Role of Echocardiography in Congestive Heart Failure

SONGSAK KIATCHOOSAKUN, MD*,
BRIAN D HOIT, MD**

Abstract

A comprehensive assessment of the nature and severity of heart failure is often the initial step in the management of patients with congestive heart failure. Unlike many other available methods, imaging and Doppler echocardiography can repetitively and noninvasively characterize left ventricular systolic and diastolic function and estimate prognosis. Recently, new Doppler applications (tissue Doppler and color M-mode-Doppler) have been shown to provide a more precise estimate of LV relaxation than the traditional Doppler echocardiography. The objective of this review was to critically evaluate the clinical impact of conventional echocardiographic methods on the management of heart failure patients.

Key word : Echocardiography, Heart Failure

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Congestive heart failure (CHF) is a widespread clinical syndrome that represents a lethal and final common pathway of a variety of disparate cardiac disorders. The risk of death is 5-10 per cent annually in patients with mild symptoms and increases to as high as 30-40 per cent annually in patients with severe disease(1). Heart failure possesses the unfortunate distinction of being the only major cardiovascular disorder that is increasing in incidence and prevalence (1,2). Echocardiography is an accepted diagnostic method that complements measurements of functional capacity, neurohumoral activation, ectopic ventricular activity, and hemodynamics, provides prognostic information, and directs therapeutic strategies in patients

* Department of Medicine, Faculty of Medicine, Khon Kaen University, Khon Kaen 40002, Thailand.
** Department of Medicine, University Hospitals of Cleveland and Case Western Reserve University, Cleveland, Ohio, USA.

with CHF[3]. This review will focus on the role of conventional imaging and Doppler echocardiography on the management of patients with systolic and diastolic left ventricular dysfunction.

Echocardiography for the evaluation of patients with CHF

The advent of two-dimensional echocardiography and Doppler flow studies has made it possible to assess cardiac performance precisely, reproducibly, and non-invasively. The safety of the procedure and its widespread availability make it the most frequently used cardiovascular diagnostic technique[4]. The unique advantage of echocardiography is its ability to repetitively provide both anatomic and functional information, such as cardiac chamber dimensions, wall thickness, shape, concomitant valvular, myocardial, and pericardial abnormalities, ejection phase measurement of systolic function and volumetric (and to a lesser extent, isovolumic) diastolic function, and estimates of intracardiac pressures in patients with CHF.

Systolic function

Assessment of global left ventricular ejection fraction (LVEF) is one of the most common indications for echocardiography in a patient with suspected CHF because clinical management decisions rely on the status of LV function. LVEF estimated visually by an experienced echocardiographer is reliable and usually sufficient for clinical purposes. Because of its unidimensional nature, 2D guided M-mode echocardiography may either over- or underestimate actual systolic function in the presence of regional wall motion abnormalities or hyperdynamic function. More accurate measurement of LV volume and LVEF can be obtained from 2D echocardiographic volumetric calculation based on modified Simpson's rule algorithm or area-length methods[5]. Theoretically, the greatest advantage of the 2D method is gained in asymmetric ventricles with regional wall motion abnormalities, such as occurs post infarction. However, assessment of LV volume by 2D echocardiographic techniques is based on geometric assumptions, and the underestimation of LV volumes relative to other techniques has been described[6]. In contrast, 3D echocardiography requires no accuracy limiting geometric assumptions. The LV volumes and ejection fraction assessed by 3D echocardiography correlate and agree well with those assessed by either 3D magnetic resonance tomography or radionuclide angiography[6,7]. However, routine use of 3D echocardiography in patients with heart failure in clinical practice is limited by its relatively low frame rate and the image process time.

