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PATHOPHYSIOLOGY

Echocardiographic Evaluation of Left Ventricular Systolic and Diastolic Function in Hypertension

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ABSTRACT

Hypertension is a significant health problem, i.e., associated with considerable morbidity and mortality. The hallmark of hypertensive disease is a gradual increase in left ventricular (LV) mass, resulting in concentric hypertrophy and eventual diastolic dysfunction of the left ventricle secondary to LV stiffness and impaired relaxation. Late stages may be characterized by severe LV systolic dysfunction and dilatation. Echocardiography offers clinicians a quick, reliable, and inexpensive method of assessing changes in LV function resulting from hypertension. In this review, we summarize various echocardiographic parameters, including their advantages and disadvantages, and clinicians should be familiar with in order to ascertain an assessment of cardiovascular risk in hypertensive patients.

Keywords: Echocardiography, Hypertension, Left ventricular diastolic function, Left ventricular systolic function, Three-dimensional echocardiography, Two-dimensional echocardiography.

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INTRODUCTION

Cardiovascular diseases account for a significant amount of health problems worldwide, and hypertension is a major risk factor for cardiovascular diseases. The prevalence of systemic hypertension is estimated at 25% in the Western world, and increases dramatically with advancing age.[1]

The 2003 American College of Cardiology (ACC) and American Heart Association (AHA) practice guidelines recommend echocardiography as the noninvasive procedure of choice to evaluate the cardiac effects of systemic hypertension, given that it is the most common cause of left ventricular (LV) hypertrophy and congestive heart failure in adults.[2] These guidelines are further supported by the 2013 European Society of Hypertension (ESH)/European Society of Cardiology (ESC) guidelines for systemic hypertension and 2014 Canadian Hypertension Education Program (CHEP) guidelines, which recommend echocardiography to not only diagnose LV hypertrophy, but also refine cardiovascular and renal risks.[3-5]

Hypertensive heart disease is a constellation of signs and symptoms, including LV hypertrophy, systolic and diastolic dysfunction, arrhythmias, and decompensated heart failure.[6] Hypertension results in LV thickening as a compensatory response to elevated blood pressure, which through a series of poorly understood events, results in LV dilation and systolic heart failure characterized by a reduced ejection fraction (EF).[7] In those hypertensive patients with preserved LV function, hypertension has been associated with gradual diastolic LV dysfunction, defined as diastolic heart failure.[8] Echocardiography can quickly and cost-effectively evaluate multiple systolic and diastolic properties of the LV, including speed and extent of contraction, end-systolic wall stress, and ventricular filling rate throughout diastole.[9,10]

This review aims to summarize current literature regarding echocardiographic evaluation of LV systolic and diastolic dysfunction in hypertension.

SYSTOLIC DYSFUNCTION

The paradigm of systolic dysfunction in hypertension is that hypertensive disease results in concentric hypertrophy of the LV leading to the "burned out" dilated LV, characterized by a reduced EF.[11] Left ventricular hypertrophy is defined as an increase in LV mass. Echocardiography allows for the rapid assessment of LV systolic function and M-mode and two-dimensional (2D) echocardiographic measures of LV mass have been shown to be more sensitive and specific when compared to electrocardiograms (EKG) or chest X-ray in diagnosing LV hypertrophy and concentric remodeling.[3,12-16]

Assessing LV mass and geometry is the most common role of echocardiography in hypertensive patients, with measurements having excellent correlation with necropsy

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study of LV mass.[17] Measurements can be obtained either using the 2D directed M-mode at the level of the mitral valve tip or using 2D apical views. Calculating LV mass requires accurate measurement of both the interventricular septum and LV posterior (inferolateral) wall thickness, as well as the interventricular cavity dimension, with certain cutoff values being used to classify LV hypertrophy based on gender (115 gm/m^2 men and 95 gm/m^2 women using M-mode method, or 102 gm/m^2 men and 88 gm/m^2 women using 2D method). With these measurements, the American Society of Echocardiography (ASE) recommends the following equation to calculate LV mass:

$$\text{LV mass} = 0.8 \times 1.04 \times (\text{LVIDd} + \text{PWTd} + \text{SWTd})^3 + 0.6$$

LVIDdt (LV internal dimension at end-diastole)

PWTd (LV posterior wall thickness at end-diastole)

SWTD (interventricular septal wall thickness at end diastole)

Although this formula correlates well with necropsy studies, small variations in the measurements can result in large calculation differences.[17]

Three-dimensional (3D) echocardiography would provide more accurate measurements of LV mass, as it does not assume the LV to be a truncated ellipsoid as 2D echocardiography. The benefit of this is largely seen in patients with regional wall abnormalities or LV aneurysms, where more accurate LV volumes can be obtained by 3D *vs* 2D echocardiography.

