The impact of heart failure (HF) on the global health care community is well recognized. Moreover, the incidence and prevalence of HF is increasing, both in developed and developing countries. In the US alone, HF accounts for approximately 727,000 emergency department visits, 1 million hospital admissions with an estimated overall annual cost of about $29 billion way back in 2006. However, its current prevalence in our country is not well known. One of the reasons for increased prevalence is more ageing of the population thus exposing those more to certain conditions like coronary artery disease (CAD), hypertension, diabetes mellitus etc.

The definition of heart failure has been variable but as per ACC/AHA guidelines, HF is a complex clinical syndrome that can result from any structural or functional cardiac disorder which impairs the ability of the ventricle to fill with or eject blood. As such HF can result from disorders of pericardium, myocardium, endocardium or great arteries. Being a progressive disorder, a rapid diagnosis and management is extremely beneficial.

Echocardiography, according to ACC/AHA guidelines on HF, is the single most useful diagnostic testing in the evaluation of HF because of its ability to accurately and non-invasively provide measures of ventricular function and assess causes of structural heart disease. The main strengths of this technique are:

- Portability
- Bedside setting
- Ease of study & convenience
- Widespread applicability in any clinical scenario i.e. irrespective of how unstable the patient is
- Rapid acquisition of data with immediate diagnosis
- Economically viable
- Repeated follow-up studies can be performed safely

The present day echo comprises of (a) 2-dimensional echo (2-D) which provides full structural and functional information i.e. size of various chambers of the heart, any valvular, myocardial or pericardial abnormalities, evaluation of right ventricle etc. The major strength is in evaluation of left ventricle (LV) and right ventricle (RV) functions (b) Doppler echo which, by virtue of assessing blood flow velocities and gradients etc., provides complete hemodynamic information like pulmonary artery and right atrial pressure. As a result of this, invasive studies are not required in large number of cases (c) Tissue Doppler imaging which provides myocardial tissue velocities, which when combined with mitral inflow and pulmonary vein Doppler provides information about pattern of LV filling and left atrial (LA) pressure (d) other sophisticated technologies like transesophageal echo, strain rate imaging, speckle tracking 3-D echo and myocardial contrast echo (MCE) provide supporting help. However, in this paper, echo refers to conventional 2-D echo, Doppler and color flow mapping.

Heart failure can be broadly classified into systolic HF and Heart failure with normal ejection fraction (HFN EF) also earlier known as primary diastolic heart failure. There can also be a combination of both. As such the two entities will be discussed separately.

**Systolic HF**

Systolic HF has been classically related with LV dysfunction leading to congestion and reduced systemic perfusion, which in most of the cases, manifest clinically as dyspnoea and fatigue. Some of the advanced states of myocardial disorders lead to progressive LV dilatation with or without hypertrophy followed by LV spherical remodeling. These morphological changes cause further stress on the myocardium by increasing wall tension. Many of these adaptations lead to mitral regurgitation (MR), which in turn, leads to further dilatation and contractile dysfunction in a vicious cycle. Such remodeling is often the final common pathway for many although not all etiologies of HF.

Some of the more commonly encountered causes of systolic heart failure are ischemic cardiomyopathy, dilated cardiomyopathy, valvular heart disease, congenital cardiac lesions, hypertension etc, though a host of other cardiac disorders in their end stage can lead to systolic HF.

