Echocardiography

Key words: Transthoracic, Transoesophageal, Stress, Echocardiography, Doppler

ABSTRACT

Despite advances in novel cardiac imaging techniques, echocardiography remains the primary non-invasive imaging modality to assess cardiac structure and function. It is readily available, portable and yet gives comprehensive quantitative and qualitative evaluation of cardiac anatomy and function. It is also highly adaptable to be implemented in multiple modalities such as transthoracically, transoesophageally or in conjunction with stress (exercise or pharmacological). The following is a succinct review of echocardiography for the interested physician.

INTRODUCTION

Echocardiography is the imaging of cardiac structures using high frequency (>1Mhz) acoustic waves. Acoustic waves are produced by piezoelectric crystals in a transducer which reflect off cardiac structures and return to the transducer were signals are transformed to images. The most important technical aspect of echocardiography is its high sampling rate (>1kHz) and thus excellent temporal resolution, allowing accurate imaging of the cardiac structures throughout the cardiac cycle. This imaging technique can be performed transthoracically or tranoesophageally.

A. TRANSTHORACIC ECHOCARDIOGRAPHY

Transthoracic Echocardiography (TTE) has become a key component of routine evaluation of patients with suspected or known cardiovascular disease. Its availability, portability, ease of use and lack of radiation make it a safe and immediately available imaging tool to help the caring physician with diagnosis and management of the patient. Indications for TTE are listed in Table 1. It gives essential information on both cardiac structure (chamber size and wall thickness, valve pathology, pericardial thickening or effusion, aortic size and pathology, cardiac masses or thrombus) and function (left and right ventricular systolic and diastolic function, left ventricular outflow obstruction, valvular stenosis and regurgitation, cardiac tamponade, constrictive or restrictive physiology and pulmonary pressures). Multiple images are taken from 4 main echocardiographic windows - left parasternal (Figures 1A-C), apical (Figure 1D), subcostal (Figure 1E) and suprasternal (Figure 1F) windows. Different echocardiographic modalities are available to obtain as much information as possible. M-mode echocardiography (Figure 1A) depicts a single line of ultrasonic data over time. It has high sampling rate and superb temporal resolution and is useful to measure chamber dimensions and timing events in the cardiac cycle. M-mode has been nearly totally replaced by two-dimensional (2-D) imaging (Figures 1B-F).

Table 1 - Indications for Transthoracic Echocardiography

1. Symptoms
Chest pain
Shortness of breath
Palpitations
Presyncope/Syncope
Lower extremity swelling
2. Heart murmur
3. Abnormal ECG
4. Hypertension
5. Screening for elite athletes
6. Screening for inherited diseases

2-D imaging is the result of interpolating data between multiple scan lines to give a sector image of the heart and reiterative acquisition over the cardiac cycle results in a live movie of the heart. Harmonic tissue imaging is further used to enhance image resolution by eliminating artifact and improving signal-to-noise ratio. 2-D imaging allows for global functional assessment such as for left ventricular ejection fraction estimation and for assessment of wall motions to exclude regional wall motion abnormalities.

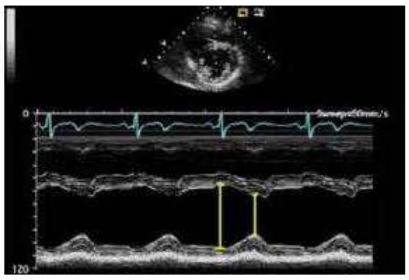

Figure 1A. M-mode measuring left ventricular dimensions in diastole and systole which can be used to calculate left ventricular ejection fraction

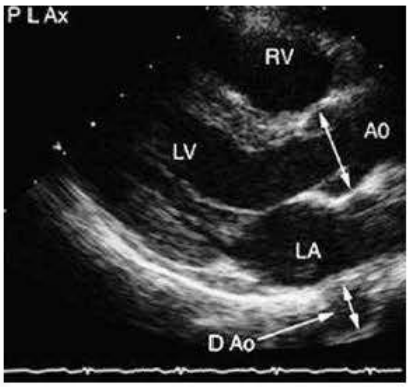

Figure 1B. 2-D echocardiography in the parasternal long axis view. LV= left ventricle, RV= right ventricle, LA= left atrium, Ao= aorta, D Ao = descending aorta

