

Echo for diastology

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ABSTRACT

Diastolic dysfunction ranging from impaired relaxation of the left ventricle to heart failure with preserved ejection fraction (HFpEF) is a common finding in the cardiac surgery population. It is important for the peri-operative echocardiographer to have a developed understanding of the pathophysiology of diastolic dysfunction and the echocardiographic features that determine where on the spectrum of diastolic function and dysfunction a patient lies

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INTRODUCTION

Diastolic dysfunction ranging from the impaired relaxation of the left ventricle to heart failure with preserved ejection fraction (EF) is a common finding in the cardiac surgery population.^[1] It is important for the perioperative echocardiographer to have a developed understanding of the pathophysiology of diastolic dysfunction and the echocardiographic features that determine where on the spectrum of diastolic function and dysfunction a patient lies.

Recently, the American Society of Echocardiography and the European Association of Cardiovascular Imaging (ASE/EACI) updated recommendations for the evaluation of diastolic function by echocardiography. This review will discuss the pathophysiology of diastolic dysfunction, review the echocardiographic parameters, and discuss updated recommendations for assessing diastolic function.

DIASTOLIC FUNCTION

In contrast to the left ventricular (LV) systole, which is the output phase of the heart, LV diastole is the equally important input requirement to maintain stroke volume. LV diastole is an adenosine triphosphate (ATP) consuming process^[2] comprised isovolumetric relaxation, rapid diastolic filling, diastasis, and atrial systole.^[3,4] Early in diastole, with the

elastic recoil of the left ventricle, LV pressure decreases below that of the left atrium and the mitral valve opens. A healthy ventricle has a suction effect that allows rapid diastolic filling.^[5] As the transmitral pressure gradient decreases, filling slows. This phase is referred to as diastasis. Atrial contraction then provides the remaining 20–30% of LV end diastolic volume in a healthy heart.^[3]

The process of the myocardium relaxing or lusitropy is an energy consuming state that requires sequestration of calcium from the cytosol.^[2] Myocardial relaxation allows the ventricular chamber to fill without significant increases in pressure. The relationship of myocardial relaxation, myocardial compliance, and LV pressures forms the basis of our understanding of the echocardiographic parameters that define stages of diastolic dysfunction.

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DIASTOLIC DYSFUNCTION

Diastolic dysfunction comes about when there is an abnormality in ATP-dependent myocardial relaxation and passive ventricular filling. Four mechanisms for diastolic dysfunction are (1) Slow or incomplete relaxation, (2) impaired LV filling rate from elevated filling pressures, (3) altered elasticity causing stiff myocardium, and (4) pericardial constriction causing a mechanical limitation to LV filling.^[3] Increased age, ischemia, and LV hypertrophy are common causes of impaired LV relaxation. Myocardial fibrosis and scarring is a common mechanism for decreased ventricular compliance and elevated filling pressures.

Diastolic dysfunction can be seen as a continuum from impaired relaxation with normal filling pressures to restrictive filling with extremely elevated filling pressures. Common nomenclature for this continuum is shown in Table 1.

The stages of diastolic dysfunction can be understood through the echocardiographic parameters that categorize the pathologic state. To get a basis for these parameters, the echocardiographic normal will be discussed as well as the three stages of diastolic dysfunction.

ECHOCARDIOGRAPHIC ASSESSMENT OF LEFT VENTRICULAR DIASTOLIC FUNCTION

Echocardiography uses a combination of two-dimensional (2D) and Doppler methods to assess LV diastolic function. In addition, as the updated ASE/EACI guidelines emphasize, the overall clinical picture provides important clues for assessing diastology. Therefore, the first step in diastolic assessment is reviewing the patient's clinical picture, risk factors for heart dysfunction, and current hemodynamic status including heart rhythm. A similarly holistic approach is used for assessing the

echocardiogram. The assessment begins with a thorough 2D assessment making note of 2D findings which may predispose the patient to diastolic dysfunction and also findings which may influence diastolic parameters, such as heart rhythm, LV EF, mitral annular calcification, and other mitral valve disease, hardware, etc. 2D echo findings in a heart with normal diastolic function, in the absence of other significant cardiac pathology, will include normal chamber size and function and no significant tricuspid regurgitation (TR) velocities or TR gradient. Granted, normal diastolic function can coexist with cardiac pathology that alters the above findings for reasons other than diastolic dysfunction.

