Intensive Care Med (1996) 22:34–38

ORIGINAL

A. Descorps-Declère
N. Smaïl
B. Vigué
J. Duranteau
O. Mimoz
A. Edouard
K. Samii

Transgastric, pulsed Doppler echocardiographic determination of cardiac output

Received: 16 March 1994
Accepted: 24 February 1995

A. Descorps-Declère (✉) · N. Smail · B. Vigué · J. Duranteau · O. Mimoz · A. Edouard · K. Samïl
Service d'Anesthésie Réanimation, Hôpital de Bicêtre, 78 rue du Général Leclerc, F-94275 Le Kremlin Bicêtre Cedex, France

Abstract *Objective:* The aim of this study was to evaluate the accuracy of cardiac output measurement with transesophageal echocardiography (TEE) using a transgastric, pulsed Doppler method in acutely ill patients.
Design: Cardiac output was simultaneously measured by thermodilution (TD) and a transgastric, pulsed Doppler method.
Setting: The study was carried out in a surgical intensive care unit as part of the management protocol of the patients.
Patients: Thirty consecutive acutely ill patients with a Swan-Ganz catheter, mechanically ventilated, sedated and with a stable hemodynamic condition were included.
Measurements: Pulsed Doppler TEE was performed using a transgastric approach in order to obtain a long axis view of the left ventricle. Cardiac output was calculated from the left ventricular outflow tract diameter, the velocity time integral of the blood flow profile and heart rate.
Results: One patient was excluded because of the presence of aortic regurgitation and another, because of the impossibility of obtaining a transgastric view. Twenty-eight simultaneous measurements were performed in 28 patients. A clinically acceptable correlation and agreement were found between the two methods (Doppler cardiac output = 0.889 thermodilution cardiac output +0.74 l/min, $r = 0.975$, $p < 0.0001$).
Conclusion: Transgastric pulsed Doppler measurement across the left ventricular outflow tract with TEE is a very feasible and clinically acceptable method for cardiac output measurement in acutely ill patients.

Key words Cardiac output · Transesophageal echocardiography · Doppler ultrasonography

Introduction

Transesophageal echocardiography (TEE) is now frequently used in intensive care units for hemodynamic monitoring of acutely ill patients. However, the standard for cardiac output measurement remains thermodilution (TD).

The feasability of cardiac output measurement by TEE has recently improved with the description of a long axis view of the heart using a transgastric approach [1] and with the availability of biplane probes permitting an easier visualization of the left ventricular outflow tract and/or a more accurate measurement of the mitral annulus area.

Recently, published studies using single plane or biplane probe and pulsed or continuous wave Doppler methods for cardiac output measurement have obtained similar good agreement with the thermodilution method [2–6]. However, biplane probes and single plane probes with continuous Doppler are not available in all institutions in France.

The aim of this study was to evaluate the correlation between pulsed Doppler TEE cardiac output measurement using a single-plane probe and TD simultaneous measurement in acutely ill patients.

Materials and methods

Thirty consecutive acutely ill patients (26 men and 4 women, mean age 46 years, range 23–73 years) were studied. The inclusion criteria were the presence of a Swan-Ganz catheter, controlled ventilation, sedation and a stable hemodynamic condition. The exclusion criteria were aortic or tricuspid insufficiency, left ventricular outflow tract obstruction arrhythmia and esophageal abnormality. The study was approved by the institutional ethics committee.