Systolic dysfunction is characterized by a LVEF less than 40 per cent; greater values of LVEF characterize isolated diastolic dysfunction[8]. LVEF is the most powerful predictor of cardiovascular morbidity and is associated with increased all- cause mortality[3,9]. Furthermore, serial changes in LVEF may have an impact on the survival rate; thus, patients in whom LVEF had decreased by more than 5 per cent had a higher 1-year mortality rate compared to patients in whom LVEF was either unchanged or increased [10]. Echocardiographic data from a primary care center showed that measurement of LVEF led to a change in management in more than two-thirds of patients with CHF[11]. In another study[12], underutilization of echocardiography in the community was associated with inappropriate use of medication and poorer survival. Echocardiography is also used to assess other determinants of prognosis i.e., LV size, mass and shape[4,13]. LV hypertrophy is associated with cardiovascular events in patients with chronic LV dysfunction (LVEF $< 35\%$), independent of the presence or absence of heart failure symptoms[9].

Doppler echocardiography can also be used for determining global LV systolic function. For example, aortic velocity time integral provides an assessment of left ventricular stroke volume, the first half of aortic flow is used to calculate LV ejection force, and peak aortic velocity and acceleration show a good correlation with LV ejection fraction[14]. Furthermore, dividing LV fractional shortening by aortic ejection time provides the mean velocity of circumferential shortening (Vcf). Although assessment of the aortic velocity waveform provides sensitive indexes of global LV systolic function[15,16], the Doppler derived variables are influenced by load and heart rate[17-19]. Thus, aortic Doppler should be used in conjunction with other echocardiographic indices. Another Doppler method used to assess global LV systolic function is by the mitral regurgitation (MR) waveform. Thus, the rate of rise of LV pressure (+dP/dt) is reflected by the rate of rise of MR velocity. According to the simplified Bernoulli equation ($P=4v^2$), the change in MR velocity from 1 to 3 m/sec corresponds to a change in the pressure gradient from 4 to 36 mmHg. Therefore, by assuming LA pressure to be negligible LV +dP/dt can be calculated by taking the amount of an increase of LV pressure (32 mmHg) and divided by the time interval taken for the MR velocity to rise from 1 to 3 m/sec (i.e. 32/Δt). LV dP/dt obtained from Doppler echocardiography correlates well with dP/dt obtained during cardiac catheterization[20-22] and may predict survival in patients with chronic congestive heart failure[23].

Diastolic function

Although CHF is commonly associated with impaired systolic function, in approximately one-third to one-half of cases, CHF occurs exclusively on the basis of diastolic dysfunction[24,25]. Diastolic dysfunction may be caused by structural abnormalities that influence ventricular distensibility (e.g., pericardial constriction or myocardial restriction, obstruction of ventricular filling at the level of pulmonary vein, left atrium, mitral valve, and with shortening of diastole as occurs in tachycardia) or abnormalities in myocardial relaxation (e.g., myocardial ischemia or cardiac hypertrophy). These factors can exist alone or in combination in any given patient and eventually lead to heart failure[26]. Primary diastolic dysfunction is typically seen in patients with hypertension (often elderly women) and hypertrophic or restrictive cardiomyopathy, but may complicate other cardiac diseases. Although the prognosis for patients with diastolic heart failure is more favorable than that for systolic failure, the mortality risk is increased fourfold when compared with the normal population[27].

Assessment of diastolic function

M-mode and 2D echocardiography

M-mode echocardiography has been used extensively to exam the LV filling, the timing and extent of wall motion reflects changes in chamber volume. Measurements of the amplitude, slope, and duration of the early relaxation period and of atrial contraction provide useful information regarding diastolic function[28-30]. The disadvantages of M-mode include a high rate of technically difficult studies and its unidimensional nature. LV filling dynamics can also be measured by 2D echocardiography. The technique involves frame-by-frame measurement of LV volume either in short-axis or apical four-chambers views. LV filling rates and their derivatives are subsequently calculated from the volume measurements. However, 2D echocardiography is limited by a low sampling rate and suboptimal lateral resolution[31].

Doppler echocardiography

Doppler echocardiographic measurement of mitral and pulmonary vein flows are used to determine LV diastolic pressure, ventricular and atrial filling patterns and diastolic ventricular function[32-34]. Assessment of transmitral flow (LV filling) and pulmonary vein flow (left atrial filling) by Doppler-echocardiography provide a useful guide for the treatment of patient with diastolic heart failure and has an important impact on prognosis and outcome[33].