**Diagnosis:** As mentioned earlier 2-D echo provides structural and functional information. In providing structural/anatomic information, 2-D echo provides unmatched information. One can assess LV dimensions, LA enlargement, LV mass besides any...
abnormality of valves, pericardium etc. For a large number of cases of valvular and congenital heart disease, a complete echo examination obviates the need for invasive studies. Despite several other methods, ejection fraction (EF) continues to be the gold standard for clinicians. This is the most common indication for performing echo. It is calculated by modified Simpson's method which assesses maximal LV volume in diastole (EDV) and systole (ESV) and the EF is calculated as EDV-ESV/ EDVx100. It has a good correlation with angiographic studies, provided there is good endocardial delineation, because endocardial borders are traced to get the respective volumes. In this regard 3-D echo and MCE have been some very good developments. The M-mode methods are currently not utilized for determination of EF, especially in patients with regional wall motion abnormalities. EF has a significant prognostic value. Besides this, precise and reproducible EF measurements play an increasingly important role in guiding important interventions. The new American Society of Echocardiography guidelines define an abnormal EF < 55%, with the cut off's for moderately abnormal and severely abnormal at 44% and 30% respectively. Similarly the reference ranges for LV dimensions are best indexed to body surface area, with reference ranges 2.4 – 3.2 cm/m² and cut off values of 3.5 and 3.8 cm/m² for moderate and severe dilatation respectively.

DIAGNOSIS OF FEW SPECIFIC DISORDERS

Ischemic cardiomyopathy: In this condition there is usually a history of previous myocardial infarctions. Regional wall motion abnormalities, especially akinetic or dyskinetic segments, are present. The presence of thin, atrophic and scarred myocardium is also a characteristic feature. This is associated with LV enlargement and dysfunction. Other associated features like MR, pulmonary arterial hypertension (PAH) etc. can be present at some stage of the disease (Fig. 1).

Dilated cardiomyopathy (DCM). It is a usually common condition and in USA it accounts for about 25% cases of heart failure. It can be idiopathic or secondary to some known causes. There is also a genetic and familial basis. Echo is an important modality in diagnosis. It is characterized by a dilated, hypotcontractile LV with dysfunction. Echo, besides assessing the degree of systolic function impairment can also assess diastolic dysfunction which has a separate prognostic significance. At some stage of the disease there is, MR, PAH and right ventricular dysfunction. There may be regional wall motion abnormalities (RWMA) but usually there is no akinetic or dyskinetic segment. But, at times, it may be difficult to differentiate between DCM and ischemic cardiomyopathy which require tests like dobutamine echo or coronary angiography.

Peripartum cardiomyopathy, a variant of DCM has four diagnostic features (a) cardiac failure within last month of pregnancy or within 5 months of delivery (b) absence of other identifiable causes of failure (c) no prior heart disease within last month of pregnancy (d) depressed cardiac functions as assessed by echo.

LV noncompaction: It is a relatively uncommon genetic variant of DCM, but now is being increasingly reported. It results from intrauterine arrest or non-compaction of the loose interwoven meshwork of fetal myocardium. It is a cardiomyopathy characterized by deep trabeculations (> 3) in the ventricular wall, involving usually apex and lateral wall, with deep interventricular recesses communicating with the main chamber (Fig 2). There is 2 layered structure of endomyocardium with an increased noncompacted to compacted ratio of > 2.0. This is associated with systolic and diastolic dysfunction.

Arrhythmogenic right ventricular dysplasia (ARVD). It is a non-ischemic type of cardiomyopathy with a familial association in about 30% cases. The presentation is with ventricular tachyarrhythmia, cardiac failure, syncope etc. In ARVD there is progressive replacement of myocardium with fibro-fatty tissue. It is a common cause of sudden cardiac death in young individuals (about 17%). Echocardiographically the main findings are (a) right ventricular outflow tract diameter of > 3.5 cms (b) right ventricular (RV) dysfunction (c) localized thinning of RV due to fibro-fatty tissue (d) localized segmental RV outpouchings (e)
localized RV aneurysm (f) hyperreflective moderator band of RV (g) excessive trabeculations (Fig 3 A & B)

Valvular heart disease (VHD): This is still a common cause of HF in our country, especially in economically weaker sections of the society due to their inability to get early intervention. A good echo-Doppler study completely obviates the need for cardiac catheterization in VHD unless the coronary artery evaluation is required. The role of echo in VHD is manifold: (a) diagnosis, as there are several causes of cardiac murmurs (b) assessment of severity of the lesion (c) presence of other valvular lesions, if any (d) evaluation of cardiac functions. This is important to assess for the timing of intervention in mitral and aortic valve lesions, because an EF value which is normal for other diseases could be less for VHD (e) assessment of indirect hemodynamic effects like PAH (f) visualizing other complications like vegetations or a thrombus which have a bearing on management (g) guide to time and type of intervention, like in mitral stenosis whether it is amenable to balloon dilatation or will need surgery (h) serial follow up.

