Review

Echocardiographic Assessment of Postmyocardial Infarction Diastolic Dysfunction

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ABSTRACT Diastolic dysfunction has a major impact on the symptoms, treatment and prognosis of patients with coronary artery disease, and in systolic and diastolic heart failure, independent of the etiology. In coronary artery disease, left ventricular diastolic dysfunction is more frequent and patients with diastolic heart failure and coronary artery disease have a higher mortality than patients with isolated diastolic heart failure. Diastolic dysfunction appears early after myocardial infarction, but there is limited information related to the exact moment or to prognosis. It is believed that left ventricular dilation after the infarction contributes to the appearance of the signs and symptoms of diastolic heart failure, with increased mortality, independent of the systolic function. Echocardiography is the main non-invasive method for the assessment of diastolic function. We aim to make an up-to-date review of the echocardiographic methods and parameters of diastolic dysfunction, and of their importance in post-myocardial infarction patients.

KEY WORDS echocardiography, myocardial infarction, diastolic dysfunction

Introduction

A diagnosis of primary diastolic heart failure requires three obligatory conditions:
(1) the presence of signs or symptoms of congestive heart failure;
(2) the presence of normal or only mildly abnormal left ventricular systolic function;
(3) evidence of abnormal left ventricular relaxation, filling, diastolic distensibility or diastolic stiffness.

Due to these changes, left ventricle diastole is represented by diastazis and atrial contraction; diastolic heart failure can be diagnosed by demonstrating a low diastolic distensibility or an increased diastolic stiffness.

For the diagnosis there are necessary invasive investigations.

Diastolic distensibility is changed by left ventricular filling and relaxation and diastolic heart failure can be diagnosed using left ventricle filling and relaxation using noninvasive assessments.

Diagnostic criteria for diastolic heart failure

Signs or symptoms of congestive heart failure

Exertional dyspnoea (eventually objective evidence by reduced peak exercise oxygen consumption < 25 ml/kg-min), orthopnea, gallop sounds, lung crepitations, pulmonary oedema.

Normal or mildly reduced left ventricular systolic function:

Left ventricular ejection fraction (LVEF) > 45% and left ventricular end-diastolic internal dimension index (LVEDIDI) < 3.2 cm/m² or left ventricular end-diastolic volume index (LVEDVI) < 102 ml/m² and

Evidence of abnormal left ventricular relaxation, filling, diastolic distensibility and diastolic stiffness:

1. Slow isovolumic left ventricular relaxation:
   LVdP/dtmin < 1100 mmHg/s, and/or
   IVRT < 40s > 92 ms, IVRT 30 – 50s > 100 ms, IVRT > 50s > 105 ms, and/or
   τ > 48 ms
   and/or

2. Slow early left ventricular filling:
   PFR < 160 ml/s·m² and/or
   PFR < 40s < 2 EDV/s, PFR 30 – 50s < 1.8 EDV/s, PFR > 50s < 1.6 EDV/s and/or
   E/A < 40s < 1 and DT < 50s > 220 ms, E/A > 50s < 0.5 and DT > 50s > 280 ms and/or
   S/D < 50s > 1.5, S/D > 50s > 2.5
   and/or

3. Reduced left ventricular diastolic distensibility:
LVEDP > 16 mmHg or mean PCW > 12 mmHg and/or
A. pulmonary flow > 35 cm/s and/or
A. pulmonary flow > A mitral flow + 30 ms and/or
A/H 0,2
and/or
4. Increased left ventricular chamber or muscle stiffness:
   b > 0,27 and/or b* > 16.

