Intraoperative Transesophageal Echocardiography: A Critical Appraisal of Its Current Role in the Assessment of Diastolic Dysfunction

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WITH AN ESTIMATED PREVALENCE of approximately 2% of the adult population in developed countries, and increasing with age, heart failure is a major healthcare burden, with significant implications for quality of life, mortality, and healthcare costs.[1–4] Heart failure is well established as a risk factor for adverse perioperative outcomes, for which it has been reported to be present in 3% to 10% of selected patients undergoing noncardiac surgery[5–7] and 9% to 46% of patients undergoing cardiac surgery.[8–10] Heart failure with preserved ejection fraction accounts for almost half of all patients with the clinical syndrome of heart failure,[11] often reflecting diastolic dysfunction. Moreover, echocardiographically identified diastolic dysfunction has been reported to be an independent predictor of mortality.[4,12]

The widespread availability and use of transesophageal echocardiography (TEE) in cardiac surgery has made the intraoperative evaluation of diastolic function readily achievable. However, the clinical utility of TEE in this context remains poorly defined. Current Society of Cardiovascular Anesthesiologists/American Society of Echocardiography (SCA/ASE) guidelines for performing a comprehensive TEE examination make little specific comment on the assessment of diastolic function,[13] and expert narrative reviews are conflicting as to whether such an assessment should be a routine component of a comprehensive intraoperative examination.[14,15] The aim of the current review is to critically assess the evidence for the intraoperative assessment of left ventricular diastolic function by TEE, identifying and highlighting important knowledge gaps and suggesting a research agenda to better define the role and limitations of intraoperative echocardiography for this purpose.

WHAT IS DIASTOLIC DYSFUNCTION?

Diastolic dysfunction refers to an abnormality of ventricular relaxation, compliance, or filling that results in the requirement for an elevated left atrial pressure to achieve left ventricular filling. It exists as a continuum, from asymptomatic patients whose impairment is identified only by cardiac catheter or echocardiographically based parameters, to those with overt clinical heart failure (diastolic heart failure) and may exist either in isolation or coincident with systolic dysfunction.[16]

Physiology of Diastole

A thorough review of the pathophysiology of diastolic dysfunction is beyond the scope of this article, being described in detail elsewhere.[17–21] Briefly, performance of the left ventricle (LV) depends on its ability to cycle between 2 states: (1) a compliant chamber in diastole that allows the LV to fill from low left atrial pressure and (2) an appropriately stiff chamber with rapidly rising pressure in systole that ejects the stroke volume at systemic arterial pressure.[19] The diastolic properties of the LV are determined largely by the volume of the LV chamber, thickness and physical properties of the ventricular wall, and the process of myocardial relaxation.[17] This process of relaxation is energy-dependent, with calcium re-uptake into the sarcoplasmic reticulum important to both the rate and extent of myocyte relaxation and lengthening.[22] Abnormal calcium homeostasis, seen particularly in the context of myocardial ischemia and reperfusion, may contribute to acute changes in diastolic function.[23]

How Is Diastolic Function Measured?

The most accurate measurement of diastolic function requires invasive cardiac catheterization, enabling quantification of LV relaxation and stiffness. Parameters of relaxation include the peak instantaneous rate of LV pressure decline (dP/dt_{min}) and tau (τ), the time constant for isovolumetric pressure decline in the LV.[20] Approximating the time required for LV pressure to fall by two-thirds during isovolumetric relaxation, τ may be considered the gold standard for identifying abnormal relaxation, with diastolic dysfunction present when τ is >48 ms.[20,24] Myocardial stiffness may be calculated from the pressure-volume relationship of the LV.[20] The primary physiologic consequence of diastolic dysfunction is an elevated filling pressure. Filling pressures are considered elevated when mean pulmonary capillary wedge pressure (PCWP) is >12 mmHg or when left ventricular end-diastolic pressure is >16 mmHg.[24]

