Original Article

Oesophageal Doppler Ultrasound in the Assessment of Haemodynamic Status of Patients Admitted to the Medical Intensive Care Unit with Septic Shock

Huck Chin Chew,[1] *MMed (A&E), MRCP(UK), MMed (Int Med)*, Anantham Devanand,[1] *MBBS, MRCP (UK), FAMS (Resp Med)*,
Ghee Chee Phua,[1] *MRCP (UK), MMed (Int Med), FAMS (Resp Med)*, Chian Min Loo,[1] *MRCP (UK), FCCP, FAMS (Resp Med)*

Abstract

Introduction: Haemodynamic monitoring is an essential element in the management of critically ill patients in the intensive care unit (ICU). However, there have been increasing concerns about the clinical utility and safety profile of the invasive pulmonary artery catheter (PAC). Oesophageal Doppler (ED) monitoring has emerged recently as a safer and less invasive tool which can be used by the intensivist to estimate cardiac output in the critically ill patient. Validation studies have thus far only been performed in surgical patients perioperatively and in mixed surgical/medical ICU patients. Currently, minimal data are available in any sizeable Asian population or in patients with severe sepsis. The assumption that these normograms and data hold true for our local medical ICU patients may not be valid due to differences in body habitus. Materials and Methods: Our primary aim is to validate the oesophageal Doppler as a reliable measure of cardiac index, systemic vascular resistance (SVR) and preload in our local Asian population of patients with severe sepsis and septic shock in the medical ICU. This was a prospective pilot study on 12 consecutive mechanically ventilated patients in our medical ICU with the diagnosis of septic shock as defined by SCCM/ESICM/ACCP/ATS/SIS International Sepsis definitions Conference – Critical Care Medicine 2003 and required PAC haemodynamic monitoring as indicated by Medical Intensive Care Unit attending. Results: Ninety-seven paired cardiac output measurements were made. Cardiac output ranged from 2.87 to 11.0 L/min (calculated cardiac index ranging from 1.73 to 6.36 L/min/m^2) when measured using the PAC with thermodilution technique and from 2.0 to 12.1 L/min (calculated cardiac index of 1.2 to 7.2 L/min/m^2) using the trans-oesophageal Doppler. There was moderately good correlation between CIpac and CIed (correlation coefficient, r = 0.762 with PCA = 58%). The mean bias was 0.26 L/min/m^2 (*P* <0.07), while the limit of agreement was ± 1.44 L/min/m^2. Conclusion: ED has good correlation with PAC in measuring cardiac index in Asians with septic shock but is an unreliable measure of both pre-load and SVR.

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Key words: Cardiac index, Pulmonary artery cathether, Systemic vascular resistance

Introduction

Haemodynamic monitoring is an essential element in the management of critically ill patients in the intensive care unit (ICU). Over the last 3 decades, the flow-directed balloon-tipped pulmonary artery catheter (PAC), and associated thermodilution technology, has established itself as the "gold standard" of cardiac output estimation and pre-load monitoring.[1] However, there have been increasing concerns about the clinical utility and safety profile of the invasive PAC.[2,3]

Oesophageal Doppler (ED) monitoring is both non-invasive and requires minimal expertise to insert.[4] It can be used by the intensivist to estimate cardiac output in the critically ill patient.[5-7] It is both simple and safe to insert and has fewer complications when compared to the PAC.[5,8,9]

The normograms used for cardiac output calculation have been developed in Europe.[5,10] In addition, validation studies have thus far only been performed in surgical patients perioperatively and in mixed surgical/medical ICU patients.[6,7] Currently, minimal data are available in any sizeable Asian population or in patients with severe sepsis.[11,12] The assumption that these normograms and data

[1] Department of Respiratory and Critical Care Medicine, Singapore General Hospital, Singapore
Address for Correspondence: Dr Chew Huck Chin, Department of Respiratory and Critical Care Medicine, Singapore General Hospital, Outram Road, Singapore 169608.
Email: chinnjing@pacific.net.sg

hold true for our local medical ICU patients may not be valid due to differences in population body mass indexes and body habitus.

Materials and Methods

Our primary aim was to evaluate the ED as a reliable measure of cardiac index, systemic vascular resistance (SVR) and preload in our local Asian population of patients with severe sepsis and septic shock in the medical ICU.