**Evaluation of the transmitral Doppler flow**

- E wave: represents left ventricle active relaxation, early diastolic filling which generates the gradient between left atrium and left ventricle; it is influenced by interaction between left atrium compliance and left ventricle relaxation and influenced by atrial pressure during mitral valve opening and minimal left ventricle diastolic pressure; normal values:
  - $E < 30\text{y}$: 0.69 +/- 0.12 m/s
  - $E 30-50\text{y}$: 0.6 +/- 0.14 m/s
  - $E >50\text{y}$: 0.59 +/- 0.14 m/s
- Deceleration time (DT): gives information about atrial and ventricular rigidity, pressional difference between left atrium and left ventricle; normal values:
  - DT$<30\text{y}$: 179 +/- 20 ms
  - DT$>50\text{y}$: 210 +/- 36 ms
- A wave: represents left atrium contraction; its velocity depends of left ventricle compliance, left atrium volume and contractility.
- E/A ratio; normal values: E/A $<30\text{y}$ = 2.7 +/- 0.7; E/A $30-50\text{y}$ = 2 +/- 0.6; E/A $>50\text{y}$ = 1.2 +/- 0.4
- AFF: atrial filling fraction represents the percent of participation of the left atrium at left ventricle filling; it depends of age and heart rate; normal values: < 36%.

- IVRT: isovolumic relaxation time represents time interval between aortic valve closure and mitral valve opening; it can be assessed using Doppler signal in apical 5 chamber view between mitral valve and left ventricle outlet tract; it depends on left ventricle relaxation and left ventricle pressure in the moment of aortic valve closure and mitral valve opening; normal values:
  - IVRT$<30\text{y}$: > 92 ms
  - IVRT $30-50\text{y}$: > 100 ms
  - IVRT $>50\text{y}$: > 105 ms

**Evaluation of pulmonay venous flow using Doppler echocardiography**

There are three components:
- S: systolic phase is positive and represents ventricular systole.
- D: early diastolic phase; during the diastole, the mitral valve is opened and the left ventricle can communicate directly with the left atrium and with pulmonary veins; during the protodiastole, the decreasing of pressure in the left ventricle with ventricular relaxation reestablishes the negative pressure gradient responsible for the blood entrance into the left atrium.

During the D phase, the flow has a smaller velocity than during the S phase.

The normal S phase is positive and often has two peaks. S1 represents the atrial relaxation leading to a decrease in pressure and a negative gradient between left atrium and pulmonary veins and consequently the entrance in the atrium; the pressure gradient is accentuated through the characteristic filling pattern of the left ventricle. S2 represents the descending of the mitral valvular ring to the left ventricular apex; the rotation of the mitral ring during the systole creates a suction effect in the left atrium.

If the maximum effect of atrial relaxation and the mitral ring movement takes place simultaneously, the S phase has one single peak.

The ratio of pulmonary vein systolic (S) and diastolic (D) flow velocities (S/D ratio) has normal values of: S/D $<30\text{y}$ = 1 +/- 0.3; S/D $>50\text{y}$ = 1.7 +/- 0.4.

- a: telediastolic phase, atrial contraction; is naturally present if the patient is in sinus rhythm; the atrial contraction produces a reverse of the previous negative pressure gradient between left atrium and pulmonary veins; a velocity > 35 m/s suggests an increased filling pressure.

**Assessment of the diastolic dysfunction:**

**1. Slow isovolumic left ventricular relaxation**

The rate of isovolumic left ventricular pressure decay is intimately coupled to timing, myocardial loading and segmental coordination. Timing refers to the time interval from the Q wave on the ECG to the onset of left ventricular relaxation. Used indices are:

1. **peak negative left ventricular dP/dt** (LVdP/dtmin): a value of LVdP/dtmin < 1100 mmHg/s is considered indicative of slow isovolumic left ventricular relaxation in man (normal value: 1864 +/- 390 ms)

2. **isovolumic relaxation time** (IVRT): a prolonged value (IVRT$<30\text{y}$ > 92 ms, IVRT$30-50\text{y}$ > 100 ms, IVRT$>50\text{y}$ > 105 ms) provides evidence of slow isovolumic relaxation, but a normal value fails to exclude it because IVRT returns to control value when elevation of left atrial pressure leads to earlier mitral valve opening.

Abnormal relaxation was seen in early stages of diastolic dysfunction. If left atrium pressure
remains normal during the rest, patients may present symptoms only during exercise and transmirtal flow return in normal during the rest. However, even these minimal changes must be considered with an increased risk.