Simultaneous cardiac output measurement with TEE and thermodilution were performed by two investigators. The same investigator always measured cardiac output with TEE and was blind to the hemodynamic data obtained by thermodilution. The thermodilution measurement of cardiac output was performed by another investigator in triplicate in each patient using 10 ml of iced saline solution. Cardiac output was computed as the average of three values with a difference of $<10\%$. If the difference between the lowest and highest values of the first three measurements was $>10\%$, two additional cardiac output measurements were performed and the extreme values were discarded before averaging. A 5 MHz single plane transesophageal transducer (Hewlett Packard, was used with a Hewlett Packard Sonos 1000 ultrasound system. After a classical examination, the sequences were recorded on a videotape. From a five chamber view of the left ventricle, the left ventricular outflow tract was displayed several times for further determination of its diameter. Then the probe was inserted further into the gastric cavity and, after anterolateral flexion of its tip, was withdrawn until the transgastric long axis view of the left ventricle was obtained. This position allowed for visualization of the left ventricular outflow tract, the aortic valves and the ascending aorta (Fig. 1). The left ventricular outflow tract and the ascending aorta were generally in good alignment for Doppler examination. In some cases, slight manipulations of the probe, such as rotation, lateral flexion or withdrawal, were necessary to obtain good alignment. Pulsed Doppler measurements were obtained by placing the sampling volume in the left ventricular outflow tract just below the aortic annulus (Fig. 2). Several Doppler waves were recorded during at least two respiratory cycles. The respiratory wave was visualized on the screen of the echocardiograph and recorded on videotape with the Doppler wave. Cardiac output was calculated off line by an investigator unaware of the results obtained by thermodilution, using the video analysis software program already incorporated into the echocardiograph. The diameter of the left ventricular outflow tract was measured at several views at the maximum opening of the aortic valves, just below the insertion of the valve leaflets and at the same site as the velocity measurements, using an inner edge-to-inner edge technique. The largest diameter was used for the calculations. The leading edge of the consecutive Doppler velocity curves during an entire respiratory cycle [4–6 measurements) were manually traced with the trackball of the echographic system, and the average velocity time integral was calculated. The Doppler cardiac output was calculated using the formula: cardiac output (l/min) = cross-sectional area (cm^2)$\times$time velocity integral (cm)$\times$heart rate (beats/min). The area was calculated from the left ventricular outflow tract diameter, assuming that just below the aortic annulus the left ventricular outflow is circular, and using the formula: area (cm^2) = [diameter (cm)]$^2 \times \pi/4$.

In five randomly selected patients, measurement of the diameter of the left ventricular outflow tract and measurement of the velocity time integral were repeated from the videotape recording. Interobserver variability was expressed as a percentage error for each measurement and was determined as the difference between the two observers divided by the mean value of the two observations.

Statistical analysis

The statistical analysis involved linear regression analysis and the use of Bland and Altman's method [7] to correlate the Doppler with the thermodilution cardiac output values. The slope and intercept of the regression line were compared to the slope and intercept of the identity line using Student's t-test. The bias of the difference be-

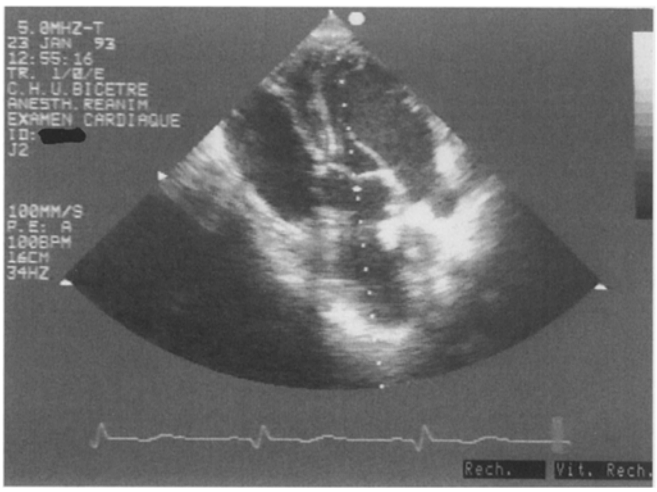

Fig. 1 The transgastric approach for transesophageal echocardiography allows visualization on the left ventricular outflow tract, the aortic valves and the ascending aorta

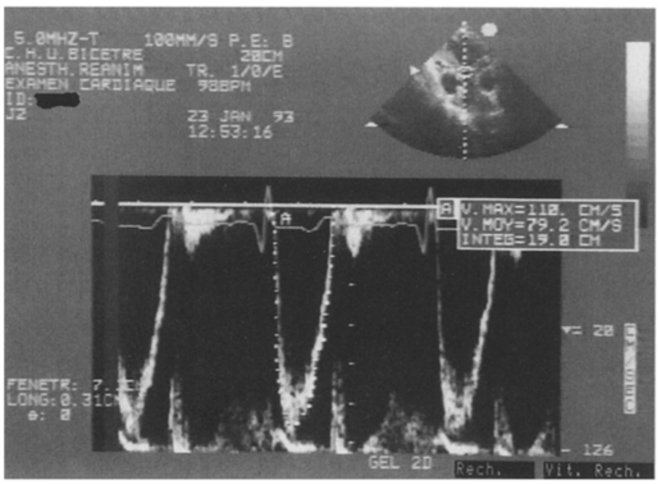

Fig. 2 The pulsed Doppler signal was measured by placing the sampling volume in the left ventricular outflow tract just below the aortic annulus

