 mL of 5% glucose at room temperature) was injected over 4 seconds into the central venous part of the Swan-Ganz catheter. The thermodilution curve was monitored on the thermodilution monitor (Cardiac Output Computer; Arrow International). Five consecutive measurements were done. The cardiac output mean value was calculated from the three of five measurements not differing reciprocally by more than 10%.

Transesophageal Echo-Doppler

Just after the induction of anesthesia, the transducer of the transesophageal echo-Doppler device (HemoSonic 100; Arrow International) was inserted through the nose and positioned in the esophagus. Before the insertion of transducer, the intended insertion depth for the ultrasound sensors must be estimated on the basis of the external anatomy. This is achieved by placing the dual sensor assembly onto the patient's chest juxtasternally at the level of the third intercostal space, approximately 35 cm from the incisors in a tracheally intubated patient. Under these conditions, ultrasonic transducers are approximately located between the fifth and sixth thoracic vertebrae, where the esophagus and the aorta run parallel for about 5 cm. Finally, the transducer handle is secured by a fixed arm attached to the operating table or bedside.

Statistics

The data were presented as mean values and standard deviations, after the normal distribution had been validated by one-sample Kolmogoroff-Smirnov test procedure. Only the subjects' age and body surface area were presented as nonparametric median values with data range.

Bivariate correlation was expressed as Pearson's correlation coefficient. Paired t-test was used for comparison of two repeated measurements of hemodynamic parameters, whereas univariate analysis of variance was used to compare measurements of cardiac output performed before and after dobutamine infusion. We compared two different methods of measuring cardiac output on the same subject using paired t-test together with Bland-Altman analysis (16,17), where the average value of the two methods was plotted against their difference. SPSS 7.5 for Windows (SPSS Inc., Chicago, IL, USA) and MedCalc 4.10 for Windows (1993/97 edition; MedCalc, Mariakerke, Belgium) software was used for statistical analysis. Only the two-tailed probability value of $p < 0.05$ was considered statistically significant.

Results

All hemodynamic parameters changed after the introduction of dobutamine infusion (Table 1). Compared with initial measurements, the values of mean arterial pressure and heart rate increased, whereas the values of central venous pressure, mean pulmonary arterial pressure, and pulmonary capillary wedge pressure significantly decreased during dobutamine treatment. Initial values of all hemodynamic

Table 1. Hemodynamic values (mean ± SD) measured in 30 patients by Swan-Ganz catheter during dobutamine infusion

Hemodynamic parameters	Measurement		t[b]	r[c]
	initial	after 30 min[a]		
Arterial pressure (mmHg)	64 ± 9	68 ± 10	-8.53	0.969
Central venous pressure (mmHg)	14 ± 2	12 ± 2	8.39	0.862
Pulmonary arterial pressure (mmHg)	24 ± 5	21 ± 5	10.85	0.962
Pulmonary capillary wedge pressure (mmHg)	19 ± 3	17 ± 4	8.74	0.930
Heart rate (beats per minute)	73 ± 8	78 ± 8	-11.95	0.958

[a]30 min after dobutamine infusion was started.
[b]$p < 0.001$.
[c]All correlation coefficients were significant at $p < 0.001$.

Table 2. Comparison of thermodilution and transesophageal echo-Doppler methods for estimating cardiac output in 30 patients during dobutamine infusion

	Cardiac output (L/min; mean ± SD)							
		during dobutamine infusion						
Method	initial	5 min	F[b]	15 min	F[b]	30 min	F[b]	F[a]
Thermodilution	3.9 ± 1.0	4.6 ± 1.1	472.4	4.6 ± 1.1	284.6	4.6 ± 1.1	56.1	294.9
Echo-Doppler	3.8 ± 1.2	4.8 ± 1.4	188.7	4.8 ± 1.4	341.4	4.8 ± 1.4	126.6	215.2
t[c]	-4.24	-4.09		-2.90		-2.58		
p[c]	< 0.001	< 0.001		0.007		0.015		

[a]Univariate repeated measures analysis of variance, with three degrees of freedom, p < 0.001 for all.
[b]Within-subject contrast after analysis of variance comparing repeated measurements with initial values, p < 0.001 for all.
[c]Paired sample t-test comparing thermodilution and echo-Doppler measurements.

parameters correlated highly and significantly with values obtained 30 min after dobutamine infusion (Pearson's r in Table 1, ranging from 0.86 for central venous pressure to 0.97 for mean arterial pressure, p < 0.001 for all).

Both thermodilution and transesophageal echo-Doppler measured significant increase in the cardiac output compared with the initial value (Table 2).

