

## Echocardiographic assessment of left ventricular diastolic function

### *Sol ventrikül diyastolik fonksiyonlarının ekokardiyografik değerlendirilmesi*

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#### ABSTRACT

Assessment of diastolic function and left ventricular filling pressures in the setting of both normal and reduced systolic function is of major importance particularly in patients with dyspnea. Since multiple echocardiography parameters are used to assess diastolic function each with some limitations, a comprehensive approach should be applied. Transmitral Doppler flow should be evaluated in combination with newer, less load dependent Doppler techniques. Tissue Doppler imaging provides accurate, well validated data regarding diastolic properties and filling pressures of the left ventricle. Tissue Doppler imaging should be the part of a routine echocardiography study due to its ease of use and high reproducibility. Pulmonary vein Doppler and flow propagation velocity should be incorporated into the evaluation when needed. (*Anadolu Kardiyol Derg 2007; 7: 310-5*)

**Key words:** Diastolic function, echocardiography, filling pressures, tissue Doppler imaging

#### ÖZET

Dispne şikayeti ile başvuran bir hastada sol ventrikül diyastolik fonksiyonlarının ve dolum basınçlarının değerlendirilmesi, gerek normal gerekse azalmış sol ventrikül sistolik işlevi varlığında çok önemlidir. Diyastolik fonksiyonların belirlenmesinde birçok ekokardiyografi parametresi kullanılmasına rağmen, her birinin belirli kısıtlılıkları vardır. Bu nedenle hastanın klinik özellikleri de göz önünde tutularak, birçok parametre birlikte değerlendirilmelidir. Mitral kapak Doppler akım hızları ile birlikte, daha yeni ve daha az yük bağımlı olan Doppler teknikleri uygulanmalıdır. Doku Doppler görüntüleme, diyastolik işlev ve dolum basınçları hakkında birçok çalışma ile kanıtlanmış ve güvenilir bilgi sağlar. Bu teknik kolay uygulanımı ve yüksek tekrarlanabilirliği nedeniyle ekokardiyografi işleminin parçası haline gelmelidir. Pulmoner ven akımları ve akım propagasyon hızı gibi diğer Doppler teknikleri de gerektiğinde diyastolik işlev değerlendirilmesine eklenmelidir. (*Anadolu Kardiyol Derg 2007; 7: 310-5*)

**Anahtar kelimeler:** Diyastolik fonksiyonlar, doku Doppler görüntüleme, dolum basınçları, ekokardiyografi

#### Introduction

Diastolic dysfunction refers to abnormal mechanical properties of the myocardium including abnormal left ventricular (LV) diastolic distensibility (chamber stiffness), impaired filling, and slow or delayed relaxation regardless of the systolic performance and patient's symptoms (1). Patients with asymptomatic diastolic dysfunction have increased risk for developing congestive symptoms, irrespective of the cause (2). Early identification of these patients may be beneficial to prevent the progression of the disease. The latest guidelines of the American College of Cardiology/American Heart Association for the diagnosis and management of chronic heart failure stated that definite diagnosis of heart failure with preserved ejection fraction (EF) can be made when the rate of ventricular relaxation is slowed and is associated with the finding of an elevated LV filling

pressure in a patient with normal LV volumes and contractility (3). Mean pulmonary capillary wedge pressure (PCWP) and mean left atrial pressure (LAP) reflect left ventricular filling pressures in the absence of mitral inflow obstruction. Elevation of these pressures is a specific marker for impaired diastolic function. Assessment of diastolic function and filling pressures are also important components of evaluation of a patient with systolic LV dysfunction. Echocardiography has emerged as the principal clinical tool for the assessment of diastolic function, being widely available, noninvasive and reliable. However, since multiple parameters determined by echocardiography may be affected by loading conditions, several parameters may need to be interpreted for an accurate diagnosis. Several echocardiographic indices for the assessment of diastolic functions both in patients with and without preserved LV function are summarized in this article, focusing on a practical approach.