Mitral flow patterns in diastolic filling assessment

Mitral flow velocities reflect the relationship between left atrial (LA) and LV diastolic pressures. The normal pattern of mitral flow consists of early (E) and late atrial (A) filling velocities. The contribution of early and late filling is commonly expressed as the E/A ratio; in a normal individual, the E/A ratio is greater than 1. The deceleration time of E velocity (DT) and isovolumic relaxation time (IVRT) are two other important parameters of diastolic function derived from the transmitral flow waveform. Using Doppler velocity patterns, diastolic abnormalities are classified into three diagnostic categories: abnormal relaxation, restrictive filling, and pseudonormalization (Table 1).

Abnormal relaxation

When myocardial relaxation is the predominant diastolic abnormality, the fall of LV pressure is slowed and the IVRT is prolonged ($\geq$ 110 msec). Because LV filling is dependent on the LA -LV pressure gradient, early filling is reduced, and compensatory filling during atrial contraction occurs in late diastole. Thus, mitral E is reduced and A velocity is increased, resulting in an E/A ratio less than 1. The DT is prolonged ($\geq$ 240 msec) because the LV takes longer to achieve diastasis with the LA. This type of abnormality is commonly seen in hypertrophic cardiomyopathy, LV hypertrophy, and myocardial ischemia/infarction and in the early stages of infiltrative cardiomyopathies[33].

Restrictive filling or decreased compliance pattern

This pattern of LV filling consists of a high early diastolic velocity, short isovolumic relaxation

Table 1. Classification of diastolic dysfunction.

	Normal	Abnormal relaxation	Restriction	Pseudonormalization
E/A ratio	1-1.5	< 1	> 2	1-1.5
DT (msec)	160-240	≥ 240	≤ 150	160-240
IVRT (msec)	60-100	≥ 110	< 60	60-100
PV S/D ratio	~ 1	> 1	< 1	< 1
A_r duration	< A	> A	> A	> A

E/A = mitral E/A ratio, DT = decelerating time,
IVRT = isovolumic relaxation time, PV S/D = pulmonary vein systolic and diastolic flow,
A_r = atrial reversal flow of pulmonary vein, A = mitral A duration

and deceleration times, and a relatively small A velocity. Decreased LV compliance and marked increased LA pressure produce this abnormality(33). Increased LA pressure results in earlier opening of the mitral valve (and hence an IVRT < 60 msec) and a higher high E velocity. A decrease in LV compliance (with its attendant high filling rate in early diastole) produces a rapid increase in LV diastolic pressure, time to diastasis, and therefore a short DT (< 150 msec). The increase in atrial systolic afterload (i.e. increased LV diastolic pressure) and (if present) atrial myocardial contractile dysfunction, results in a low A velocity and hence, an E/A ratio > 2. The restrictive mitral flow pattern is evident in patients with decompensated heart failure, restrictive cardiomyopathy, constrictive pericarditis, ischemic cardiomyopathy with high pressure, and severe mitral and aortic regurgitation(35-39). In patients with LV dysfunction, the restrictive filling pattern is associated with severe symptoms and poor prognosis(40,41). However, mitral flow patterns are dynamic and manipulation of loading conditions provides additional prognosis information. Thus, an irreversible restrictive pattern during nitroprusside infusion predicted cardiac mortality and need for heart transplantation compared to a reversible restrictive pattern(42). Moreover, serial evaluations of Doppler transmitral flow may be useful in monitoring the progression of the disease during optimal medical treatment. In patients with CHF, the persistence of restrictive pattern after optimal medical treatment was associated with high cardiac mortality and transplant rate(41,43).

Pseudonormalization

When slow myocardial relaxation and high LA pressure coexist, high LA pressure can offset the effect of slow relaxation producing a diastolic filling pattern similar to normal pattern (E/A ratio 1-1.5 and DT 160-240 msec). This pattern represents a transition period between the patterns of abnormal relaxation and restrictive filling, and is designated pseudonormalization. The distinction between true normal and pseudonormal filling may be made by the use of two-dimensional echocardiography and by preload manipulation. Because diastolic dysfunction is usually accompanied by structural abnormalities of the heart, a normal E/A ratio should be considered as pseudonormal in patients with LV hypertrophy, LA enlargement, increased LV wall thickness and or systolic dysfunction(33). Maneuvers that reduce preload such as the Valsalva maneuver or sublingual nitroglycerin may unmask the underlying abnormal LV relaxation and reduce E/A ratio to less than 1(44). However, the distinction may require examination of pulmonary venous waveforms, color M-mode, or tissue Doppler (see below).