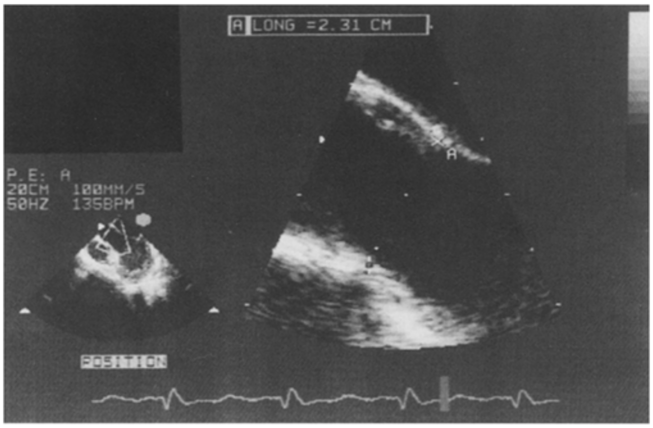

Fig. 3 The diameter of the left ventricular outflow was measured on a truncated five-cavity view of the left ventricle, which provides a good view of the left ventricular outflow tract

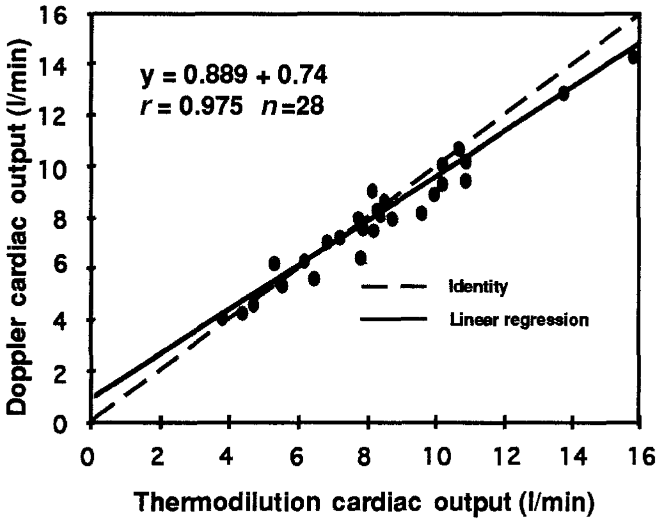

Fig. 4 Correlation between cardiac output obtained by the thermodilution and Doppler techniques

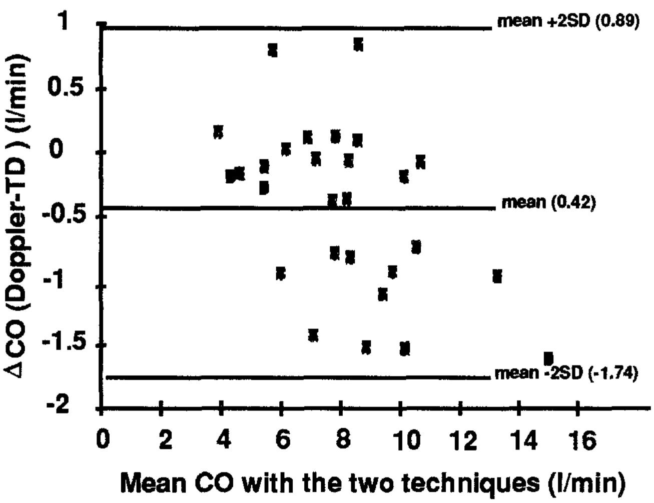

Fig. 5 Comparison of the difference in cardiac output derived by the thermodilution and Doppler techniques with left ventricular outflow, and the mean cardiac output values obtained with the two methods

tween TEE and TD was also assessed using Student's *t*-test. All the data are expressed as mean values ± SD. Statistical significance was determined as $p < 0.05$.