## Mitral valve inflow in the assessment of diastolic function

Mitral valve inflow assessed by pulsed wave Doppler remains the cornerstone of diastolic evaluation. Several parameters can be derived from mitral inflow velocities, which are useful for this evaluation. These include early diastolic transmitral velocity (E), late diastolic transmitral velocity (A) recorded at the tips of mitral valve from an apical four-chamber view, early filling deceleration time (DT), isovolumic relaxation time (IVRT) and duration of A wave (4). Since transmitral E wave is generated by the pressure gradient between left atrium and LV, E wave velocity may be influenced by the pressures and compliances of the related chambers (5). Although helpful, mitral inflow velocities vary with loading conditions, increasing age and heart rate (6-9). In young healthy hearts, rapid relaxation and fast LV pressure drop in early diastole causes a suction effect, resulting in an increase in E velocity ( $E/A > 1.5$ ) and a short DT ( $< 220$  msec) (5). With aging, as well as with ischemia or myocardial diseases, relaxation is slowed thereby leading to a decrease in suction effect of the LV, resulting in reduction in E velocity, compensatory increase in A velocity ( $E/A < 1$ ), and prolongation of IVRT and DT (10) (Fig. 1). This pattern is known as impaired relaxation or type I diastolic dysfunction and is usually associated with normal filling pressures. As the LV compliance decreases and stiffness increases, LAP rises to maintain the cardiac output. This results in a high E velocity ( $E/A > 1$ ) and a shortened DT which is referred as pseudonormal pattern or type II diastolic dysfunction (5). Further increase in LV stiffness leads to higher LAP which results in a very high E velocity, low A velocity ( $E/A > 2$ ) and a very short DT ( $< 150$  ms) (Fig. 2). This pattern is called restrictive filling or type III diastolic dysfunction (5). Valsalva maneuver can be used to assess the reversibility of this pattern by increasing intrathoracic pressure and decreasing preload, hence attempting to cause a shift from type III to type II (11). Restrictive pattern which fails to reverse with Valsalva maneuver is called fixed restrictive or type IV diastolic dysfunction (Fig. 3). Valsalva maneuver is also useful in differentiating pseudonormal from normal pattern. Since preload dependence of transmitral velocities has been shown in several studies, response to Valsalva maneuver, pulmonary venous flow profile and mitral annular tissue Doppler velocities should be evaluated in accordance with mitral Doppler indices (12-15).

Transmitral velocities, IVRT and E wave DT are useful in estimating mean LAP in patients with depressed EF, but may be deceptive in normal ventricles. An equation,  $\text{mean PCWP} = 17 + (5 \times E/A) - (0.11 \times \text{IVRT})$ , was proposed by Nagueh et al. to provide accurate estimates of mean PCWP in patients with depressed EF (16).

## Pulmonary vein velocity in the assessment of diastolic function

Pulmonary vein velocity recorded by pulsed wave Doppler provides further information about diastolic function with some limitations. The pulmonary vein flow pattern can be explained as

