

Echocardiography in Intensive Care: The Basics. Part I

K. D. DONOVAN, F. COLREAVY

Intensive Care Unit, Royal Perth Hospital, Perth, WESTERN AUSTRALIA

ABSTRACT

Objective: *To review the current status of echocardiography in critically ill patients with special reference to the advantages and disadvantages of the transthoracic and transoesophageal approaches.*

Data sources: *A review of articles published in peer reviewed journals from 1976-1999 and identified through a MEDLINE search on echocardiography.*

Summary of review: *Echocardiography uses the reflection of high frequency sound waves at tissue boundaries to construct a two-dimensional image of cardiac structures. Two-dimensional echocardiography is the cornerstone of cardiac ultrasound, although Doppler techniques (pulsed wave, continuous wave, and colour flow) form an integral part of every modern echocardiographic study. The Doppler effect is based on changes in sound frequency that occur when a sound source moves towards or away from an observer. Blood flow velocities measured by Doppler can be used to estimate pressure, valve area and stroke volume. The standard imaging positions of the probe are either outside the thorax (i.e. transthoracic echocardiography or TTE) or inside the oesophagus (i.e. transoesophageal echocardiography or TOE) both of which provide information that can be helpful in managing critically ill patients.*

Conclusions: *Echocardiography is a rapidly developing technology. Cardiac structures can be imaged in 'real time'. Image quality continues to improve. The use of transoesophageal probe positioning has also widened the potential of this bedside technique in critically ill patients. (Critical Care and Resuscitation 1999; 1: 291-295)*

Key Words: Echocardiography, transoesophageal echocardiography, transthoracic echocardiography, intensive care, critical care

Echocardiography uses ultrasound to examine the heart and great vessels and displays the reflected sonic waves on a monitor. It has rapidly evolved into a powerful diagnostic and management tool in critically ill patients¹⁻⁶ especially in cardiovascular emergencies of uncertain cause.⁷⁻¹⁰

Echocardiography may be considered in some instances as an extension of the physical examination of the cardiovascular system. In critically ill patients it is

vital to evaluate cardiovascular abnormalities detected by clinical (e.g. new murmur), radiological (e.g. enlarged cardiac silhouette on chest x-ray), or other investigations (e.g. isolated elevated cardiac enzymes) and echocardiography often provides rapid diagnosis leading to appropriate changes in treatment.^{6,7}

Monitoring ventricular function is important in seriously ill patients and echocardiography can give 'real time' bedside information to the intensivist about

cardiovascular function.

The echocardiography service in most Australian intensive care units is provided by cardiologists. Few intensivists are skilled in echocardiography and even those who are trained may find it difficult to allocate the time necessary to perform a comprehensive cardiac ultrasound examination, let alone utilise this technology for continuous measurements of cardiac performance. Cardiologists, although highly skilled in echocardiography, may not appreciate the complex pathophysiology of critically ill patients in intensive care, and they have time commitments elsewhere. In the future it may be possible to train intensive care sonographers.

PRINCIPLES AND TECHNICAL CONSIDERATIONS¹¹

Echocardiography uses the reflection of sound waves at tissue boundaries to construct a two-dimensional (2-D) image of cardiac structures. The human ear hears only sound waves with a frequency between 20Hz and 20kHz; higher frequencies are referred to as *ultrasound*. Ultrasound uses a piezo-electric crystal to generate and receive ultrasound waves.

2-D echocardiography

2-D echocardiography is the cornerstone of cardiac ultrasound as Doppler and M-mode are usually performed with reference to the 2-D image. Each 2-D image is defined by the position of the transducer (acoustic window) and image plane which is determined by the axis of the heart and not the spine (Table 1).