Doppler hemodynamics: Understanding the hemodynamic information provided by echo will be the foundation of this paper and will cover both systolic and diastolic HF. Intracardiac pressure measurements have traditionally required invasive studies. However the limitations were inability to do serial studies and moreover they had to be performed outside the intensive care units. Echocardiographic techniques have been a major breakthrough in this regard and became a non invasive surrogate. Moreover a good correlation was found between simultaneous echo and invasive studies in selected group of patients. Two very useful hemodynamic information provided by echo is enumerated below:

A. Right atrial pressure (RAP): The evaluation of RAP is important as it reflects intravascular volume status and increases as a secondary response to right heart disease. The indirect, rough 2-D evidences of increased RAP are enlarged right atrium, bulging of interatrial septum to the left side, enlarged coronary sinus and / or hepatic veins. However an estimation of RAP is obtained by (i) IVC diameter and (ii) IVC diameter response to inspiration. As per the current guidelines, the normal IVC diameter is 1.7 cms but based on some studies the upper limit of normal is 2.0 cms.

In normal individuals the IVC collapse, during spontaneous breathing, is > 50%. This is mainly dependent on mean RA pressure and chamber compliance. The higher the RA pressure the less will be the inspiratory collapse. This is explained in the following flow chart:

![IVC Physiology Flow Chart](image)

The % IVC collapse, as assessed from subcostal views, is calculated as

\[
\text{Mean RA pressure} = \frac{\text{IVC max} - \text{IVC min}}{\text{IVC max}} \times 100
\]

As a general guideline, in a normal sized IVC with > 50% collapse, the mean RA pressure is 10mmHg. Fig 4 shows an example of calculation of IVC collapse.

The following chart shows an assessment of the RA pressure based on size of IVC and degree of collapse.

![Right Atrial Pressure Chart](image)
**PA & RV systolic pressure.** These pressures are the same provided there is no RVOT obstruction like pulmonary stenosis. There is a strong correlation between echo and invasively determined PA pressure. The tricuspid regurgitation (TR) velocity is used to calculate these pressures, as the TR jet velocity reflects the pressure gradient between RV and RA. As per modified Bernoulli equation the PA pressure = 4 x V^2 + RAP where V is the velocity of TR jet & RAP is mean RA pressure. An example of this calculation is shown in Fig 5.

**HEART FAILURE WITH NORMAL EJECTION FRACTION (HFWNEF)**

This condition, also earlier known as primary diastolic heart failure, has assumed significant importance in last many years. In Western countries its incidence is almost 40%-50% of all HF patients. The morbidity, mortality and recurrent hospitalizations are almost the same as systolic heart failure. The treatment remains empirical and unsatisfactory. Some of the conditions associated with HFWNEF are hypertension, cardiomyopathy, coronary artery disease, diabetes mellitus, obesity, sleep apnoea, constrictive pericarditis etc. The diagnosis of HFWNEF is based on the following criteria:

- Presence of clinical syndrome of HF
- Normal systolic LV functions (EF > 45-50%)
- Presence of diastolic dysfunction: A normal ventricle fills without any abnormal increase in end diastolic filling pressure (LVEDP). In diastolic dysfunction there is an abnormal increase in LVEDP for a given end diastolic volume, so that basically there is an increased filling pressure

- Ratio of early diastolic mitral velocity to tissue Doppler early diastolic velocity > 15:1
- LV end diastolic volume index > 97 ml/m^3 (optional)

Echocardiography has made a significant contribution in non invasive assessment of indices of diastolic function and tissue Doppler. The main aim is to determine LV filling pressures. For a better understanding a brief description of these functions is discussed.