Spectral Doppler is a cornerstone of diastolic assessment. A large variety of Doppler techniques has been developed contributing to the complexity of diastolic assessment. Diastolic function is one of the more complex areas of echocardiographic assessment and there is a significant gray area. The approach, therefore, should be to build a case for a particular stage of diastolic function based on several parameters. The individual parameters will first be discussed and then be put together based on the ASAE/EACI's algorithm for assessing diastolic function.

The first Doppler-derived indices that will be discussed are based on the mitral valve inflow pattern. Mitral valve inflow is obtained with pulse wave Doppler with the sample gate placed between the mitral valve leaflet tips in the four-chamber view. The resultant spectral Doppler in a healthy young individual will show a spectral tracing in the direction of diastolic blood flow with an early rapid filling E-wave and a lower velocity atrial contraction A-wave. Several parameters have been developed from the mitral inflow pattern including peak E-wave velocity, peak A-wave velocity, mechanical ventilation (MV) A duration, MV E/A ratio, and mitral valve deceleration time, which is the time from peak E velocity to termination of the E-wave.

The next set of parameters is based on mitral annular tissue Doppler. Tissue Doppler e' velocity is measured in the apical four-chamber view with a pulsed-wave sample volume placed at the lateral and septal base of the LV. The resultant wave will be in the direction of LV relaxation of the base and has a septal e' -wave and a lateral e' -wave. From both mitral inflow pattern and tissue Doppler, the Mitral E/ e' can be calculated.

Pulmonary venous inflow can be assessed by placing pulsed-wave Doppler into a well-aligned pulmonary

Table 1: The stages of diastolic dysfunction

Parameters	Grade	Findings
Impaired relaxation	Grade I	With or without evidence of elevated left ventricular filling pressures
Pseudonormal filling pattern	Grade II	Elevated filling pressures
Restrictive filling pattern	Grade III	Elevated filling pressures
Nonreversible restriction	Grade IV	

vein. In transthoracic echocardiogram (TTE), the recommended view is the apical four-chamber view. In TEE, the left upper pulmonary vein from a modified two chamber is often easy to obtain and well aligned. Pulsed-wave Doppler gate is placed 1–2 cm into the pulmonary vein. The resultant spectral waveform in a healthy individual is a systolic (PV S-wave) greater than diastolic wave (PV D-wave) in the direction of pulmonary blood flow into the atrial. At the termination of diastole, a retrograde A wave (PV AR-wave) can often be seen. A caveat to a normal pulmonary venous pattern is that many young individuals and athletes will have an $S < D$ relationship. This is thought to be secondary to exaggerated pulmonary venous inflow during diastole from a powerful suction during the early rapid filling phase of diastole.^[5] Peak PV S-wave velocity, peak PV D-wave velocity, PV AR-wave duration, and PV S/D ratio (using the ratio of respective velocity-time integrals) are all methods used in diastolic assessment.

Additional parameters that play a significant role in the new guidelines are left atrial (LA) maximum volume index, tricuspid regurgitant systolic jet velocity, and the use of valsalva for dynamically assessing reversal mitral inflow velocity E/A. Left atrial size is obtained at end atrial diastole by the method of disks and indexed to the patient's body surface area. Tricuspid regurgitant systolic jet velocity is measured by continuous wave Doppler from the apical four-chamber view in TTE and the best-aligned jet available in TEE, usually a modified bicaval view.