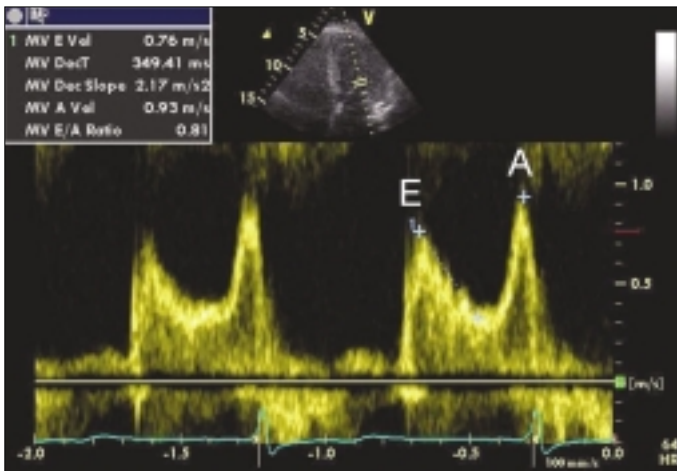
follows. In normal relaxation, the left atrial pressure decline during ventricular systole drives flow into the left atrium (peak systolic pulmonary vein velocity, S wave). When the mitral valve opens, the second antegrade flow occurs during early diastole (peak diastolic pulmonary vein velocity, D wave) which is coincident with the mitral E velocity (17). As the atrium contracts, a small retrograde flow (atrial reversal, AR) is seen into the pulmonary vein. When the left atrial pressure is increased, S wave becomes diminished and D wave becomes predominant (Fig. 4) (18, 19). However, this index is relatively insensitive when the systolic function is preserved as opposed to the setting of reduced EF (20). When the left atrium contracts against a high LV end-diastolic pressure, the retrograde flow (AR) will increase both in velocity and in duration (Fig. 3). A peak velocity of AR  $> 35$  cm/s has been proposed as a marker of elevated filling pressures. A difference greater than 20 milliseconds between AR duration and the mitral A velocity duration suggests an increased LV end-diastolic pressure (21).

The major challenge in interpreting the mitral and pulmonary vein velocities is to distinguish normal relaxation from pseudonormal pattern. A young subject with normal relaxation and a patient with diastolic dysfunction and high LAP will have the same mitral inflow pattern and E/A ratio; first one because of the "suction effect" of the ventricle and the latter one due to the "pushing effect" of the high atrial pressure. Similarly diastolic pulmonary vein velocity may predominate in a hyperdynamic heart due to diastolic suction effect. These velocities are also limited in the absence of sinus rhythm, severe mitral regurgitation and can not be used in the presence of mitral inflow obstruction. Two relatively new echocardiographic techniques discussed below provide valuable information in the assessment of diastolic function, differentiating normal and pseudonormal patterns and providing a more accurate estimation of left ventricular filling pressures.

## Color M-mode propagation velocity in the assessment of diastolic function

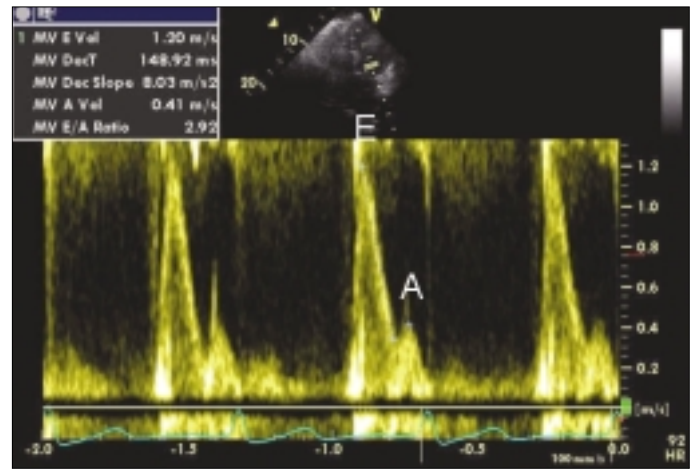
Propagation velocity ( $V_p$ ) is the velocity of blood that travels from mitral annulus to the apex. This velocity can be assessed by Color M-mode by placing the M-mode cursor aligned parallel to LV inflow extending from the apex to the tips of mitral valve (7). The slope drawn for flow from the mitral valve into the LV cavity during early diastole gives the  $V_p$ . It has been shown that  $V_p$  is relatively independent of loading conditions (22). Flow propagation velocity has been reported to correlate with DT and IVRT in hypertensive patients (23). A  $V_p$  value of less than 40 cm/s implies diastolic dysfunction with slow relaxation and can be used to distinguish pseudonormal pattern from normal relaxation (24). A ratio of mitral E velocity to  $V_p$  greater than 2.5 has been shown to be an index of increased PCWP (24).