Diastole starts with closure of aortic valve and ends with closure of mitral valve. Diastolic LV pressure is the main determinant of LA, pulmonary vein (PV) and pulmonary capillary wedge pressure (PCWP), all of which are virtually synonymous. This is evident from their normal values like: LVEDP = 5-12 mmHg, (<15mmHg), Mean LAP = 2-12 mmHg, PCWP = 4-12 mmHg. The two major determinants of diastolic dysfunction are (a) relaxation i.e. the maximum rate of LV pressure decline (b) compliance i.e. the ease of LV filling. The consequences of an increase in LV filling pressure is shown in the following flow chart:

- **Consequences of diastolic dysfunction**
  - Increased filling pressure for a given volume
  - Increased LA volume and LA remodeling
  - Pulmonary venous hypertension
  - Heart failure with normal EF

**Echocardiographic techniques to evaluate diastolic dysfunction**

Echocardiography, being a simple non-invasive technique, has gained wide acceptance in the evaluation of diastolic properties of LV. The following parameters are being widely employed:

- 2-D Echo
- Mitral inflow Doppler
- Valsalva, which is an additional source to evaluate validity of mitral Doppler
- Pulmonary vein Doppler, more as a complementary method
- Tissue Doppler imaging
- Mitral inflow color propagation velocity
- LA volume and function
- Strain imaging for regional diastolic dysfunction only

However due to constraint of space only a few techniques will be discussed. In a 2-D echo, in the background of etiological factors, presence of LV hypertrophy, LA enlargement, and normal LV functions can give indirect clue for the presence of diastolic dysfunction (Fig 6).

**Mitral inflow Doppler:** Traditionally the mitral inflow Doppler is the first step in the assessment. Normally three parameters are
assessed (a) early diastolic filling wave known as ‘E’ wave which is due to rapid filling of LV due to atrio-ventricular gradient in early diastole. Almost 80% of the LV filling occurs during this phase (b) deceleration time (DT). As a result of rapid LV filling, the LV pressure increases and LA pressure decreases. As such momentarily LV pressure may exceed LA pressure and this results in deceleration of mitral inflow known as deceleration time (DT) i.e. the rapidity with which the LV – LA pressure equalize (c) ‘A’ wave. During the late diastolic phase the LA acts as a ‘booster pump’ with a late diastolic filling of LV and contributes to almost 20% of LV filling in normal subjects. Normally the ‘E/A’ ratio is less than 1.50:1 and DT 190 ± 30 msec. Fig.7 shows the normal transmitral flow waves.

**Tissue Doppler Imaging (TDI)**: This is a novel ultrasound modality that records the motion of myocardial tissues with Doppler echo. The conventional Doppler records high velocity flows with erythrocytes as a target. The velocities of myocardial tissues are much lower (1-20 cms/sec). Therefore the Doppler ultrasound systems have been modified to record the low velocities of myocardial tissues and reject the high velocities generated by blood flow. TDI is not dependent on imaging quality and tracings are easily obtainable. A normal TDI velocity has five components/waves (Fig.8) (a) isovolumic contraction (ICT), (b) systolic wave (S), (c) isovolumic relaxation (IVRV), (d) early diastolic wave (E’ i.e. E prime or Em wave) (e) late diastolic wave (‘A’ at the time of atrial contraction). In HFVNEF the E’ is the most important wave and a good indicator of LV myocardial relaxation and hence gets reduced in all grades of diastolic dysfunction. A value below 8 cms/sec. is seen in various grades of diastolic dysfunction.

**E / E’ ratio**: The ratio between mitral ‘E’ wave and TDI ‘Em wave has been shown, in large number of studies’ to be a good marker for evaluating increased LV filling pressure. This has been well correlated with simultaneous invasive studies. The normal value is < 8:1, while a value > 15:1 is indicative of increased LV filling pressure. This is explained under restrictive flow pattern.