Secondary measures for LV diastolic assessment include propagation velocity (Vp), isovolumic relaxation time (IVRT), and T E-e' time interval. Vp uses color M-mode in the direction of mitral valve inflow and requires a measurement of the slope of inflow velocity at 4 cm from the mitral valve into the LV. IVRT is obtained with continuous wave Doppler through the LVOT to simultaneously assess the end of aortic ejection and the beginning of mitral inflow. T E-e' time interval is the time between peak QRS complex R wave and onset of E velocity and subtracted from the tie interval between the QRS complex and the onset of e'.

Figure 1 shows mitral valve inflow and tissue Doppler patterns in the normal heart and various grades of diastolic dysfunction. Slowing of myocardial relaxation lowers E and e' velocities. An E/A ratio of <0.8 is evidence for Grade I diastolic dysfunction. As the myocardium

becomes less compliant, LV filling pressures increase to maintain ventricular filling. On the continuum of diastolic dysfunction, filling pressures increase as the heart progresses to the pseudonormal filling pattern. This pattern is characterized by a "normal" E/A ratio (0.8–2), but evidence of elevated filling pressures. The restrictive filling pattern is characterized by an E/A ratio of ≥ 2 .

Filling pressures can be estimated by a combination of parameters that, when congruent, can build a case for normal or elevated left atrial pressure (LAP) and left ventricular end-diastolic pressure. The new guidelines emphasize abnormal cutoffs of an LA volume index >34 ml/m², increased TR velocity >2.8 m/s, and average E/e' >14 for suggesting elevated filling pressures. Pulmonary venous inflow pattern showing a systolic greater than diastolic VTI ratio is also suggestive of normal LA filling pressures.

THE AMERICAN SOCIETY OF ECHOCARDIOGRAPHY/THE EUROPEAN ASSOCIATION OF CARDIOVASCULAR IMAGING GUIDELINE UPDATE

The ASE/EACI update on diastology in April of this year is meant to simplify guidelines for assessing diastolic function. The approach is to first determine if the patient has a normal EF (EF $\geq 50\%$). The delineation is made because the focus changes slightly in diastolic assessment in patients with decreased EF to primarily identifying increased filling pressures. With normal EF, more variables are often required to establish grade and pressure status. Figure 2 shows the general algorithm for first determining the presence or absence of diastolic dysfunction in patients with normal EF. Consistency in variables is important. If diastolic dysfunction is determined to be present, that is, the patient has myocardial disease and a normal EF, then specifically characterizing the grade and the presence or absence of filling pressures is achieved with the use of the algorithm displayed in Figure 3. Diastolic dysfunction is determined to be present if $>50\%$ of the variables if LA volume index is >34 ml/m², TR velocity is >2.8 m/s, and average E/e' is >14 , and septal e' velocity <7 and lateral e' velocity <10 . The author has found that a surprising number of patients have to be placed in the indeterminate category because there is so frequently a sufficient TR jet to measure TR velocity.

Figure 3 is used in patients with a normal EF and myocardial disease causing diastolic dysfunction and in