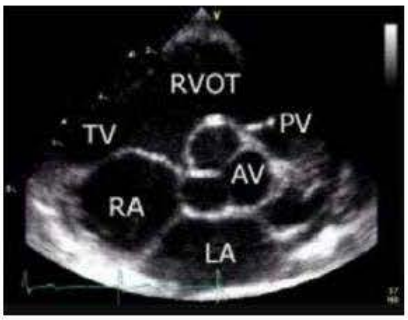

Figure 1C. 2-D echocardiography in the parasternal short axis view at the base of the heart. AV = aortic valve, LA = left atrium, RA = right atrium, TV = tricuspid valve, RVOT = right ventricular outflow tract, PV = pulmonary valve

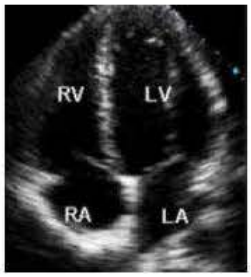

Figure 1D. 2-D echocardiography in the apical 4 chamber view. LV = left ventricle, RV = right ventricle, LA = left atrium and RA = right atrium

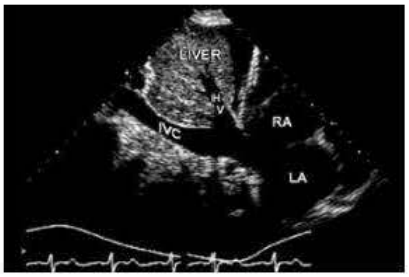

Figure 1E. 2-D echocardiogram in the subcostal view. IVC = inferior vena cava, HV = hepatic vein, RA = right atrium, LA = left atrium

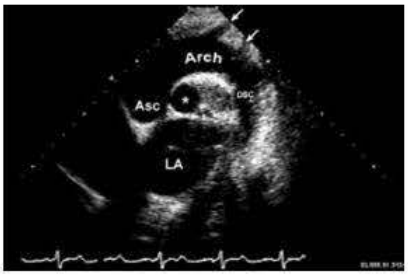

Figure 1F. 2-D echocardiography in the suprasternal long axis view. Asc = Ascending aorta, Arch = arch of aorta, Desc = descending aorta, LA = left atrium, * = left pulmonary artery

Global left ventricular systolic function is classified as hyperdynamic (=>75%), normal (55-74%), mildly decreased (46-54%), moderately decreased (36-45%) and severely decreased (<=35%). The left ventricular myocardium is divided into 17 standardized segments. Regional wall segments are classified as normal, hypokinetic, akinetic, dyskinetic or aneurysmal, and abnormalities are suggestive of underlying coronary artery disease. A hyperechogenic thinned area suggests the presence of scarring. 2-D imaging suffices for most routine echocardiograms, but 3-D imaging is now available and has the advantage of providing more accurate volume assessment (comparable with MRI) and further detailed valvular evaluation especially prior to surgery (Figures 2D, 2E).

Furthermore, analysis of tissue and blood motion within the heart is performed with Doppler-based technologies. This uses the Doppler equation to assess the tissue or blood velocity by proportionality of velocity with the frequency shift of returning ultrasound. Pulsed Doppler allows accurate blood velocity measurement over time in the cardiac cycle (such as the left ventricular outflow tract (LVOT)), and integrating the velocity time integral (VTI) spectral curve and multiplying by the area of the orifice results in flow volume (such as left ventricular stroke volume = LVOT VTI x LVOT area). Continuous Doppler velocities are depicted as spectral tracing of all velocities along a sampling cursor. This is most useful in measuring peak velocities and gradients across a valve such as for aortic stenosis. The gradient is directly proportional to velocity by the simplified Bernoulli equation [Gradient(mmHg) = $4V^2$ where V= Doppler velocity in m/sec]. Both peak and mean gradients can be determined by measuring the maximal velocity and the velocity time integral. Furthermore, valve area can by calculated using the continuity equation. For example, for the aortic valve (AV), Aortic valve area = (LVOT VTI x LVOT area)/AV VTI. Colour Doppler flow employs multigate pulsed Doppler to portray blood flow overlying the 2-D image. By convention, blue represents blood flowing away from the transducer and red towards the transducer. Lighter colours signify higher velocities and turbulent velocities may have a green hue or a mix of colours due to aliasing. This is useful in detecting valvular stenosis or regurgitation (Figures 2B, 2C), left ventricular outflow obstruction such as in hypertrophic cardiomyopathy and also for shunts. Tissue Doppler imaging is used to assess low-velocity movements

of the myocardium and performing this technique on mitral and tricuspid annular motion correlates to both systolic and diastolic performance of the ventricles.

