# Invasive Validation of the Echocardiographic Assessment of Left Ventricular Filling Pressures Using the 2016 Diastolic Guidelines: Head-to-Head Comparison with the 2009 Guidelines

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*Background:* Recent American Society of Echocardiography (ASE)/European Association of Cardiovascular Imaging (EACVI) guidelines for echocardiographic evaluation of left ventricular (LV) diastolic function provide a practical, simplified diagnostic algorithm for estimating LV filling pressure. The aim of this study was to test the accuracy of this algorithm against invasively measured pressures and compare it with the accuracy of the previous 2009 guidelines in the same patient cohort.

*Methods:* Ninety patients underwent transthoracic echocardiography immediately before left heart catheterization. Mitral inflow E/A ratio, E/e′, tricuspid regurgitation velocity, and left atrial volume index were used to estimate LV filling pressure as normal or elevated using the ASE/EACVI algorithm. Invasive LV pre-A pressure was used as a reference, with >12 mm Hg defined as elevated.

*Results:* Invasive LV pre-A pressure was elevated in 40 (44%) and normal in 50 (56%) patients. The 2016 algorithm resulted in classification of 9 of 90 patients (10%) as indeterminate but estimated LV filling pressures in agreement with the invasive reference in 61 of 81 patients (75%), with sensitivity of 0.69 and specificity of 0.81. The 2009 algorithm could not definitively classify 4 of 90 patients (4.4%), but estimated LV filling pressures in agreement with the invasive reference in 64 of 86 patients (74%), with sensitivity of 0.79 and specificity of 0.70.

*Conclusions:* The 2016 ASE/EACVI guidelines for estimation of filling pressures are more user friendly and efficient than the 2009 guidelines and provide accurate estimates of LV filling pressure in the majority of patients when compared with invasive measurements. The simplicity of the new algorithm did not compromise its accuracy and is likely to encourage its incorporation into clinical decision making. (J Am Soc Echocardiogr 2017;■:■-■.)

*Keywords:* Left ventricular filling pressure, Left atrial pressure

The burden of heart failure continues to increase as the population ages, with commensurate increases in the financial and social costs of hospitalizations and readmissions. Projections estimate that >8 million people will have heart failure by 2030 and that health care costs could exceed $50 billion.[1,2] Determining left ventricular (LV) filling pressure is clinically important for the management of patients with congestive heart failure, as elevated LV filling pressure results in increased risk for hospitalization and poor outcomes.[2,3]

Although invasive methods are considered the "gold standard" for measuring intracardiac filling pressures, echocardiography is routinely used as a noninvasive alternative. This has been done using an algorithm based on Doppler-derived parameters, described in the joint recommendations of the American Society of Echocardiography (ASE) and the European Association of Cardiovascular Imaging (EACVI) from 2009.[4] These guidelines have been reported as cumbersome to use because of the number and laboriousness of measurements involved, thereby limiting application in clinical practice.[5] In addition, the guidelines proposed the use of different algorithms for patients with normal versus depressed LV function, adding complexity to the diagnostic paradigm.

Accordingly, the ASE and EACVI recently developed a new set of guidelines for the evaluation of LV diastolic function,[5] which includes a practical, simplified algorithm for estimating LV filling pressures that can be used in all patients irrespective of LV ejection fraction (LVEF). As stated in the revised guideline document, this recommended algorithm is based on expert consensus that stems from collective experience. The authors also state that this algorithm needs to be validated in a systematic manner against an invasive reference technique. Two

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**Abbreviations**

**ASE** = American Society of Echocardiography

**EACVI** = European Association of Cardiovascular Imaging

**LA** = Left atrial

**LAVi** = Left atrial volume index

**LV** = Left ventricular

**LVEF** = Left ventricular ejection fraction

**NPV** = Negative predictive value

**PPV** = Positive predictive value

recent multicenter studies compared echocardiographic estimates of LV filling pressures against invasive measurements by cardiac catheterization and reported high feasibility and good accuracy irrespective of LV function, especially when combined with clinical data.[6,7] These studies were performed by investigators who constituted the core of the guidelines writing group and have extensive specific expertise in the evaluation of diastolic function by echocardiography.

Our primary goal was to assess the validity of the echocardiographic estimates of left-sided filling pressure using the latest guidelines by an independent laboratory that did not participate in the development of the ASE/EACVI guidelines. To achieve this goal, we compared echocardiographic determinations of LV filling pressures against gold-standard invasive measurements, including testing the relationship between their accuracy with LV function and also with gender. In addition, we tested the hypothesis that the accuracy of the new 2016 algorithm would not be compromised by its simplicity compared with the previous 2009 guidelines.