A comparison of cardiac output values obtained with thermodilution and transesophageal echo-Doppler revealed a significant difference between the methods (Table 2). The initial cardiac output measured with transesophageal echo-Doppler showed significantly lower values. In other measurements, transesophageal echo-Doppler method yielded significantly higher values (p < 0.05 for all four comparisons). The difference between cardiac output increase and the initial value was statistically lower when measured with thermodilution than when measured with transesophageal echo-Doppler.

The agreement between the methods was confirmed by Bland-Altman statistical analysis (Figs. 1-4). Initial values obtained by thermodilution and transesophageal echo-Doppler showed clinically acceptable agreement (Fig. 1), with a mean difference of only +0.09 L/min (95% confidence interval (CI), –0.42 to +0.61). Almost the same agreement between the methods was found for all three measurements after 5, 15, and 30 min. The mean difference between the two methods was highest when the initial measurement and measurement repeated 5 min after dobutamine infusion were compared (–0.29 L/min, with 95% CI, –1.06 to +0.48, Fig. 2). For other two measurements, the mean difference between the two methods was positioned at –0.23 L/min after 15 min (95% CI, –1.10 to +0.63, Fig. 3), and at –0.22 L/min after 30 min (95% CI, –1.12 to +0.68, Fig. 4). Slightly wider but still clinically irrelevant 95% CI limits range were observed in repeated measurements of cardiac output in our patients.

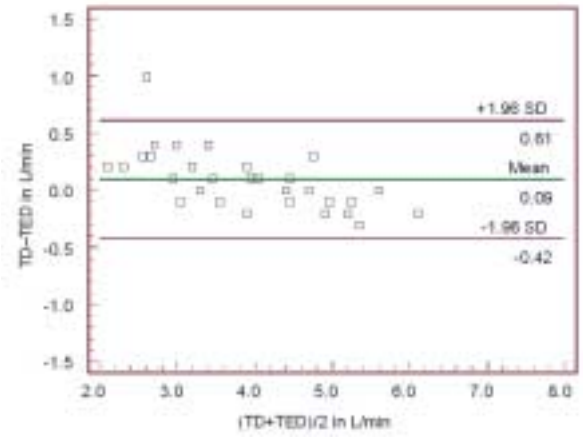

Figure 1. Bias plot according to Bland and Altman (14,15) of cardiac output initial measurement by thermodilution (TD) vs transesophageal echo-Doppler (TED) methods.

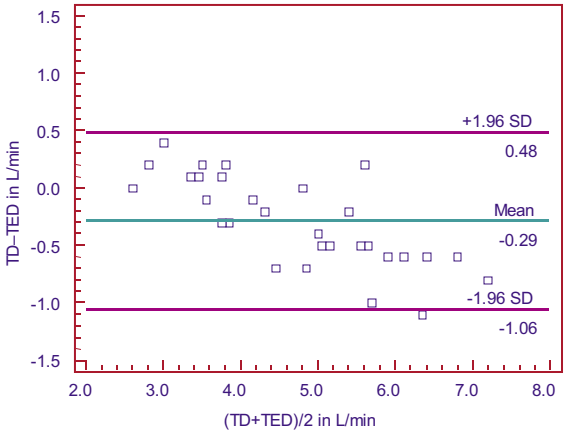

Figure 2. Bias plot according to Bland and Altman (14,15) of cardiac output measurement 5 minute after dobutamine infusion by thermodilution (TD) vs transesophageal echo-Doppler (TED) methods.

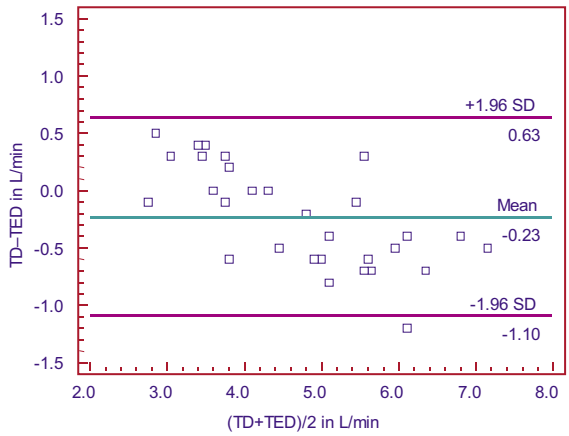

Figure 3. Bias plot according to Bland and Altman (14,15) of cardiac output measurement 15 minute after dobutamine infusion by thermodilution (TD) vs transesophageal echo-Doppler (TED) methods.