M-mode echocardiography

Rapidly repeated transmit and receive cycles ($1800.\text{sec}^{-1}$ vs $30.\text{sec}^{-1}$ for 2-D) allows production of images with good resolution. M-mode echocardiography complements 2-D echocardiography. The beam is not scanned but stays in a fixed position allowing the display of structures along the beam as a function of time. The rapid sampling rate makes identification of thin moving structures such as valve leaflets, relatively easy. The cursor is usually directed through a 2-D image giving a one dimensional slice or 'ice pick' view. Distance (depth) is on the vertical and time is on the horizontal axis (Figure 1).

Doppler echocardiography

Doppler echocardiography is vital for obtaining haemodynamic information and is an integral part of every ultrasonic cardiac study. The Doppler effect is based on changes in sound frequency that occurs when a sound source moves towards or away from an observer.

Table 1. The standard views in transthoracic and transoesophageal echocardiography.

TRANSTHORACIC	
<i>Acoustic window</i>	<i>Image plane</i>
Parasternal	Long axis Short axis
Apical	Four chamber Long axis
Subcostal	

TRANSOESOPHAGEAL	
<i>Acoustic window</i>	<i>Multiple image planes from (distance from incisors) 0° to 180°</i>
Mid-oesophageal (28-32 cm)	e.g. Basal short axis
Mid-oesophageal (29 - 33 cm)	e.g. Four chamber long axis
Transgastric (38 - 42 cm)	e.g. Mid-papillary short axis

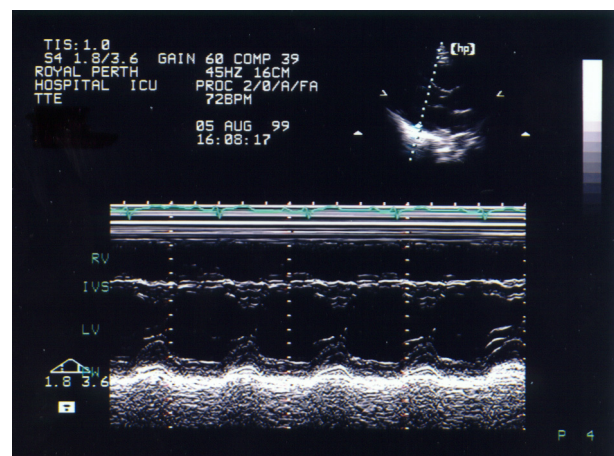


Figure 1 M-mode echocardiogram showing 'ice pick' view through right and left ventricles.

One classic example is that of an ambulance siren; as it comes toward a listener the sound frequency increases (higher pitch) and after the ambulance moves away from the observer the sound frequency decreases (lower pitch). The relationship between the Doppler shift and blood flow velocity is expressed in the Doppler equation:

$$V = \frac{C \times \Delta f}{2f_t \times \cos \theta}$$

Where,

- V = velocity of blood flow
- C = speed of sound in tissue (1540m.sec⁻¹)
- Δf = Doppler shift [i.e. difference in frequency between received (f_r) and transmitted (f_t) ultrasound]
- θ = angle between ultrasound beam and direction of blood flow (Figure 2).

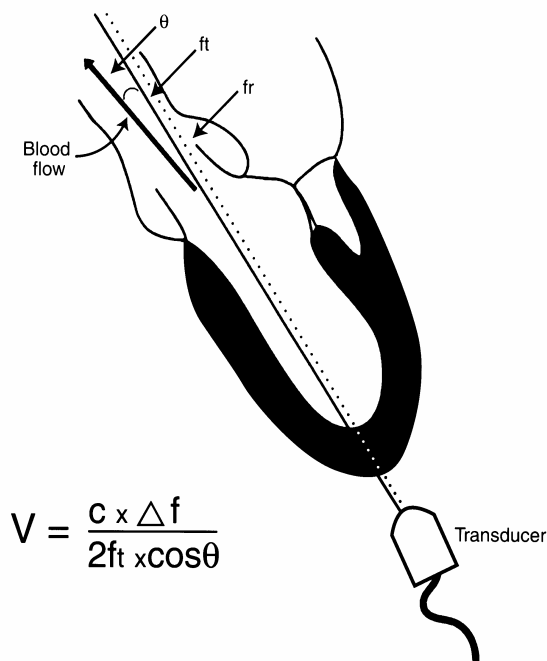


Figure 2. The Doppler equation.