This method is limited in patients with concentric hypertrophy and small hyperdynamic ventricles due to the small size of the ventricle and also in patients with severely enlarged ventricles due to the eccentric blood flow directed to the lateral wall. Another limitation is the difficulty in identifying clearly the slope of flow propagation and hence obtaining reproducible results (25).



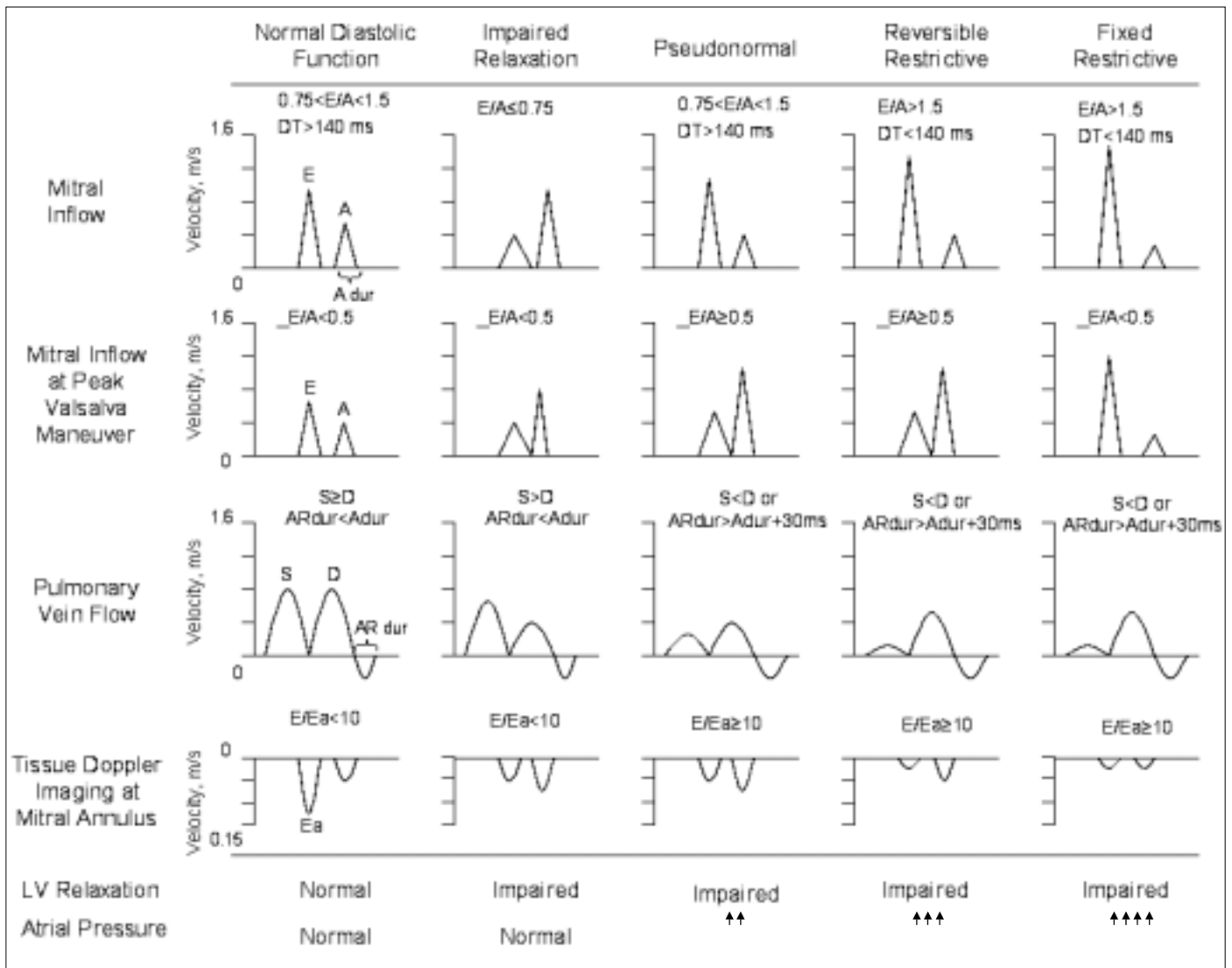
**Figure 1. Impaired relaxation pattern. Note that E/A ratio <1 (0.81) and deceleration time (DecT) is prolonged (349 ms)**