Pulmonary vein velocities in diastolic filling assessment

The pattern of blood flow in the pulmonary vein (PV) provides additional information on diastolic filling. The velocity of PV flow can be measured by transthoracic echocardiography but is better assessed by transesophageal echocardiography. There are four distinct velocity components in pulmonary venous Doppler recordings: two systolic velocities (S_1 and S_2), diastolic velocity (D), and atrial reversal (A_r). The pattern of pulmonary vein flow is due largely to suction effects created by LA and LV events. Systolic waves represent LA filling during atrial relaxation (S_1) and ventricular contraction (S_2) and diastolic forward flow occurs after the opening of mitral valve. Atrial reversal flow represents retrograde flow during atrial contraction. An isolated LV relaxation abnormality is characterized by predominant systolic flow (↑S/D ratio) and increased A_r. In contrast, decreased systolic forward flow and increased diastolic forward flow (↓S/D ratio) are seen in the restrictive pattern. The pulmonary flow patterns complements mitral flow patterns, and are especially useful when the pseudonormalized pattern is suspected. The extent and duration of pulmonary atrial reversal flow is directly related to LA pressure (and LV diastolic pressure), whereas the mitral A duration is inversely related to LV diastolic pressure. Therefore, in patients with high LV diastolic pressure, the duration of pulmonary atrial reversal flow is longer than that of forward transmitral flow during the A wave(45,46). A difference greater than 30 msec is a strong predictor of cardiac mortality and hospitalization in patients with LV dysfunction(47).

Other uses of Doppler echocardiography

Assessment of pulmonary artery pressure

Pulmonary artery (or more accurately, RV) systolic pressure can be measured indirectly from the tricuspid regurgitation (TR) jet's maximal velocity and an estimate of RA pressure: RV systolic pressure = $4\,(\text{TR velocity}_{max})^2$ + RA pressure. Pulmonary hypertension in patients with LV dysfunction is a marker of poor prognosis and is associated with poor outcomes after heart transplantation(48). The degree of pulmonary hypertension is also independently associated with the restrictive LV filling pattern and functional mitral regurgitation(49).

Myocardial performance index (MPI)

The MPI is a Doppler index that estimates combined systolic and diastolic function; it is defined as the sum of LV isovolumic relaxation time and isovolumic contraction time divided by aortic ejection time. MPI is related to morbidity and mortality in patients with various cardiovascular diseases(50-52). Preliminary data suggest that the MPI has a narrow range in healthy subjects and is independent of heart rate and preload(53,54).

Limitations of traditional Doppler echocardiography

Although Doppler echocardiography is a useful and very cost-effective technique for assessing ventricular function, it has inherent limitations. In addition to technical factors (e.g., location of the sample volume, angle of ultrasound beam, and poor acoustic windows caused by obesity or chronic obstructive pulmonary disease), various physiologic conditions (e.g. loading conditions, heart rate and rhythm) can alter the diastolic filling pattern(55). An increase in preload significantly increases the transmitral E velocity and shortens DT and IVRT. Similarly, an increase in preload increases diastolic and systolic forward velocities of pulmonary venous flow, and in a normal ventricle, increases the S/D ratio. However, in the presence of an abnormal ventricle, increased preload is associated with a decreased S/D ratio(56). A decrease in preload reduces the transmitral E velocity and E/A ratio and prolongs the IVRT and DT; in addition, pulmonary venous diastolic and atrial reversal velocities are decreased(57). An increase in afterload can produce the same effects as a decrease in preload. Absent atrial contraction, as in atrial fibrillation and rapid heart rate, complicates interpretation of diastolic filling(55). Finally, the same diastolic filling pattern may be seen in patients despite disparate underlying mechanisms(33,35,37-39).