## METHODS

### Population and Study Design

We prospectively studied 90 patients (mean age, 61 ± 13; 41 men [46%]) referred for clinically indicated left heart catheterization (including for chest pain, acute coronary syndrome excluding ST-segment elevation myocardial infarction, transcatheter aortic valve replacement, preoperative evaluation, and history of ventricular arrhythmia or cardiac arrest) who also underwent transthoracic two-dimensional echocardiography just before catheterization. Hemodynamically unstable patients as well as those with atrial fibrillation, moderate or greater mitral regurgitation, moderate or greater calcification of the mitral annulus, mitral stenosis, heart transplantation, sinus tachycardia, or prosthetic valves were excluded. The study was approved by the institutional review board.

Echocardiographic measurements were performed by a panel of three board-certified echocardiographers blinded to the invasive data who finalized each measurement by consensus. These measurements were used to obtain estimates of LV filling pressure using the 2016 algorithm, resulting in classification as normal, elevated, or indeterminate. After excluding indeterminate estimates, the echocardiographic determinations of normal or elevated filling pressures were compared with invasive LV preatrial contraction (pre-A) pressure measurements, which were defined as either normal or elevated if >12 mm Hg, using the same cutoff as used by Andersen *et al*[6] In addition, cutoffs of 15 and 18 mm Hg were also evaluated in a subanalysis to take into account interlaboratory variability. Comparisons were first performed for the entire study group to test the accuracy of the algorithm, using $\kappa$ statistics of agreement. Subsequently, these comparisons were repeated for two subgroups of patients with normal (LVEF ≥ 50%) and reduced LV function, as well as male versus female patients, to determine the accuracy of this methodology in these subgroups.

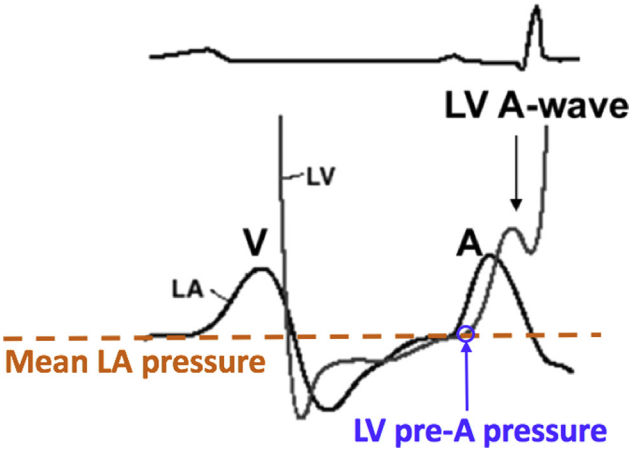


**Figure 1** Hemodynamic tracings of LV (*gray line*) and LA (*black line*) pressures: LV pre-A pressure (*blue arrow*) most closely approximates mean LA pressure (*dashed orange line*), which is estimated by the ASE guidelines.

In addition, to test whether the simplification of the new guidelines algorithm affected the accuracy, the same panel of three board-certified echocardiographers used the 2009 guidelines to estimate filling pressures and compare the results against the same invasive reference. Because the 2009 algorithm includes two separate flowcharts to estimate filling pressures in patients with normal and reduced LVEF, the appropriate chart was used in each patient according to LV function. All available parameters were examined in the context of the algorithm, and the determination was made on the basis of which arm of the algorithm had more parameters meeting criteria. When the numbers were similar in both arms of the algorithm, simultaneously suggesting normal and elevated left atrial (LA) pressure, these cases were classified as "indeterminate." The readers were blinded to both the invasive data and the results of the classification using the 2016 guidelines.

### Echocardiographic Imaging and Analysis

Two-dimensional echocardiographic imaging was performed using commercial equipment (iE33 imaging system with an X5 transducer; Philips Medical Systems, Andover, MA). Imaging included apical two- and four-chamber views, from which LA and LV volumes were measured using the method of disks (Xcelera; Philips Medical Systems). These volumes were used to calculate LA volume index (LAVi) and LVEF. Pulsed-wave Doppler of the mitral inflow at the level of valve leaflet tips was used to measure the peak early (E-wave) and late (A-wave) diastolic flow velocities and calculate the E/A ratio. In addition, pulsed-wave Doppler tissue imaging was performed with the sample volume at the lateral and septal mitral annulus to obtain average peak longitudinal early diastolic annular (e′) velocity, which was used to calculate the E/e′ ratio. Peak velocity of the tricuspid regurgitant jet was determined using continuous-wave Doppler. Subcostal windows were acquired to assess diameter and respiratory variation of the inferior vena cava to estimate right atrial pressure. Pulsed-wave Doppler of the pulmonary vein flow was also acquired in the apical views to allow S- and D-wave measurements.