A- late diastolic transmitral velocity, E- early diastolic transmitral velocity



**Figure 2. Restrictive filling pattern with an E/A ratio >2 (2.9) and shortened deceleration time (DecT) (148 ms)**

A- late diastolic transmitral velocity, E- early diastolic transmitral velocity



**Figure 3. Echocardiographic classification of diastolic function**

A- late diastolic transmitral velocity, Adu - duration of A wave, ARdu - duration of atrial reversal velocity, E- early diastolic transmitral velocity, Ea- early diastolic myocardial velocity at mitral annulus, D- peak diastolic pulmonary vein velocity, DT- deceleration time, LV- left ventricular, S- peak systolic pulmonary vein velocity (Adapted from Redfield MM et al. Burden of systolic and diastolic ventricular dysfunction in community. JAMA 2003; 289: 194-202 with permission, 'Copyright © (2003), American Medical Association. All rights reserved'.)

### Tissue Doppler velocities of the mitral annulus

Tissue Doppler (TD) is a recently developed imaging modality that allows measurement of myocardial velocities with Doppler. When the pulsed wave Doppler cursor is placed at the mitral annulus from the apical window, the recorded velocities represent the longitudinal contraction (positive systolic wave, Sa) and relaxation (early negative diastolic wave, Ea, and late negative diastolic wave) (26). The Ea has been shown to be a good index for LV relaxation (27, 28). It correlates strongly with the time constant of isovolumic relaxation (29). Ea is related to age, since there is normal age dependent reduction in diastolic function (30). An Ea value of less than 10 cm/s implies impaired relaxation in individuals > 45 years of age (Fig. 5) (31). In normal individuals mitral E wave and Ea occurs simultaneously, whereas it was shown that in patients with restrictive cardiomyopathy peak velocity of Ea occurs after mitral E wave (32). It was also reported that in patients with delayed relaxation and pseudonormal filling Ea is delayed and the time interval between the onset of Ea and onset of E may be used as an index for diastolic dysfunction (33).

### Estimation of filling pressures

Compared with mitral inflow velocities, Ea is less influenced by the LAP and preload changes (31, 34). The ratio of mitral E to Ea can correct for the influence of relaxation on E velocity and it relates to filling pressures. Several studies have reported good correlations between the E/Ea ratio and PCWP (31, 35, 36). It has been shown that E/Ea yielded accurate estimation of filling pressures in many clinical conditions including sinus tachycardia, atrial fibrillation and hypertrophic cardiomyopathy (37-39). Nagueh et al (31) demonstrated that an E/Ea ratio > 10 detected a mean PCWP > 15 mmHg with a sensitivity of 97% and a specificity of 78%. The equation: mean PCWP = 1.9 + 1.24E/Ea