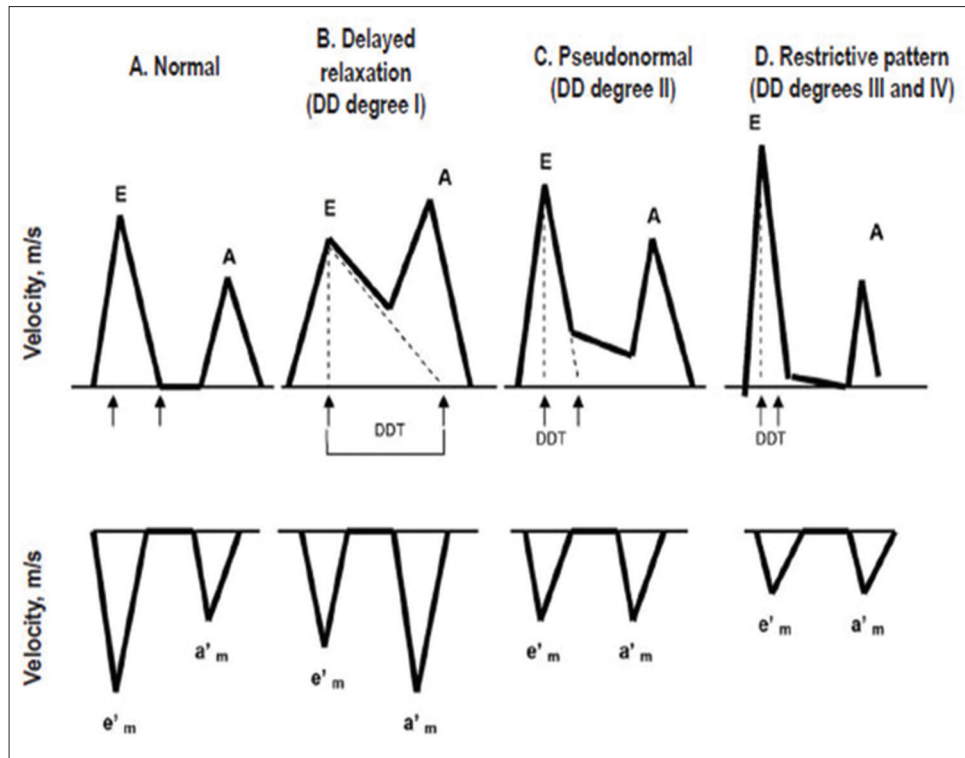


Figure 1: Mitral inflow pattern showing relative E-wave and A-wave velocities in normal and the progression of diastolic dysfunction on top. On the bottom, tissue Doppler velocities denoted by e' and a'. Figure obtained from heart failure with preserved ejection fraction: fighting misconceptions for a new approach by R. Fontes-Carvalho and A. Leite-Moreira (Arq. Bras. Cardiol. Vol. 96 no. 6 São Paulo June 2011)

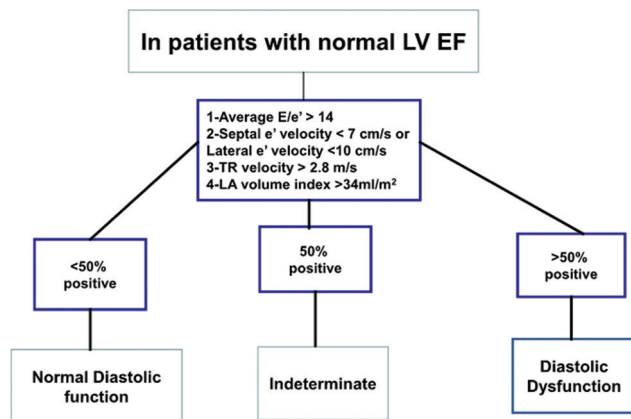


Figure 2: Assessing the presence of diastolic dysfunction in patient with normal ejection fraction. Figure obtained from the 2016 recommendations for the evaluation of the left ventricular function by echocardiography: An update from the American Society of Echocardiography and the European Association of Cardiovascular Imaging (JASE April 2016 Volume 29, Issue 4, Pages 277-314)

patients with an EF < 50%. If the E/A of the mitral inflow pattern is < 0.8 and the peak E velocity is ≤ 50 cm/s; then, the patient has Grade I diastolic dysfunction (impaired relaxation) and normal LAP. If the patient has an E/A < 0.8 and the peak E velocity is > 50 cm/s, or the E/A > 0.8 but < 2; then, additional criteria

need to be evaluated. These criteria are LA volume index > 34 ml/m², increased TR velocity > 2.8 m/s, and average E/e' > 14. If two or three of the criteria are negative, the patient has normal LAP and impaired relaxation. If only one of the criteria is positive, one negative, and one not available, the patient falls in the indeterminate category. If two or three of three are positive, the patient has pseudonormal pattern and elevated filling pressures. In patients with depressed EF, S/D ratio may be used if one of the three parameters in not available. Systolic wave VTI/diastolic wave VTI less than one is consistent with elevated filling pressures. If the E/A is greater or equal to two, no additional criteria need to be assessed; the patient can be said to have a restrictive filling pattern with elevated filling pressures.