Relative wall thickness (RWT) can also be calculated from measurements obtained from 2D echocardiography, and can differentiate LV hypertrophy into concentric (RWT > 0.42) or eccentric hypertrophy (RWT < 0.42).[18] Essentially, RWT is a ratio between the end-diastolic inferolateral wall thickness and end-diastolic LV internal dimension. Concentric hypertrophy correlates with an increased number of adverse cardiovascular events and is associated with the greatest mortality rate in patients with coronary artery disease.[19,20]

Beyond LV mass, echocardiography allows for estimates of LV systolic function in the form of LVEF. Ejection fraction is the most common parameter of systolic function and is often used as a prognostic factor in patients with underlying heart disease, based on the severity (summarized in Table 1).[21] Two methods can be used to determine EF. In the modified Simpson's method, the LV endocardial border is traced at end-systole/diastole in orthogonal planes including the apex. The LV is then divided along the long axis into ellipsoid discs of the same height. The volume of each disk is then calculated and added to determine the LV volumes in end-systole/diastole. This method gives a single number for the EF, LV volumes, and limits variability of measurements by using computer software to calculate volumes. However, the EF is calculated from only 2 or 3 views, the LV is assumed to be ellipsoid which may not be accurate if significant wall motion abnormalities are present, and the determined EF is not reliable if LV endocardial dropouts exist. Visual estimation of EF is the most commonly practiced method. This can be an accurate method for experienced echocardiographers and has the advantage of accounting for all available views. However, there can be large variability between intra- and inter-observations with less experienced users, and this method is not useful if LV volumes are needed. Echocardiographic contrast agents have been developed which when injected intravenously make the blood in LV cavity "visible" akin to LV angiography, thereby enhancing the delineation of LV endocardial borders. These result in more accurate assessment of LVEF and LV volumes and less intra- and interobserver variability.

Table 1: Left ventricular ejection fraction (LVEF) by echocardiography stratified by gender and severity

Classification	*LVEF (Men)*	*LVEF (Women)*
Normal LV function	52–72%	54–74%
Mild LV dysfunction	41–51%	41–53%
Moderate LV dysfunction	30–40%	30–40%
Severe LV dysfunction	<30%	<30%

Recent advancements in 3D echocardiography offer more advantages over traditional M-mode and 2D echocardiography. Evaluation of LV mass using 3D echocardiography has high correlation ($r = 0.95$, $p < 0.001$) with magnetic resonance imaging (MRI).[22] Furthermore, 3D echocardiography measurements correlate strongly with cardiac MRI and does not assume the LV is a prolate ellipse when calculating LV volumes, resulting in more accurate EF measurements and lower inter-observer variability in patients with LV aneurysms or regional wall abnormalities.[23-25] Unfortunately, the image quality is typically poorer compared to 2D modalities.

The other echocardiographic findings include LV long-axis function, assessed with atrioventricular plane displacement, that has been shown to be abnormal in patients with hypertension without obvious signs of systolic dysfunction.[26] Mitral annular velocity can be used to identify subclinical systolic dysfunction and is decreased in hypertensive patients with normal EFs.[27,28] Mitral annular velocity is obtained through tissue Doppler imaging, where systolic velocities <7 cm/s typically represent systolic dysfunction.

Speckle tracking echocardiography (STE) can be used to assess myocardium deformations by tracking natural sound markers generated by the interaction between ultrasound waves and the myocardium. It is largely angle independent with respect to the angle of insonation between the ultrasound beam and studied tissue.

Speckle tracking echocardiography can assess for subtle myocardial dysfunction and may be clinically valuable for hypertensive patients with subclinical disease at the risk of progressing. It can be used to determine angle-independent and multidirectional myocardial strain values. Strain echocardiography is a relatively new way of measuring overall myocardial function and can be used to detect organ damage earlier than other echocardiographic measurements. Longitudinal strain has been shown to be decreased in hypertensive patients with normal LV systolic function.[29] Three-dimensional strain echocardiography allows analysis of the entire LV, and circumferential strain measured by 3D strain echocardiography has shown a high correlation with LVEF when compared to global longitudinal and radial strain.[30]