B. TRANSOESOPHAGEAL ECHOCARDIOGRAPHY

Transoesophageal echocardiography (TOE) allows for excellent visualization of cardiac structures due to the proximity of the oesophagus and the left atrium (Figure 2C). TOE is complementary to TTE with its own strengths and weaknesses. It provides an unobstructed echocardiographic window by avoiding intervening lung and chest wall issues that limit TTE. TOE is relatively contraindicated with esophageal pathology (stenosis or varices), cervical spondylosis or severe respiratory conditions (unless intubated). The patient is asked to fast for at least 6 hours prior to the procedure and a 20-guage intravenous cannula is inserted for administration of medications and contrast if needed. Lidocaine spray is routinely used for topical anesthesia and midazolam +/- fentanyl are used intravenously for moderate sedation. The patient is then intubated with a lubricated probe whilst in the left

Table 2 – Indications for Transoesophageal Echocardiography

Valvular disease, especially prior to cardiac surgery and for prosthetic valve dysfunction
Infective Endocarditis, looking for vegetations and valvular dysfunction severity
Cardiac source of embolism including left atrial appendage or left ventricular thrombus, patent foramen ovale, aortic atheroma or fibroelastomas
Atrial fibrillation, to exclude left atrial appendage thrombus prior to DC cardioversion
Aortic pathology (aneurysm, dissection, atheroma)
Cardiac masses
Congenital heart defects
Intraoperative cardiac monitoring
Guiding structural interventional procedures such as atrial septal defect/patent foramen ovale closure and transcatheter aortic valve implantation
Poor transthoracic images

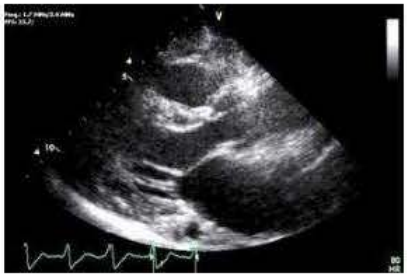

Figure 2A. Transthoracic parasternal long axis 2-D echocardiogram showing incomplete closure of the mitral leaflets due to tethering of both leaflets as a complication of septal myectomy for hypertrophic cardiomyopathy.

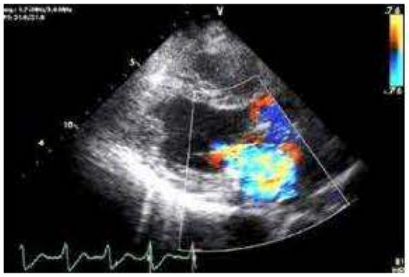

Figure 2B. Transthoracic parasternal long axis 2-D echocardiogram with Colour Doppler showing the severe mitral regurgitation secondary to incomplete closure of the mitral leaflets.

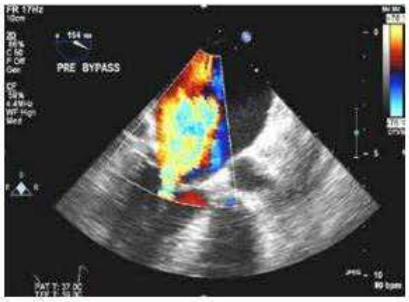

Figure 2C. Transoesophageal 2-D echocardiogram with Colour Doppler showing the severe mitral regurgitation into an enlarged left atrium secondary to incomplete closure of the mitral leaflets. In transoesophageal echocardiography, the top of the picture depicts the left atrium due to its close proximity to the oesophagus where the probe lies.

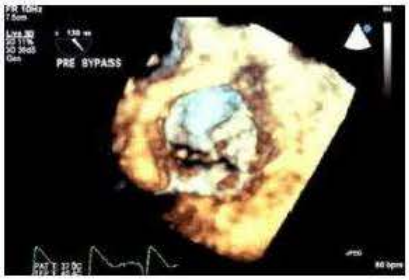

Figure 2D. Transoesophageal 3-D echocardiogram showing the anatomy of the mitral valve with incomplete closure of the mitral leaflets due to significant tethering posterior>anterior leaflets.

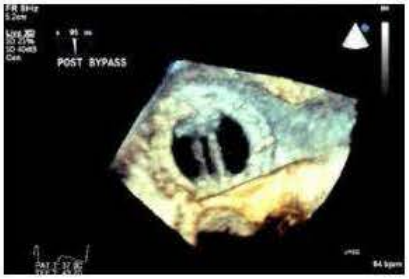

Figure 2E. Transoesophageal 3-D echocardiogram showing the prosthetic mitral valve after mitral valve replacement during surgery.