It is important that the ultrasound beam is parallel or nearly parallel with the direction of blood flow. If θ is > 20° then the velocity of blood flow will be incorrectly estimated. Doppler data is processed and a spectral display plots instantaneous blood velocities over time. Blood flow velocity can be expressed as peak velocity or mean velocity throughout a cardiac cycle (velocity time integral:VTI) (Figure 3).

The most common uses of Doppler are, pulsed wave, continuous wave, and colour flow Doppler.

Pulsed wave (PW) Doppler

A single ultrasound transducer is used to transmit and receive ultrasound signals. In PW Doppler mode, blood flow velocities of a small volume of blood, the ‘sample volume’ are obtained at a specific depth.

Because PW Doppler repeatedly samples the returning signal, there is a limit to the blood flow velocity that can be measured accurately. A waveform must be sampled at least twice during its cycle to determine wavelength. Therefore the maximum frequency shift (Nyquist limit) that can be determined by PW Doppler is half the pulse repetition frequency. The maximum measurable velocity is usually < 2m/sec. If the frequency shift is higher than the Nyquist limit then aliasing occurs i.e. the Doppler signal is ‘cut off’ and the remaining signals are recorded on the opposite side of the baseline. PW Doppler is usually performed with a duplex transducer (2-D and Doppler) and is used for measuring relatively low velocities at specific cardiac sites, for example the left ventricular outflow tract (LVOT).

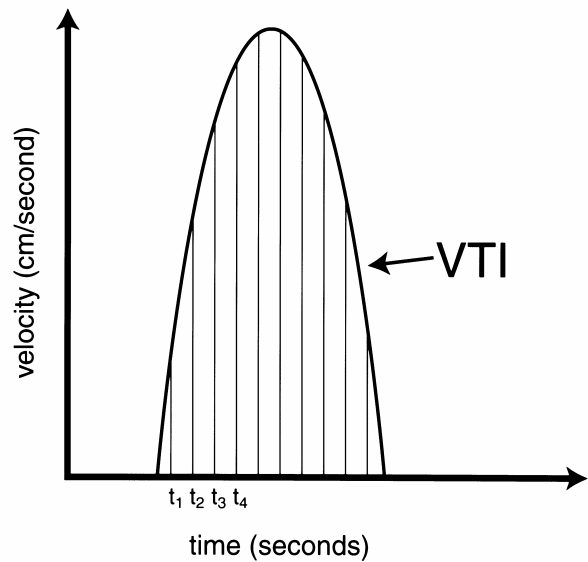


Figure 3. Velocity time integral (cm/s) = area under the velocity curve: sum of velocities (cm/s) during the ejection time (sec); t₁ = time one, t₂ = time two, etc.

Continuous wave (CW) Doppler

The transducer consists of two crystals, one continuously transmits and the other continuously receives the ultrasound waves. Because sampling is continuous, very high frequency shifts (velocities) can be measured. Unlike PW Doppler, CW Doppler measures all the frequency shifts (velocities) along the beam path. CW Doppler can be performed using either a duplex transducer or a ‘stand-alone’ non-imaging transducer. The non-imaging transducer is small making it especially suitable for the interrogation of a high velocity jet such as occurs with aortic stenosis.

Blood flow velocities measured by Doppler can be converted to pressure gradients using the simplified Bernouilli equation, ΔP = 4V², (where ΔP is the instantaneous pressure gradient and V is the

instantaneous velocity) to provide estimates of pressure, valve area, stroke volume, instantaneous dp/dt, and other variables.

Colour flow Doppler

This is based on PW Doppler principles. Colour flow information is superimposed on 2-D images. Multiple sample volumes are recorded with blood flow velocities encoded in colour (flow towards the probe is coloured red, away blue). Each colour is shaded according to blood velocity: the brighter the red or blue colours appear on the screen, the higher the blood flow velocity. When the Nyquist frequency limit is exceeded colour reversal (aliasing) occurs.