PERIOPERATIVE ECHOCARDIOGRAPHY

It is explicitly stated in the ASE/EACI 2016 update on diastology that current TTE-derived guidelines may not be applicable in the perioperative setting.^[6] These guidelines are based on extensive population studies in which echocardiographic parameters were compared to catheter-derived gold standards of ventricular relaxation and pressures to come up with the accepted

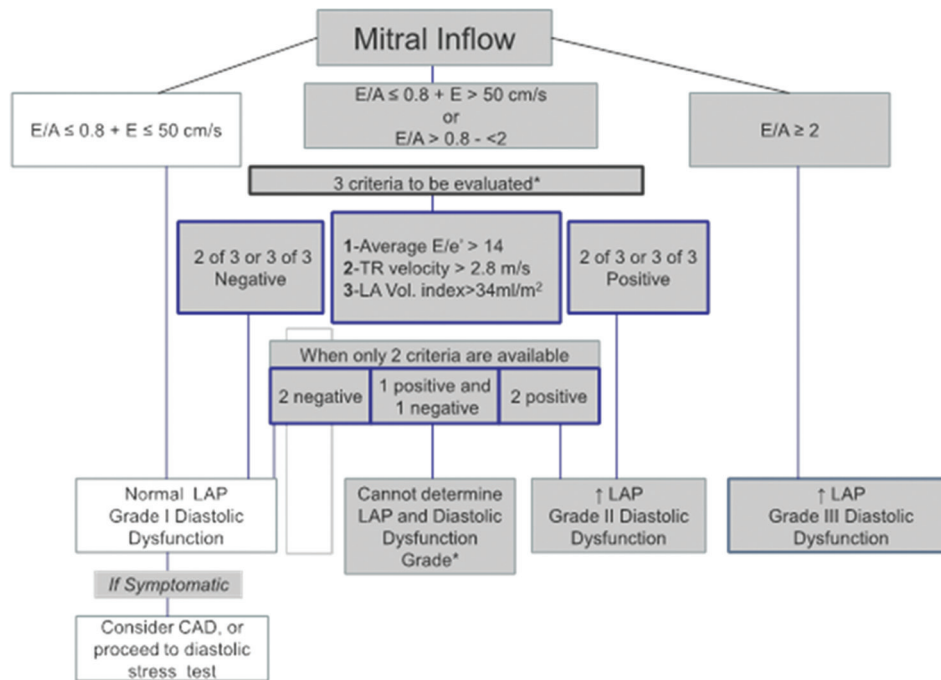


Figure 3: Assessing the grade of diastolic function and elevated filling pressures. Figure obtained from the 2016 recommendations for the evaluation of the left ventricular function by echocardiography: an update from the American Society of Echocardiography and the European Association of Cardiovascular Imaging (JASE April 2016 Volume 29, Issue 4, Pages 277-314)

parameters recommended in current guideline papers. These validated indices were obtained noninvasively in an awake and spontaneously breathing patient in the left lateral decubitus position.^[7] Perioperatively, patients under general anesthesia are under positive pressure ventilation, are usually in the supine position, frequently receive inotropes and vasopressors, can have extensive fluid shifts, are frequently paced, and undergo surgical insult, many of which can affect lusitropy, myocardial compliance, and filling pressures.^[7-9] In addition, TEE, in comparison to TTE, has limitations in optimizing insonation angle, frequently provides better views of the posterior aspects of the heart, and may or may not provide good visualization of the anterior aspects of the heart.^[10]

Other perioperative challenges for assessing diastolic dysfunction include clinical time pressure limiting complex assessments and the utility of diastolic information in the perioperative setting. With regards to usefulness, several studies have investigated diastolic function changes with various pharmacologic interventions. While no specific pharmacologic therapy has been isolated as making a significant difference in outcomes,^[7,11,12] many clinicians use diastolic information to generally guide intraoperative care.^[13] For example, limiting fluids in the setting of elevated

filling pressures or maintaining normal sinus rhythm and limiting tachycardia in the setting of impaired relaxation.