New Doppler echocardiographic applications

Tissue Doppler Imaging

Tissue Doppler Imaging (TDI) is similar to the conventional pulsed Doppler, but measures the high amplitude, low velocity of myocardium, rather than the low amplitude, high velocity of blood flow. Qualitatively, the normal velocity pattern of mitral annulus TDI resembles that of transmitral flow(58), but compared to the flow velocity waveform, TDI is load independent(59). TDI of mitral annulus motion is a useful surrogate to help distinguish constrictive pericarditis, which has rapid early diastolic annulus motion (> 8 cm/s), from restrictive cardiomyopathy, which has a slower annulus motion(60). Myocardial velocities assessed by TDI are also very useful in differentiating patients with normal diastolic function from those with abnormal diastolic function. Indeed, when compared with standard transmitral and pulmonary venous flow, early diastolic myocardial velocity was the best discriminator between normal and pseudonormal patients(61).

Color M-mode (CMM) Doppler

Color M-mode Doppler has the advantage over traditional pulse wave Doppler echocardiography, in that it measures the flow velocities at many points along a single scan line, and provides the spatiotemporal distribution of these velocities. Like TDI, CMM Doppler is relatively load independent(62). The propagation velocity of early diastole flow into the left ventricle (Vp), derived from color M-mode, is inversely correlated with the time constant of LV relaxation(60). Preliminary data suggest that Vp has a role in distinguishing restrictive cardiomyopathy from constrictive pericarditis; while these patients may have a similar tranmitral flow pattern, patients with constrictive pericarditis have higher Vp than those with restrictive cardiomyopathy(62).

SUMMARY

Congestive heart failure is a common clinical disorder. Complete evaluation of the patient with signs and symptoms of heart failure should include the assessment of the nature and the severity of heart failure in order to provide the data for diagnosis, therapeutic intervention and prognosis. In addition to history and physical examination, echocardiography is frequently used to evaluate the nature and the severity of heart failure. Echocardiography in conjunction with Doppler technique provides comprehensive evaluation of cardiac function including systolic and diastolic function. The information obtained by echocardiography has a prognostic value and is a guide to proper therapy. An additional benefit of echocardiography is its ability to detect and quantify other cardiac abnormalities (e.g. valvular heart disease, pericardial disease) that may be corrected by specific intervention. Currently, new Doppler echocardiographic applications allow us to differentiate various cardiac diseases that may have the same pattern of diastolic filling flow velocities with the traditional Doppler technique. Future studies of these new applications will provide valuable information and lead to more favorable outcomes in patients with heart failure.

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การตรวจคลื่นเสียงสะท้อนหัวใจในภาวะหัวใจล้มเหลว

ทรงศักดิ์ เกียรติชูสกุล, พบ, Brian D Hoit, MD***

การหาสาเหตุและประเมินความรุนแรงของภาวะหัวใจล้มเหลว เป็นสิ่งจำเป็นในการดูแลรักษาผู้ป่วย การตรวจด้วยคลื่นเสียงสะท้อนหัวใจ (echocardiography) ซึ่งมีใช้กันอย่างแพร่หลายในปัจจุบัน เป็นการตรวจที่มีประโยชน์ในการวินิจฉัยและประเมินความรุนแรงของภาวะหัวใจล้มเหลวได้อย่างแม่นยำและปลอดภัย บทความได้รวบรวมความรู้เกี่ยวกับประโยชน์ของคลื่นเสียงสะท้อนหัวใจในผู้ป่วยที่มีหัวใจล้มเหลว ทั้งในแง่การวินิจฉัย การรักษาและการพยากรณ์โรค

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ทรงศักดิ์ เกียรติชูสกุล, Brian D Hoit
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* ภาควิชาอายุรศาสตร์, คณะแพทยศาสตร์ มหาวิทยาลัยขอนแก่น, ขอนแก่น 40002

** Department of Medicine, University Hospitals of Cleveland and Case Western Reserve University, Cleveland, Ohio, USA.