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Despite representing the gold standard for identifying and quantifying diastolic dysfunction, the invasive nature of these measurements limits their role in the routine assessment of diastolic function. In clinical practice, transthoracic echocardiography (TTE) is used to assess both systolic and diastolic function. Consensus recommendations have been published for the echocardiographic evaluation of LV diastolic function and endorsed by both the European Association of Echocardiography (EAE) and the ASE.[19] These recommendations advocate the integrated use of multiple echocardiographic parameters including spectral Doppler analysis of mitral inflow and pulmonary venous flow, propagation velocity of mitral inflow, and tissue Doppler indices of diastolic annular motion for a comprehensive assessment and grading of LV diastolic (dys) function (Table 1). In addition to the estimation of LV filling pressure, TTE also may allow for indirect assessment of isovolumetric relaxation time (IVRT) and LV dP/dt_{min}. Normal values for each of these parameters, as well as specific clinical scenarios that may limit their use, have been well characterized (Table 2).[19,25,26]

The right ventricle (RV) is also subject to diastolic dysfunction, and separate consensus guidelines for the echocardiographic evaluation of the RV have been published.[27] However, studies formally evaluating the clinical impact of RV diastolic dysfunction remain limited. While RV diastolic dysfunction identified by intraoperative TEE has been associated with increased difficulty separating from CPB in one study,[28] the remainder of this review will focus on the more extensively evaluated diastolic dysfunction of the left heart.

VALIDATION OF DIASTOLIC DYSFUNCTION MEASURED BY TTE

Although diastolic dysfunction exists as a continuum, indirectly measurable by a variety of echocardiographic parameters, algorithms for the categorization of diastolic dysfunction into specific grades have been developed to facilitate risk stratification and prognostication.[4,19] Typical grading progresses from impaired relaxation, through pseudonormalization, to a restrictive filling pattern, each reflecting increasingly severe diastolic dysfunction (Table 3).[4,14,15,19,25,29] Guidelines for the echocardiographic assessment of diastolic function are based on data from large numbers of patients across a range of clinical contexts undergoing TTE. A demonstrated association between diastolic dysfunction graded by TTE and important outcomes, such as quality of life, development of heart failure and mortality,[4,30,31] supports the validity of this noninvasive method of assessment.

PERIOPERATIVE IMPACT OF PREOPERATIVELY EVALUATED DIASTOLIC DYSFUNCTION

Despite some inconsistency, existing studies generally support the utility of varying degrees of diastolic dysfunction identified preoperatively with TTE to predict adverse perioperative outcomes including atrial fibrillation, respiratory complications, prolonged hospital stay and a composite of major perioperative morbidity and mortality in patients undergoing both cardiac surgery[32–36] and noncardiac vascular surgery.[37–39]

INTRAOPERATIVE ASSESSMENT OF DIASTOLIC DYSFUNCTION BY TEE

Globally, intraoperative TEE is used routinely by most cardiac anesthesiologists for both valvular and coronary artery bypass graft surgery.[40] Although intraoperative assessment of diastolic function has been advocated as part of a comprehensive evaluation, the same authors acknowledge that existing recommendations for a TTE-based assessment of diastolic function may not be entirely applicable to TEE.[15] Despite the relative ease of attaining the various measurements to evaluate diastolic function with intraoperative TEE, a recent survey suggests that only 46% of academic centers currently perform an assessment of diastolic function routinely during cardiac surgery.[40]

DOES DIASTOLIC FUNCTION CHANGE UNDER ANESTHESIA?

Anesthetic agents are thought to affect calcium homeostasis at the sarcoplasmic reticulum,[41] an important component of normal myocardial relaxation.[22] Invasive animal studies

Table 1. Common Echocardiographic Parameters of Diastolic Function

Imaging Mode	Parameter
Mitral valve inflow–spectral Doppler	Peak early diastolic flow velocity (E)
	Peak late diastolic flow velocity (A)
	Ratio of peak early:late flow velocities (E/A)
	E-wave deceleration time (E_{DT})
	Isovolumetric relaxation time (IVRT)
	A-wave duration (A_{dur})
Pulmonary vein flow–spectral Doppler	Peak systolic flow velocity (S)
	Peak anterograde diastolic velocity (D)
	Ratio of peak systolic:diastolic flow velocities (S/D)
	Peak atrial flow reversal velocity (A_r)
	Atrial flow reversal duration (A_{rDur})
Color M-mode flow propagation velocity	Mitral inflow propagation velocity ($V\rho$)
Tissue Doppler imaging of mitral annulus	Early diastolic annular velocity (e′)
	Late diastolic annular velocity (a′)
	Ratio of early:late diastolic annular velocity (e′/a′)
	Ratio of peak early diastolic flow velocity:early diastolic annular velocity (E/e′)
2D Echo	Left atrial volume