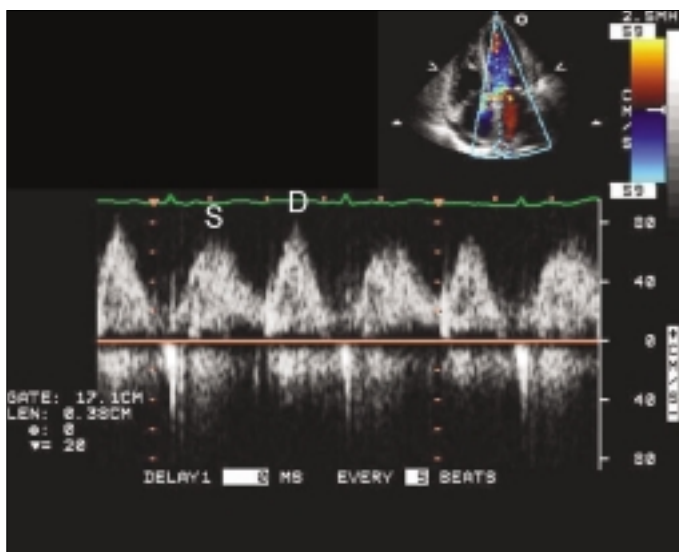


Figure 4. Pulmonary vein velocities with predominant diastolic wave (D) and lower systolic wave (S) indicating increased left atrial pressure

has been shown to provide an estimate of PCWP with an r value of 0.87 in the same study. Overall, if the ratio is less than 8 it is more than 90% predictive that PCWP is in normal range. On the other hand, a ratio of 15 or more is over 90% predictive of a mean PCWP of 15 mmHg or higher. When the E/Ea ratio is between 9 and 14, the prediction of filling pressures is somewhat indeterminate and borderline elevated. In these cases, other echocardiographic parameters such as left atrial size, pulmonary artery systolic pressure, difference between durations of pulmonary vein and mitral A velocities should be considered to help prediction of the filling pressures.

Several limitations should be kept in mind when using Ea as an index for relaxation. In normal hearts, Ea is load dependent, and may be less accurate in determining filling pressures (29). Furthermore, Ea is a regional parameter and errors may occur, in extrapolating a regional measurement to global LV relaxation when there is a regional wall motion abnormality. Although there is still controversy in literature as to which site to use for tissue Doppler measurements, it is recommended to use the average of lateral and septal base in dilated large ventricles with depressed EF and also in regional wall motion abnormalities (21). For the patients with normal EF, measurement of Ea from the lateral base provides a better estimate of mean PCWP than the septal base (21).

### Conclusion

Evaluation of diastolic function and estimation of filling pressures are essential in clinical practice particularly for patients presenting with congestive symptoms. A systematic approach should include 2-dimensional echocardiographic imaging of the heart, interrogation of mitral valve inflow and pulmonary vein velocities and newer modalities like propagation velocity and tissue Doppler imaging (Fig. 6). Tissue Doppler imaging should become a routine application in the assessment of diastolic function. In patients with depressed EF and dilated ventricles, mitral E/A ratio, pulmonary vein velocities and deceleration time are good indicators for filling pressures. Relatively load independent parameters E/Vp and E/Ea should be used in patients with normal EF.