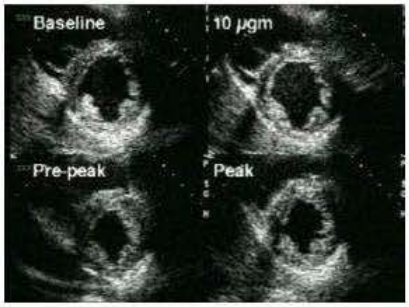

Figure 3. Dobutamine Stress Echocardiography, showing the parasternal short axis images in quad view for direct comparison at rest, low-dose, mid-dose and peak dose dobutamine. There is thickening of the myocardium with a smaller LV cavity with increasing dobutamine dose, which is the normal response to stress.

lateral position and images are obtained from the mid-oesophageal and gastric positions. Contrast in the form of agitated saline is often performed as a bubble study to exclude right to left shunting through a patent foramen ovale. The procedure lasts for about 20 minutes and possible complications are rare but include throat pain, respiratory distress and/or hemodynamic instability due to sedation and esophageal perforation. The major indications for performing a TOE are listed in Table 2.

An interesting case of mitral regurgitation using 2D transthoracic as well as 2D and 3D transoesophageal imaging is shown in Figures 2A-E.

C. STRESS ECHOCARDIOGRAPHY

A stress echocardiogram is a further modality which gives additional information to the clinician. Table 3 lists common indications for stress echocardiography. It is used primarily to detect the presence and extent of coronary artery disease by provoking regional ischemia with resultant wall motion abnormalities. The addition of Doppler permits evaluation of valvular function, pulmonary artery pressure and left ventricular outflow tract gradients. The sensitivity (85%) and specificity (80%) of stress echocardiography for significant coronary artery disease are comparable to MIBI scan and superior to stress ECG. The stress part of the study, which aims to achieve at least 85% of target maximal heart rate, may be done with exercise (treadmill or bike) or with pharmacological stress (dobutamine infusion). Stress echocardiography is particularly important in patients who have abnormal ST segments on ECG at rest (such as left bundle branch block, V-pacing, pre-excitation, left ventricular hypertrophy with strain, digoxin changes) for which a stress ECG would be non-diagnostic. It is also extremely helpful in patients who require a stress test but cannot exercise - in these cases a dobutamine stress echocardiogram is indicated. Dobutamine infusion is performed in five 3 minute stages at 5mcg/kg/min followed by 10, 20, 30 and 40 mcg/kg/min. The addition of 0.5mg iv atropine is sometimes required to reach target heart rate.

Table 3 - Indications for stress echocardiography

Diagnosis of ischemia in patients with chest pain or dyspnea
Determine physiological significance of coronary stenosis prior to revascularization
Risk stratification after myocardial infarction or in asymptomatic patients with prior revascularization (2 years after PCI and 5 years after CABG)
Preoperative risk stratification in patients at increased risk for perioperative events
Evaluation of patients with heart failure or cardiomyopathy for possible underlying ischemic heart disease
Assess physiological significance of valvular lesions, particularly mitral stenosis and regurgitation
Viability testing (looking for hibernating myocardium) using dobutamine stress
To assess patients with low gradient severe aortic stenosis - differentiates true aortic stenosis from pseudo-aortic stenosis in patients with low cardiac output
Evaluation of left ventricular outflow tract obstruction, mitral regurgitation and pulmonary pressures with stress in patient with hypertrophic obstructive cardiomyopathy

Images are taken in 4 standard views - the parasternal long axis, parasternal short axis, apical 4 chamber and apical 2 chamber. These are taken at rest and immediately post-stress in exercise echo and at rest, low-dose, mid-dose and peak dose with dobutamine infusion (Figure 3). Then direct comparison of images is performed. Sometimes, contrast agents are given to enhance the endothelial border for better visualization and more accurate assessment of response of the myocardium to stress. A normal stress echo results in hyperdynamic response of all myocardial segments with increase in ejection fraction and reduction in left ventricular cavity size. The development of new or worsening segmental wall motion with stress suggests the presence of hemodynamically significant coronary artery stenoses supplying the abnormal segment. Features of a high-risk abnormal stress test include decreased left ventricular ejection fraction and/or increase in left ventricular end-systolic volume with stress, extensive ischemia (multiple dysfunctional segments) with stress or ischemia at low workload.

CONCLUSION

In summary, echocardiography is a readily available, portable non-invasive imaging modality to assess cardiac structure and function. In modern day medicine, nearly all patients presenting with cardiac symptoms should be assessed with the help of this extremely versatile tool which no doubt equips the clinician with insight into the diagnosis and management of the patient.