To simplify diastolic assessment in the operating room, Swaminathan, *et al.*, developed a simplified algorithm for intraoperative TEE use that utilized only MV inflow pattern and tissue Doppler. This simplified approach [Figure 4] was demonstrated in coronary artery bypass graft patients to increase the percentage of patients classified as a diastolic grade and worsening diastolic grade was a risk factor for the development of major adverse cardiac events.^[14]

In the aforementioned study and others,^[15-19] the severity of diastolic dysfunction has been shown to have prognostic significance. A recent meta-analysis based on a total population of almost 4000 noncardiac surgery, patients concluded that perioperative diastolic dysfunction is an independent risk factor for cardiac events in noncardiac surgery.^[20] Despite this, the intraoperative clinician is still somewhat in the dark about the intraoperative assessment of diastology and therapeutic options. More research is required to validate diastolic parameters in TEE in the perioperative period and elucidate their significance. In the meantime, understanding the physiologic basis of the

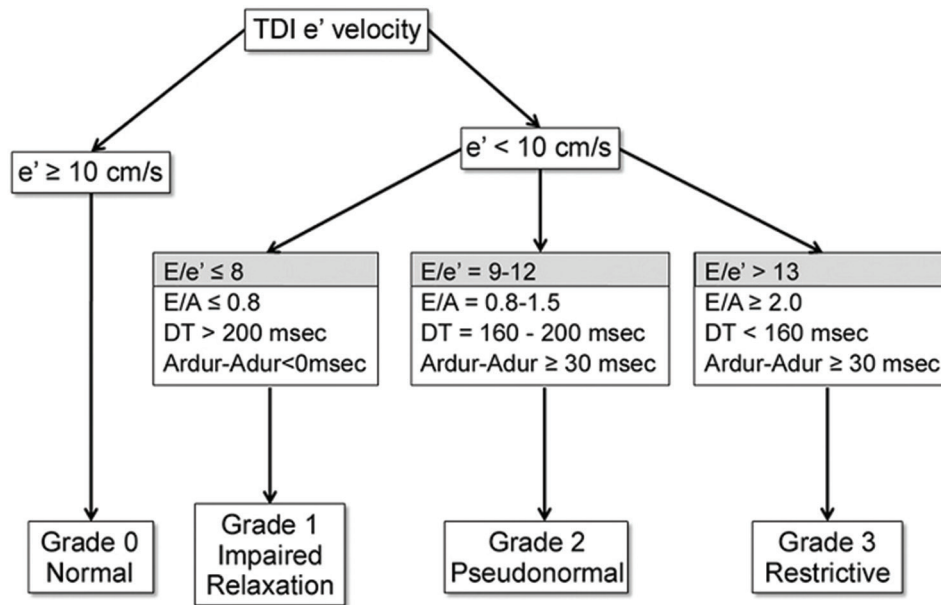


Figure 4: Simplified approach to grading diastolic dysfunction perioperatively using tissue Doppler and transmitral flow pattern. Figure obtained from utility of a simplified algorithm to grade diastolic dysfunction and predict outcome after coronary artery bypass graft surgery (Swaminathan M, Nicoara A, *et al.* Ann Thor Surg. 2011; 91, Pages 1844-51)

indices and using a holistic approach based on clinical findings, hemodynamic setting, and a combination of recommended 2D and Doppler indices is the prudent approach to the perioperative patient.

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Conflicts of interest

There are no conflicts of interest.

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TAKE HOME MESSAGES

In this review the author discusses in detail the pathophysiology of diastolic dysfunction. She describes the detailed echocardiographic parameters for the same with particular reference to the new ASE/EACT guidelines on diastology. The Swaminathan et al algorithm using TDI and trans-mitral flow pattern for perioperative diastolic dysfunction is also discussed, in this well written review.