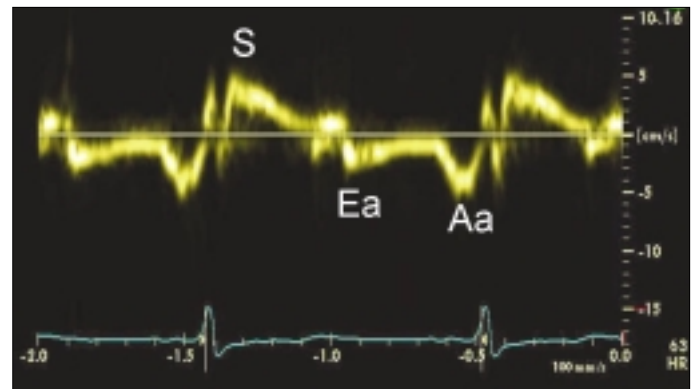
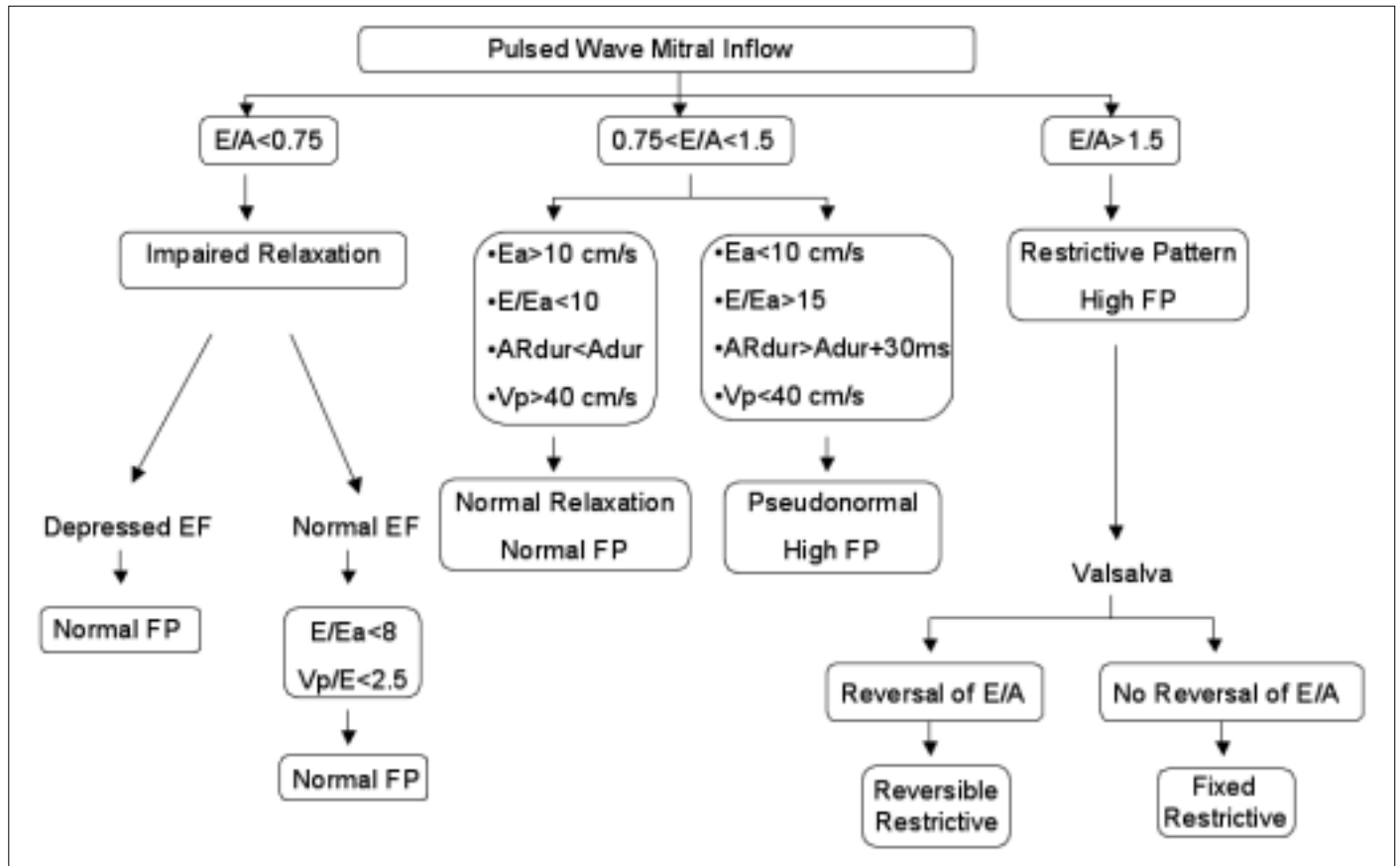


Figure 5. Tissue Doppler imaging of the mitral annulus. Note that Ea velocity is depressed (< 5cm/s) indicating impaired relaxation

Aa- late diastolic mitral annular wave, Ea- early diastolic mitral annular wave



**Figure 6. A practical approach in evaluation of diastolic function**

A- late diastolic transmitral velocity, Adu- duration of A wave, ARdu- duration of atrial reversal velocity, E- early diastolic transmitral velocity, Ea- early diastolic myocardial velocity at mitral annulus, FP- filling pressures, Vp- propagation velocity

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