This was a prospective, open label, non-randomised, partially blinded pilot study on 12 consecutive mechanically ventilated patients in our medical ICU who met both inclusion and exclusion criteria. The protocol was approved by the Institutional Review Board and informed consent obtained from the patients or their healthcare proxy.

Patients were eligible if they met the following criteria

1. Septic shock characterised by persistent arterial hypotension (systolic arterial pressure below 90 mmHg, mean arterial pressure lower than 60 mmHg or a reduction in systolic blood pressure of more than 40 mmHg from baseline, despite adequate volume resuscitation) in the absence of other causes of hypotension.[13]
2. PAC haemodynamic monitoring as indicated by MICU attending.

Those with known or suspected oesophageal or aortic disease, orofacial injuries that may hinder probe insertion, valvular heart disease, concomitant intra-aortic balloon pumps or established peripheral vascular disease that could confound interpretation of FTc (flow time constant) were excluded.

Cardiac Output Measurements

Simultaneous paired measurements of cardiac output were obtained by thermodilution using the PAC and trans-oesophageal Doppler. Patients were sedated but not paralysed during measurements. In each case, intensivists managing the patients inserted the PAC and haemodynamic management was based solely on the results obtained via PAC. The trans-oesophageal Doppler was inserted with measurements taken simultaneously but logged separately by intensivists not involved in the management of the patient. The intensivists were blinded to the values obtained using the Doppler technique and vice versa. Operators had inserted at least 5 trans-oesophageal Dopplers each prior to study. Data were routinely obtained at 6 hourly intervals and when therapeutic decisions were required based on the patient's parameters. The study concluded when either the PAC or transoesophageal Doppler was removed.

Trans-oesophageal Doppler

A 5-MHz, continuous-wave ED transducer (Deltex TM) connected to a spectral analyser (CardioQ, Deltex Medical, Chichester, UK) was inserted and orientated. Following oral introduction, the probe was advanced gently until its tip was located in the mid-oesophagus and then orientated until the transducer obtained the characteristic blood flow signal. Gain setting was adjusted to obtain the best outline of the aortic velocity waveform within 30 seconds. The average of 5 consecutive readings was taken. Prior to each measurement, probe position was verified to ensure optimal acquisition of the maximal velocity signal. Both cardiac output and flow time constant (FTc) were measured for each patient.

Stroke volume (SV, mL) was calculated as:

$$SV = CSA_{Ao} \ \text{x} \ K \ \text{x} \ \int_0^T V_{Ao}(t)\,dt^{1}$$

where $V_{Ao}(t)$ represents instantaneous maximum aortic velocity, T is the cardiac ejection time (the integral of instantaneous maximum velocity during cardiac ejection representing the stroke distance), CSA_{Ao} is the cross-sectional area of the descending thoracic aorta (cm^2), and K is a correcting factor (=1.43) whose purpose is to transform the blood flow measured in the descending thoracic aorta into global cardiac output, assuming that a constant fraction (70%) of the total blood flow passes through the descending aorta. CSA_{Ao} is estimated from a nomogram based on the patient's age, weight and height. The monitor was preset to calculate cardiac output (CO_{TED}, L/min) by averaging stroke volume over 10 beats and multiplying the value obtained by the heart rate.

Thermodilution Cardiac Output Measurement

Measurements of cardiac output using thermodilution was performed with a 7-Fr balloon-tipped PAC (Baxter Edwards Critical-Care, Irvine, CA) and calculated using a computer. This was taken as the mean value of 3 measurements (not differing by more than 10%) using 10 mL of cold saline randomly injected throughout the respiratory cycle.

The central venous pressure was measured via an electronic transducer which was attached to the central venous catheter port which gives a continuous readout of CVP along with display of the waveform. "Zeroing" was carried out before each measurement at the mid-axillary line in the fourth intercostal space with the patient in the supine position.

The pulmonary artery cathether was sited in the central vein and then "floated" along the central vein with the balloon inflated, through the right atrium and ventricle until it lay in a branch of the pulmonary artery. The position was predicted by the pressure waveform obtained by measuring the pressure at the tip of the PAC which was connected to an electronic transducer. The mean value of 3 measurements (not differing by more than 10%) was thus obtained.