SAFETY

Ultrasound at the power levels used clinically to image cardiac structures has no known adverse biologic effects.¹² Transoesophageal echocardiography (TOE) in trained, experienced hands is a well developed and safe procedure.¹³ Nevertheless, TOE is semi-invasive and serious complications and even deaths have occurred. TOE is contraindicated in the presence of oesophageal stricture, neoplasm, diverticulum or fistula or previous oesophageal surgery, total gastrectomy or chest radiation. TOE should be deferred in patients with any symptoms of dysphagia until the cause has been found. Oesophageal varices, severe coagulopathy, significant cervical spine abnormalities are relative contraindications to TOE.

Routine antibiotic prophylaxis does not appear to be necessary before TOE in intensive care patients¹⁴ although some experienced centres¹⁵ recommend prophylaxis in high-risk patients (e.g. prosthetic valves, previous bacterial endocarditis etc.).

TRAINING

At present there are no Australian guidelines for the training of intensivists in either transthoracic or transoesophageal echocardiography. Standards in training and competence for cardiologists have been published by the Cardiac Society of Australia and New Zealand¹⁶ and include the performance of ≥ 300 cardiac ultrasound examinations and the supervised reporting of ≥ 600 echocardiograms, at least 50 of which should be transoesophageal studies.

Intensivists need adequate training in echocardiography although the Australian experience generally mimics the United Kingdom anaesthetic experience,¹⁷ with a small core of enthusiasts having access to suitable equipment dedicated to learning echocardiography, often in their spare time. Ideally one or two trained intensivists in each major intensive care unit could supervise the training of other intensive care

specialists and junior staff. Adequate training for this initial core of intensivist/echocardiographers remains a significant problem.

At our institution the Department of Cardiology has been extremely helpful in providing flexible access to training, a peer review period of all echocardiographic studies performed by intensivists, open access to weekly cardiology echocardiography case presentations, and to the routine daily reporting sessions. It is vital that communication with cardiological colleagues and particularly those with a special interest in echocardiography, is open so that the benefits of echocardiography are maximised in the care of critically ill patients.

Transthoracic or transoesophageal approach?

Transthoracic echocardiography (TTE). This should nearly always be considered first before TOE in critically ill patients. The transthoracic route is better for some problems, for example assessment of the severity of aortic stenosis. Nevertheless, TTE images may be unsatisfactory in patients with, for example, obesity, chronic lung disease, or after cardiac surgery. Mechanical ventilation is a further limiting factor.

Transoesophageal echocardiography (TOE). The transducer is located in the oesophagus or stomach close to the heart (Figure 4). Compared with TTE, TOE provides additional information in 32-100% of intensive care examinations and unexpected new diagnoses in 38-59% leading to significant changes in treatment.⁵ About 20% of patients with unexplained hypotension require surgery on the basis of new TOE findings.⁷⁻⁹

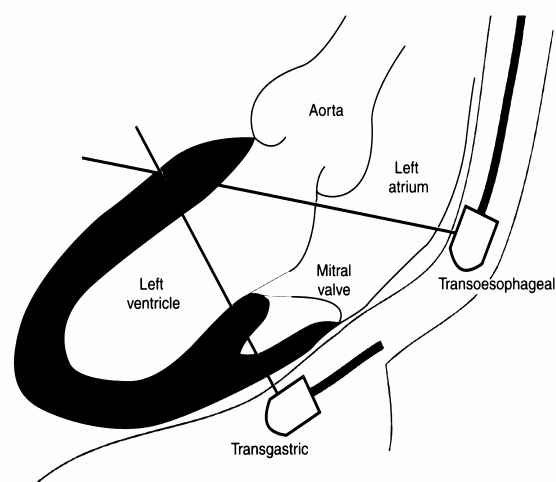


Figure 4. Transducer position in transoesophageal echocardiography.

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