**LA volume**: It is an extremely important parameter of diastolic dysfunction. It reflects the cumulative effect of filling pressure over time and is a ‘barometer’ of chronicity of diastolic dysfunction. It is increased in all advanced grades of diastolic dysfunction as shown below:

<table>
<thead>
<tr>
<th>Elevated LV Diastolic Pressure</th>
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<tbody>
<tr>
<td>High LA pressure (LA afterload)</td>
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<tr>
<td>Increased atrial stretch</td>
</tr>
<tr>
<td>Atrial dilatation</td>
</tr>
<tr>
<td>Increased LA volume</td>
</tr>
</tbody>
</table>

The normal value of LA volume is 22 cc ± 6 cc / msq while a value above 40 cc / msq indicates severe abnormality.

**Restrictive flow pattern**: It is considered the worst and most advanced form of diastolic dysfunction (grade 3). It is commonly associated with major myocardial pathology such as myocardial ischemia, scar, infiltrative – restrictive abnormalities, heart failure etc. The basic pathophysiology is significantly elevated LA pressure + all the echo parameters of abnormal relaxation. Due
to significantly increased LA pressure there is increased LA-LV
gradient. As such, in early diastole, the mitral E wave is very tall.
Because most of the LV filling and LA emptying is in early diastole,
less blood remains in late diastole, hence E/A ratio is significantly
increased – usually more than 2:1. These patients mostly have a
poor LV compliance which leads to rapid elevation of LV diastolic
pressure. This restrictive pattern is responsible for “square root
sign” on invasive studies. This also leads to rapid deceleration of
‘E’ wave and the deceleration time is < 150 msec. (Fig. 9) The
associated relaxation abnormalities lead to E/E’ ratio which is
more than 15:1.

To summarize, restrictive pattern is characterized by: tall mitral E
wave, small A wave, increased E/A ratio, decreased deceleration
time, E/Em ratio of more than 15:1 (Fig 10). A word of caution is
that young, healthy individuals who have excellent active relaxation
can show similar mitral E and A wave pattern. However these
individuals are usually asymptomatic with normal 2-D echo and
TDI.

**ROLE OF ECHOCARDIOGRAPHY IN ASSESSING
PROGNOSIS IN HEART FAILURE**

It is well recognized that LV ejection fraction is an important
determinant of prognosis in various cardiac disorders, especially
CAD. Survival rates decline in relation to LV dysfunction. In a
study by Aronow et al in patients with CAD and heart failure, a
survival rate in those with normal EF, despite CAD, was 78% at 1
year, 62% at 2 years and 44% at 4 years. The corresponding figures
for those with LV dysfunction were only 53%, 29% and 15% at 1, 2
and 4 years respectively. LVEF has a short term prognostic value
also. Sabia et al in a study of 175 patients of CAD observed that
those who had LV dysfunction had a 48 hours event rate of 26.9%
as compared to 3.3% in those with preserved LV systolic function.
The LV end diastolic and end systolic volumes have also been
correlated with prognosis in CAD. An LVEDV index of > 120 ml/
m² and LVESV of > 45 ml/m² has shown a poor outcome. These
volumes can be calculated with echo.

In patients with CAD, with or without failure, and significant LV
dysfunction, the presence of viability is a strong prognostic factor.
Viability is defined as dysfunctional myocardium with reduced
contractility that improves after restoration of blood flow. This
applies to hibernating myocardium which is a viable ischemic
myocardium which can have a complete or partial recovery
following revascularization. The medical therapy carries a higher
mortality. Dobutamine stress echo has a considerable utility in
demonstrating viable myocardium

Right ventricular (RV) functions have received due attention in
last few years. Zornoff et al, studied 416 patients of AMI with LV
dysfunction with a mean follow up of 671 days. Of these 79 patients
had RV dysfunction. Those who had no RV dysfunction, 26.7%
had death or progressive heart failure, while the corresponding
figure was 50.6% for those who had RV dysfunction. In another
study of HF patients with class 2 or 3 symptoms, the RV ejection
fraction was an independent predictor of 1 and 2 years survival
and event – free survival. At 2 years, the event free survival rates
from cardiovascular mortality and urgent transplantation was
93% for those with an RV EF of 35%, 77% for those with an RV
EF of ≥ 25% but < 35%; and 59% for those with RV EF of <25%.