Both central venous pressure and the pulmonary arterial wedge pressure were measured at 6 hourly intervals by the managing intensivist. Other measurements taken include systemic arterial pressure, systemic vascular resistance and pulmonary artery wedge pressure.

Statistics

The correlation between both forms of cardiac indices measurements was performed using linear regression analysis with Bland and Altman representation.[14] The paired *t*-test was used to test the significance of biases.

Results

Ninety-seven paired cardiac output measurements were made, using trans-oesophageal Doppler and the thermodilution technique in 12 mechanically ventilated, critically ill patients in septic shock recruited from the medical intensive care unit of our institution. Table 1 shows selected clinical characteristics of our patients.

Cardiac output ranged from 2.87 to 11.0 L/min (calculated cardiac index ranging from 1.73 to 6.36 L/min/m^2) when measured using the PAC with thermodilution technique and from 2.0 to 12.1 L/min (calculated cardiac index of 1.2 to 7.2 L/min/m^2) using the trans-oesophageal Doppler. Figure 1 and 2 demonstrate the good correlation between CIpac and CIed (correlation coefficient, r = 0.762 with PCA = 58%). The mean difference between the paired values CIpac-CIed, representing the bias of trans-oesophageal Doppler with respect to thermodilution, was 0.26 L/min/m^2 (P <0.07), while the limits of agreement (bias ± 2SD) were 1.7 and -1.18 L/min/m^2.

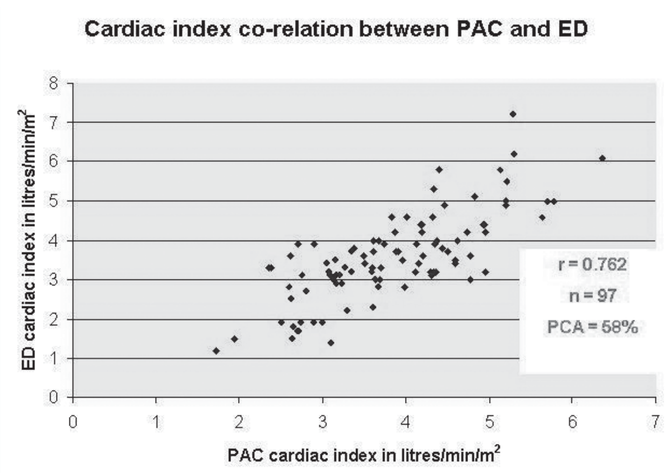

Fig. 1. Scatterplot of paired cardiac output measurements obtained using thermodilution (CIpac) and trans-oesophageal Doppler (CIed). PCA = percentage of clinical agreement.

Table 1. Selected Clinical Characteristics of Patients

Patients (n)	12
Age (y)	59.1 ± 16.9
Gender – n (%)	
Male	10 (83.3%)
Female	2 (16.7%)
Ethnicity – n (%)	
Chinese	8 (66.7%)
Malay	3 (25.0%)
Indian	1 (8.3%)
Height (cm)	163 ± 5.18
Weight (kg)	60.1 ± 13.4
Median APACHE II (range)	26 (21-34)
Main diagnosis – n (%)	
Severe pneumonia	9 (75.0%)
Urosepsis	1 (8.3%)
Necrotising fasciitis	2 (16.7%)
Indication for ICU admission – n (%)	
Mechanical ventilation	12 (100.0%)
Haemodynamic instability	11 (91.7%)
Acute renal replacement therapy	5 (41.7%)
Mean Positive End Expiratory Pressure (PEEP) mmHg (range)	15 (5-40)
Catecholamine infusion (at time of readings) – n (%)	
Dopamine	10 (83.3%)
Dobutamine	5 (41.7%)
Noradrenaline	9 (75.0%)
Vasopression	2 (16.7%)