Results

One patient was excluded from the study because of the presence of moderate aortic regurgitation, and in another patient the transgastric view was impossible to obtain. Twenty-eight simultaneous, pulsed-wave Doppler and thermodilution cardiac output measurements were performed in 28 patients. The mean left ventricular outflow tract diameter was 2.38 ± 0.22 cm (range 1.9 – 2.72 cm), the mean calculated area was 4.48 ± 0.82 cm^2 (range 2.83 – 5.81 cm^2), and the mean pulsed Doppler time velocity integral was 17.01 ± 3.25 cm (range 10.56 – 26.2 cm). The mean heart rate was 103 ± 16 min^{-1} (range 70 – 136 min^{-1}), the mean Doppler cardiac output was 7.85 ± 2.41 l/min (range 3.99 – 14.2 l/min) and the mean thermodilution cardiac output was 8.27 ± 2.73 l/min (range 3.82 ± 15.8 l/min). Good correlation and agreement were found between the two methods with Doppler cardiac output = 0.889 thermodilution cardiac output + 0.74 l/min, $r = 0.975$, $p < 0.0001$ (Fig. 4). However the slope of the regression line was significantly different from the identity line ($p < 0.0001$) and the intercept was significantly different from zero ($p < 0.001$). The plot of TEE–TD versus (TEE + TD)/2 according to the Bland and Altman method showed a mean bias ± 2 SD of the mean bias of −0.42 ± 1.31 l/min (Fig. 5). The mean duration of a Doppler cardiac output measurement was 18 ± 5 min.

The mean percentage error between the two observers for the diameter of the left ventricular outflow tract was 6%. The mean percentage error between the two observers for the velocity time integral was 5%.

Discussion

This study demonstrates the feasibility of cardiac output measurement by transesophageal echocardiography with a pulsed Doppler method across the left ventricular outflow tract using a transgastric approach, and the clinically acceptable correlation between this method and standard thermodilution. Previous studies have already demonstrated the accuracy of transthoracic Doppler echocardiography for measuring cardiac output [7 – 13]. With this method, a cross-sectional area of a particular cardiac or major vessel level is derived from a two-dimensional echocardiographic measurement of the area, and the Doppler velocity, which is obtained at the same site, is integrated with respect to the time for the calculation of a flow-velocity integral. These two values are multiplied by each other in order to determine the stroke volume, which, multiplied by heart rate, yields the cardiac output. TEE has also more recently been proposed to assess cardiac output by measuring the velocity at the mitral annulus level or at the main pulmonary artery level [5, 13–15].

At the mitral level, the annulus area measurement is theoretically not accurate, since the mitral orifice is elliptical and its shape and size change throughout diastole. With a transthoracic approach, some authors, using modified procedures for mitral annulus area evaluation, found a high reliability for cardiac output measurement [10, 11, 13]. Using TEE, the reliability of cardiac output measurement at the mitral orifice was found to be poor by Muhiudeen et al., who used a pulsed Doppler method at the mitral leaflets level [14], and good by Hozumi et al., who used also a pulsed Doppler method but at the mitral annulus level [5]. However, in Hozumi's study, the good correlation seen with a single-plane probe and a four-chamber view was much higher when a biplane probe was used ($r = 0.81$ vs. 0.93), which permitted a more accurate evaluation of the elliptical area of the mitral orifice using the annulus mitral diameter measured with a four- and two-chamber view.

At the pulmonary artery level, Muhiudeen [14] found a poor correlation with thermodilution, while Savino [15] and Gorcsan [16] found a good correlation but were frequently unable to measure the pulmonary artery diameter (13–24%).

Several recent studies have proposed using the aortic annulus or the left ventricular outflow tract and a transgastric approach in performing TEE cardiac output measurements [2–5]. All these studies found a good correlation between cardiac output measured with TEE and thermodilution. Two of these studies [3, 4] used a continuous-wave Doppler method. The other two used a pulsed-wave Doppler method [2, 5].

The pulsed Doppler method for cardiac output measurement is theoretically more accurate than the continuous Doppler method, since the velocity is measured at the precise site of the area measurement. However, both methods have been reported as reliable for cardiac output measurement. We used a single-plane probe with a pulsed Doppler, which is the most common equipment in intensive care units in France. The velocity waves we obtained were pure and similar at all the different positions along the chosen diameter. This suggests that the velocity profile could be assumed to be flat at that level, allowing for the measurement of the volume flow. Our pulsed Doppler method has an upper limit for velocity measurement (Nyquist limit). However, when measuring flow just below the aortic annulus using a transgastric approach, we found a distance of nearly 6 cm between the transductor and this site, which allows for velocity measurements of up to 126 cm/s. Since aortic flow is rarely higher than this value at this site, the Nyquist limit is in fact theoretical if the septum is not asymmetric and/or hxpertrophic. The real impact of aortic stenosis is not known because we did not have such cases in our study. An adequate transgastric window was impossible to obtain in one patient, and aortic insufficiency in another patient did not allow for an accurate measurement of flow using the pulsed Doppler method.