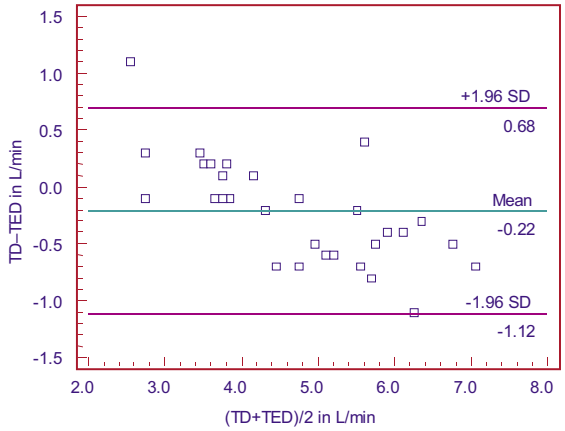

Figure 4. Bias plot according to Bland and Altman (14,15) of cardiac output measurement 30 minute after dobutamine infusion by thermodilution (TD) vs transesophageal echo-Doppler (TED) method

Discussion

Dobutamine infusion changed the values of all hemodynamic parameters and increased cardiac output regardless of the measurement method. This is explained by dobutamine's positive inotropic and chronotropic actions. Although the agreement between measurements performed with transesophageal echo-Doppler and thermodilution was reduced after dobutamine infusion was started, it remained within a satisfactory range during the entire dobutamine administration. In spite of significant differences in cardiac output changes found with thermodilution and transesophageal echo-Doppler at initial measurement and measurements during dobutamine infusion, these changes were clinically irrelevant. Cardiac output aberrations up to 15% are not clinically visible, which suggests that both methods were equally valuable in cardiac output assessment.

Schmidt et al (9) studied 16 surgical cardiac patients with extracorporeal circulation to evaluate the performance of Accucom (Datascope, Paramus, NY, USA), the second generation transesophageal echo-Doppler device. Like the previous device, the Accucom allowed the operator to monitor aortic blood flow velocities, but it used built-in nomograms in relation to the patient's height, weight, age, and sex to estimate the inner diameter of the aorta. In that study, cardiac output values measured with Accucom showed high dispersal compared with thermodilution cardiac output (correlation coefficient $r = 0.520$). The authors concluded that the second generation of transesophageal echo-Doppler devices was unsuitable for accurate measurement of cardiac output.

Variations in the cross-section area of the aorta have been suggested as possible important causes of transesophageal echo-Doppler inaccuracy. During the systole, the diameter of the aorta increases by 15% on average (18).

Transesophageal echo-Doppler devices of the new generation, such as the HemoSonic 100, measure the aortic diameter by means of transesophageal M-Mode echo ultrasonography. Signals received by the M-Mode echo transducer are displayed immediately on the screen. Jaeggi et al (19) found a weak correlation ($r = 0.3$) between the cardiac index and the values obtained using thermodilution during the application of HemoSonic 100 system. In their subjects, extracorporeal circulation was applied, but without any pharmacological support.

Another report showed that cardiac output measured with transesophageal echo-Doppler during epidural anesthesia was overestimated, which was explained by blood flow redistribution from the upper to the lower body (20). Klotz et al (21) observed an increase in the difference between values obtained by thermodilution and transesophageal echo-Doppler from –0.96 to –1.5 L/min during aortic cross-clamping in six patients, which can also be explained by blood flow redistribution from the lower to the upper parts of the body.

Cariou et al (3) compared aortic blood flow measured by transesophageal echo-Doppler and cardiac output measured by thermodilution in 20 critically ill patients. They found a very strong linear correlation, greater than 0.830. The correlation coefficient greater than 0.920 was also reported by Valtier et al (8).

Our study, which involved a specific group of subjects, may lead to a more frequent clinical application of HemoSonic 100 system as an alternative to thermodilution for the measurement of cardiac output. Moreover, our investigation confirmed the importance of direct measuring of the aortal diameter during the assessment of the cardiac output.

The limitation of the study is a relatively small and rather specific group of patients with regard to the surgical procedure (extracorporeal circulation was not applied) and hemodynamic conditions during the measurement of cardiac output (dobutamine infusion).

Our study also failed to provide a full answer to the question of precision of transesophageal echo-Doppler as a method for cardiac output measuring. The final evaluation should take into account the technical performance of the device itself, value of the cardiac output thus assessed, and hemodynamic conditions, especially because of the possible redistribution of the circulating blood during measurement.

Possible disadvantages of transesophageal echo-Doppler devices are frequent repositioning of the transducer, poor signal during manipulations in the aorta, and the use of electrosurgery. During electrosurgery, we observed occasional transient technical errors (sonographical signal artifacts).

In conclusion, transesophageal echo-Doppler as a non-invasive and relatively cheap method, with continuous agreement in measuring cardiac output, can be an alternative method to thermodilution.

Acknowledgment

The authors thank Dr. Mladen Petrovečki for his assistance with the statistical analysis of the data.

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Received: February 27, 2002

Accepted: June 12, 2002

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