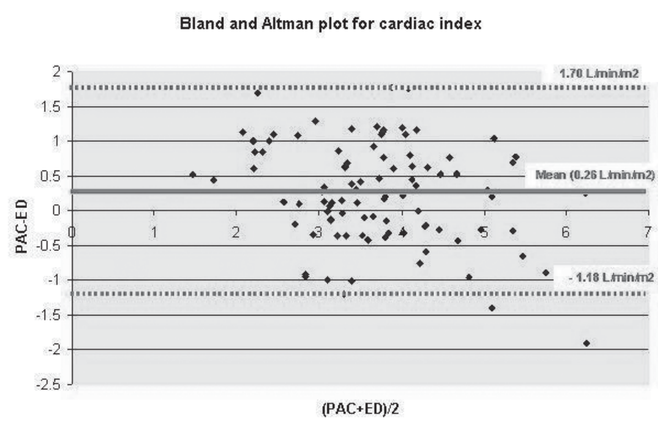

Fig. 2. Bland and Altman plot showing agreement between the two techniques. The solid line represents the mean difference between CIpac and CIed (systematic bias) and the dotted line represents the limits of agreement (-1.18 and 1.7 L/min/m^2), 95% confidence interval.

Figures 3 and 4 show the poor correlation between preload (pulmonary artery wedge pressure, mmHg) and systemic vascular resistance (SVR, dynes/sec/cm^5), obtained via PAC, and FTc obtained using the trans-oesophageal Doppler.

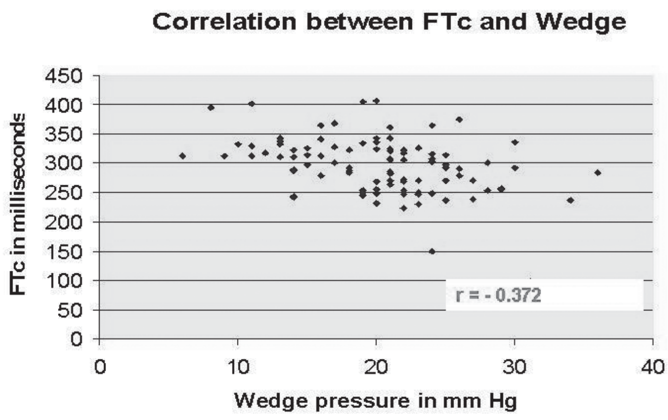

Fig. 3. Scatterplot of paired variations in FTc (obtained with oesophageal Doppler) and pulmonary artery wedge pressure (using PAC).

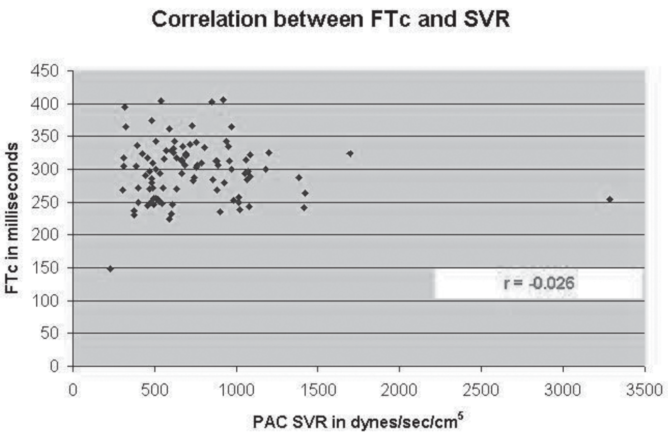

Fig. 4. Scatterplot of paired variations in FTc and systemic vascular resistance (SVR) (obtained using PAC).

Correlation coefficient was r = -0.372, between FTc and wedge pressure, and r = -0.026 between FTc and SVR.

Discussion

Trans-oesophageal Doppler has emerged as a minimally invasive alternative method available for the continuous monitoring of cardiac output in patients who are critically ill.[4-9] In this randomised trial, the cardiac output values obtained using the ED technique correlated well with those obtained using PAC. The systematic underestimation of CIed with respect to CIpac was small (<0.26L/min/m^2), and the limits of agreement were 0.26 ± 1.44 L/min/m^2. The limits of agreement are in keeping with the results of various other studies that have validated ED monitoring estimation of cardiac output compared with pulmonary artery cathether thermodilution.

The PAC seems to give a greater reading than ED. It could well be a result of the function of the normogram that is used; however, given the small numbers in our study, it would be difficult to offer any conclusions about this issue and it is likely that further larger trials will need to be conducted to answer this question.

The results of this study using patients of Asian origin in the medical intensive care unit are in tune with various trials involving Caucasian patients. This is despite the fact that normograms for the calculation of cardiac output using the ED have been derived from Caucasian populations. Other measures of cardiac indices such as FTc and SVR, using the ED, were not reliable as indicators of preload in our study.