DIASTOLIC DYSFUNCTION

The relationship between LV diastolic dysfunction and hypertension is less clear and remains poorly understood. However, it is known that suboptimally treated hypertension results in LV end-diastolic pressures that are steadily increasing and to a clinical condition we recognize as diastolic heart failure, classically characterized by limited myocardial relaxation, preserved LVEF, and a significant annual mortality.[31,32] There is no single echocardiographic measure that can be used to determine diastolic dysfunction. Various measurements need to be integrated to make an assessment. The ASE distinguishes various stages of diastolic dysfunction based on different echocardiographic parameters (Table 2).[33]

Echocardiography is a useful tool in evaluating LV diastolic function, as several echocardiographic markers can be used to estimate LV filling pressure. Enlarged left atrium (LA) size, an indicator of elevated LV filling pressure, has been documented in up to 20% of hypertensive patients, and is associated with increased morbidity and mortality.[34-38] Isovolumic relaxation time (IVRT), ratio of mitral inflow E (early diastolic filling wave) and A (late diastolic/atrial filling wave) velocities, deceleration time of E velocity, and duration of A wave can all be used to assess diastolic dysfunction, although these markers are affected by several clinical entities (age, heart rate, LA function, cardiac output).[39]

Mitral E velocity reflects the pressure gradient between the LA and LV during early diastole. E wave deceleration correlates to LV compliance. In early diastolic dysfunction, it decreases and the A wave increases; however, with progression of diastolic dysfunction and elevation of filling pressures, the E wave velocity increases and the A wave decreases and the E to A wave ratio is elevated to >2. In patients with reduced EFs, the mitral E velocity correlates better with LV filling pressures and prognosis than LVEF.[33] Prognostic information of the E/A ratio specifically in hypertensive patients has been studied as well. Schillaci et al[40] followed 1839 Caucasian hypertensive patients for up to 11 years and found that E/A transmitral ratio was predictive of subsequent cardiovascular-related adverse events in untreated and uncomplicated patients with essential hypertension.

Mitral annular velocity, assessed by pulsed-wave Doppler of the medial and lateral aspects of the mitral annulus, allows for calculation of the mitral inflow E/mitral annulus early diastolic (e') ratio, which has been shown to be a reliable indicator of LA pressure in certain circumstances.[41,42] Mitral inflow E/e' ratio <8 (e' being the average of early diastolic velocities of the medial and lateral aspects of the mitral annulus) indicates normal LV filling pressure, while >14 is highly specific for increased LV filling pressures.[33] This ratio is a poor indicator of filling pressure in patients with advanced systolic heart failure, significant valvular disease (mitral regurgitation, aortic regurgitation, and significant mitral annular calcification), and in patients with preexisting left bundle branch block.[43-45] Furthermore, indeterminate values are nonspecific.[33]

Left atrium enlargement is a common consequence of long-term hypertension and a poor prognostic factor in hypertension.[34] Left atrium size is calculated using the parasternal long-axis view at end-systole, while LA volume is calculated using apical views of traditional 2D echocardiogaraphy.[45] The LA strain rate, measured by tissue Doppler imaging or 2D STE, can detect subclinical LA dysfunction in hypertensive patients.[46] The LA maximum volume index represents chronic

Table 2: Echocardiographic findings according to LV diastolic dysfunction grades*

	LV relaxation	*LAP*	*Mitral E/A ratio*	*Average E/e' ratio*	*Peak TR velocity (m/s)*	*LA volume index*
Normal	Normal	Normal	≥0.8	<10	<2.8	Normal
Grade I	Impaired	Low or normal	≥0.8	<10	<2.8	Normal or ncreased
Grade II	Impaired	Elevated	>0.8 to <2	10–14	>2.8	Increased
Grade III	Impaired	Elevated	>2	>14	>2.8	Increased

*Assessment of elevated left atrial pressure is more reliable when more than 2 or 3 criteria given in the table are present in a given patient in the absence of caveats mentioned in the text. A: Mitral inflow late diastolic/atrial wave by pulsed wave Doppler; E: Mitral inflow early diastolic wave by pulsed wave; e': Average of medial and lateral mitral annulus longitudinal velocities by tissue Doppler echocardiography; LA: Left atrium; LAP: Left atrial pressure; LV: Left ventricle; TR: Tricuspid valve regurgitation

and cumulative effects of elevated LV filling pressures. Increased LA maximum volume index is an independent predictor of death.[33]

CONCLUSION

Hypertension is a significant disease with considerable morbidity and mortality. Echocardiography allows for rapid, noninvasive assessment of LV function in hypertensive patients. It can evaluate morphological and hemodynamic changes acutely and over time. Because of its usefulness, it is a widely used imaging modality. Understanding the various data that can be obtained with echocardiography, as well as recent technological advances in echocardiography will aid in managing and caring for patients.

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