A dilated inferior vena cava without inspiratory collapse is
associated with worse survival in patients independent of a history
of HF, other comorbidities, ventricular function and PA pressure.
In those patients with an inspiratory collapse of their IVC, the
survival rates were 99% after 90 days and 95% after 1 year, as
compared to 89% after 90 days and 67% after 1 year for those
with <50% collapse

Numerous studies have shown that the diastolic dysfunction
parameters have an important bearing on both short and long
term prognosis in HF patients. Persson et al in a study of 312
patients, with a median follow-up of 18.7 months reported that

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**Fig 9:** A restrictive filling pattern showing tall ‘E’ wave, small ‘A’
wave leading to their ratio of 2.67:1. The mitral DT is shortened to 120 msec.

**Fig 10:** Left hand tracing shows increased early mitral dia-
stolic velocity (E) while TDI, right hand tracing. Em velocity is
decreased giving E/Em ratio of 30:1.
Role of Echo-Doppler in Heart Failure

The role of echo in assessment and management of myocardial viability has already been discussed.

Implantable cardioverter – defibrillators (ICD)
Recent studies have demonstrated the benefit of prophylactic ICD for the primary prevention of sudden death in patients with HF and reduced EF. Strategies for ICDs rely on EF as a common parameter for placement of these devices in HF patients, and echocardiography is often employed to assess EF. Repeat EF assessment at 30 to 40 days after myocardial infarction and after initiation of optimal HF medical therapy is necessary to determine candidacy for ICD. Many patients’ EF rise above 30% to 35% cutoff after a month on an appropriate medical regimen and premature ICD implantation has shown no benefit.

Cardiac resynchronization therapy (CRT)
CRT is one of the established modes of therapy in subgroup of patients with advanced HF. Echocardiography has had a major contribution in evaluation and follow up of patients with CRT. Many HF patients lack coordinated contraction of the LV walls (intraventricular dysynchrony) and between the right and left ventricles (interventricular dys synchrony). Cardiac resynchronization therapy can restore coordinated contraction with demonstrated improvement in symptoms and survival. Echocardiographic measurement of dyssynchrony can accurately predict beneficial response in the form of reverse remodeling (reduction in LV volumes, improved EF, and reduced mitral regurgitation) and echocardiographically demonstrated reverse remodeling predicts improved survival. Though some questions have been raised on the role of echo in selection of patients for CRT, but its role during implantation and follow up is well established.
SUMMARY

Echocardiography is well suited to meet the growing need for non-invasive imaging in heart failure. A careful detailed study involves 2-D and M-mode echo incorporated with Doppler study. Because heart failure patients have often more than one structural and/or functional abnormality contributing to their disease state, echocardiography’s versatility in detecting valvular and pericardial pathology along with myocardial disorders yield obvious benefits. Assessment of LVEF in clinical heart failure is one of the primary measures. A normal EF virtually excludes advanced myocardial disorders which then necessitate careful evaluation of valvular lesions and HFVNEF. Doppler measurements provide important hemodynamic information like evaluation of volume status, assessing PA pressure, diagnosis and characterization of HFVNEF thereby indirectly evaluating ventricular filling pressures, and identify patients with high risk of cardiovascular morbidity and mortality. One of the major strengths of echo is repeated follow up especially in situations of new symptoms, clinical deterioration where it can provide the etiology. Echocardiography provides important data for therapeutic decision making which includes guide to medication, define candidates for implantable cardiac devices and various surgical procedures. Newer technological advances like hand held echo, 3-D echo, myocardial contrast echo etc. hold great promise in further improving the quality of care to the growing population of heart failure patients.

REFERENCES