Conclusion

Based on our results, we conclude the following:

1. ED is a reliable measure of cardiac index in Asians with septic shock
2. ED is an unreliable measure of either pre-load or SVR
3. The procedure of ED insertion is safe with minimal complications
4. ED is relatively easy to use and none of our cases had the inability to acquire waveforms

Limitations

We would like to acknowledge some limitations in our study.

Several conditions are necessary to successfully obtain a CO determination by ED. The underlying assumption is that the velocity of blood flow through the aorta is uniform and constant, and that one can obtain an accurate measurement of the velocity of descending aortic blood flow as well as precise as possible an estimate of the aortic cross-sectional area during systole.[7]

The normogram of the ED assumes that the cross-sectional area of the descending thoracic aorta is always circular, when in fact it is rather dependent on pulse pressure and aortic compliance. Furthermore, axial flow is not always laminar: anaemia, tachycardia, aortic valve disease and atheroma may all affect blood velocity measurements by causing turbulent flow. Finally, calculation of CO from the aortic blood flow is made with the assumption that aortic blood flow represents 70% of total CO, the remaining 30% corresponding to upper body flow hence for the correction factor in the calculations.[7] However, this is based upon physiological distribution of total CO, which is presumably disturbed under haemodynamic stress such as heart manipulation, myocardial ischaemia, low CO and systemic hypotension. These conditions being common in our patients with sepsis and shock.

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REFERENCES

1. Stetz CW, Miller RG, Kelly GE, Raffin TA. Reliability of the thermodilution method in the determination of cardiac output in clinical practice. Am Rev Respir Dis 1982;126:1001-4.
2. Connors AF, Speroff T, Dawson NV, Thomas C, Harrell FE Jr, Wagner D, et al. The effectiveness of right heart cathetherisation in the initial care of critically ill patients. JAMA 1993;276:889-97.
3. Pulmonary artery catheter consensus conference: Consensus statement. Crit Care Med 1997;25:910-25.
4. Chaney JC, Derdak S. Minimally invasive hemodynamic monitoring for the intensivist: current and emerging technology. Crit Care Med 2002;30:2338-45.
5. Singer M, Clarke J, Bennett D. Continuous hemodynamic monitoring by esophageal Doppler. Crit Care Med 1989;17:447-52.
6. Dark PM, Singer M. The validity of trans-oesophageal Doppler ultrasonography as a measure of cardiac output in critically ill adults. Intensive Care Med 2004;30:2060-6.
7. Valtier B, Cholley BP, Belot J, de la Coussaye J, Mateo J, Payen D. Noninvasive monitoring of cardiac output in critically ill patients using transesophageal Doppler. Am J Respir Crit Care Med 1998;158:77-83.
8. Singer M, Bennett D. Pitfalls of pulmonary artery catheterisation highlighted by Doppler ultrasound. Crit Care Med 1989;17:1060-1.
9. Gan TJ, Arrowsmith JE. The esophageal Doppler monitor: a safe means of monitoring the circulation. Am J Med 1997;86:417-20.
10. Venn R, Rhodes A, Bennett ED (1989). The esophageal Doppler. In: Vincent JL, editor. Yearbook of Intensive Care and Emergency Medicine. Berlin: Springer Verlag, 482-93.
11. Su NY, Huang CJ, Tsai P, Hsu YW, Hung YC, Cheng CR. Cardiac output measurement during cardiac surgery: esophageal Doppler versus pulmonary artery catheter. Acta Anaesthesiol Sin 2002;40:127-33.
12. Kim K, Kwok I, Chang H, Han T. Comparison of cardiac outputs of major burn patients undergoing extensive early escharectomy: esophageal Doppler monitor versus thermodilution pulmonary artery catheter. J Trauma 2004;57:1013-7.
13. Levy Mitchell M, Fink Mitchell P, Marshall John C, Abraham Edward, Angus Derek, Cook Deborah, et al. 2001 SCCM/ESICM/ACCP/ATS/SIS International Sepsis Definitions Conference. Intensive Care Med 2003;29:530-8.
14. Bland MJ, Altman DG. Statistical methods for assessing agreement between two methods of clinical measurement. Lancet 1986;I:307-10.