The real difficulty with out method lies in the exact measurement of the subaortic diameter. This diameter, which is easily visualized with the transgastric approach cannot be measured by this method because of the distance and the poor lateral resolution. We therefore used a classic five-chamber view, truncated to obtain the best view of the left ventricular outflow tract, which appeared as a cylinder, permitting several measurements and using the highest value to determine the diameter.

Another limitation in our study was the use of thermodilution, which is not the best reference standard for cardiac output measurement. Nevertheless, this method is for the moment the standard technique for monitoring critically ill patients and has been widely used as an adequate reference standard in previous studies.

We conclude that the transgastric, pulsed Doppler method across the left ventricular outflow tract using TEE is a feasible and clinically reliable method for cardiac output measurement in mechanically ventilated, acutely ill patients. In these patients under controlled ventilation, TEE is now frequently used for hemodynamic monitoring. Therefore, the use of TEE for the measurement of cardiac output avoids the use of a pulmonary artery Swan-Ganz catheter.

Acknowledgements The authors would like to thank Patricia Gillard for their excellent secretarial assistance and Xavier Mazoit for his statistical guidance.

References

1. Gadasalli SN, Sarnoski JS, Kubota J, Schmidt DH, Gal R (1992) Transesophageal echocardiography with a single plane probe. Echocardiography 9:6: 589–596
2. Descorps-Declère A, Hollande J, Beaussier M, Mimoz O, Duranteau J, Edouard A, Samii K (1992) Simultaneous comparison of transesophageal aortic flow measurement with thermodilution (TD) in critically ill patients. Intensive Care Med 18:P244 (Abstract)
3. Katz WE, Gasior TA, Quinlan JJ, Gorcsan J (1993) Transgastric continuous-wave Doppler to determine cardiac output. Am J Cardiol 71:853–857
4. Darmon PL, Hillel Z, Mogtader A, Mindich B, Thys D (1994) Cardiac output by transesophageal echocardiography using continuous-wave Doppler. Anesthesiology 80:796–805
5. Hozumi T, Shakudo M, Applegate R, Shah PM (1993) Accuracy of cardiac output estimation with biplane transesophageal echocardiography. J Am Soc Echocardiogr 6:62–68
6. Stoddart MF, Prince CR, Ammash N, Goad JL, Vogel RL (1993) Pulsed doppler transesophageal echocardiographic determination of cardiac output in human beings: comparison with thermodilution technique. Am Heart J 126:956–962
7. Bland JM, Altman DG (1986) Statistical methods for assessing agreement between two methods of clinical measurement. Lancet I:307–310
8. Ihlen H, Amlie JP, Dale J, Forfang K, Nitter-Hauge S, Otterstad J, Simonsen S, Myhre E (1984) Determination of cardiac output by Doppler echocardiography. Br Heart J 51:54–60
9. Lewis JF, Kuo LC, Nelson JG, Limacher MC, Quinones MA (1984) Pulsed Doppler echocardiographic determination of stroke volume and cardiac output: clinical validation of two new methods using the apical window. Circulation 70:425–431
10. Fischer DC, Sahn DJ, Friedman MJ (1984) The mitral valve orifice method for non-invasive, two-dimensional echo Doppler determination of cardiac output. Circulation 67:872, 877
11. Zhang Y, Nitter-Hauge S, Ihlen H, Myhre E (1985) Doppler echocardiographic measurement of cardiac output using the mitral orifice method. Br Heart J 53:130–136
12. Dittmann H, Voelker W, Karsch KR, Seipel L (1987) Influence of sampling site and flow area on cardiac output measurements by Doppler echocardiography. J Am Coll Cardiol 10: 818–823
13. De Zuttere D, Touche T, Saumon G, Nitenberg A, Prasquier R (1988) Doppler echocardiographic measurement of mitral flow volume: validation of a new method in adult patients. J Am Coll Cardiol 11:343–350
14. Muhiudeen IA, Kuecherer HF, Lee E, Cahalan MK, Schiller NB (1991) Intraoperative estimation of cardiac output be transesophageal pulsed Doppler echocardiography. Anesthesiology 74: 9–14
15. Savino JS, Troianos CA, Aukburg S, Weiss R, Reichek N (1991) Measurement of pulmonary blood flow with transesophageal, two-dimensional and doppler echocardiography. Anesthesiology 75:445–451
16. Gorcsan J, Diana P, Ball BA, Hattler BG (1992) Intraoperative determination of cardiac output by transesophageal continuous wave Doppler. Am Heart J 123:171–176