(3) the time constant of left ventricular pressure decay (τ): τ is the most widely used index of isovolumic left ventricular relaxation kinetics; normal values vary from 33 +/- 8 ms to 36 +/- 6 ms and have recently been shown to be independent of age. A significant prolongation has been reported in numerous clinical conditions including coronary artery disease in the absence of left ventricular dyssynchrony and hypertensive left ventricular hypertrophy. Provided a high quality Doppler flow velocity signal can be obtained, assessment of τ can also be performed on the Doppler flow velocity signal of mitral and aortic regurgitation during the isovolumic relaxation period.

(4): AFF > 36%.

2. Slow early left ventricular filling:
Doppler echocardiographic indices of early left ventricular filling are:
- peak early E wave Doppler flow velocity;
- deceleration time (DT);
- the ratio of pulmonary vein systolic (S) and diastolic (D) flow velocities (S/D ratio);
- E/A ratio < 1-0,5 and DT > 220 ms, depending on age;
- A peak flow = A pulmonary flow > 20-30 ms indicates an increased pressure in left ventricle and could be a marker of evolution of abnormal relaxation to pseudonormal pattern.

Slow left ventricular pressure decay, as a result of slow myocardial relaxation or of segmental incoordination related to coronary artery disease or conduction disturbances, reduces the E/A ratio, prolongs DT and increases the S/D ratio. From a physical point of view, early left ventricular filling is a function not only of the impedance to filling exerted by the mitral valve, subvalvular apparatus and left ventricular structures but also of the atrioventricular pressure gradient.

Based on these observations, echocardiographic diagnostic evidence of slow early ventricular filling consists of at least one of the following criteria:

(1) E/A<50y < 1 and DT.<50y > 220 ms or E/A<50y < 0.5 and DT.<50y > 280 ms on the mitral Doppler flow velocity signal;

(2) S/D.<50y > 1.5 or S/D.>50y > 2.5 on the pulmonary vein Doppler flow velocity signal.

3. Reduced left ventricular diastolic distensibility

Left ventricular diastolic distensibility refers to the position on a pressure-volume plot of the left ventricular diastolic pressure-volume relation and a reduction in left ventricular diastolic distensibility refers to an upward shift of the left ventricular pressure-volume relation on the pressure-volume plot, irrespective of a simultaneous change in slope. A reduction in left ventricular diastolic distensibility provides diagnostic evidence for diastolic left ventricular dysfunction. Left ventricular end-diastolic distensibility is reduced when left ventricular end-diastolic pressure (> 16 mmHg) or mean pulmonary venous pressure (> 12 mmHg) are elevated in the presence of a normal left ventricular end-diastolic volume index (< 102 ml/m²) or normal left ventricular end-diastolic internal dimension index (< 3.2 cm/m²).

Similar diagnostic information on decreased left ventricular end-diastolic distensibility can also be derived from a shortened Doppler mitral A wave deceleration time, from the Doppler pulmonary vein flow signal when it reveals reverse pulmonary venous A wave flow velocity > 35 cm/s or from the pulmonary venous A wave duration, when it exceeds mitral A wave duration. Pulmonary venous A wave duration exceeding the duration of the mitral A wave by more than 30 ms indeed predicts a left ventricular end-diastolic pressure > 15 mmHg with 85% sensitivity and a 79% specificity. Diagnostic evidence of decreased left ventricular end-diastolic distensibility can also be inferred from the apex-cardiogram at rest when the magnitude of the A wave > 0.2 of the total excursion.

4. Increased left ventricular chamber or myocardial muscle stiffness

Left ventricular stiffness refers to a change in diastolic left ventricular pressure relative to diastolic left ventricular volume (dP/dV) and equals the slope of the diastolic pressure-volume relation. Its inverse is the left ventricular diastolic compliance (dV/dP).

Because the slope of the diastolic left ventricular pressure-volume relation varies along the left ventricular pressure-volume curve, left ventricular stiffness is often compared at a common level of left ventricular filling pressures. A relation was demonstrated between Doppler mitral inflow deceleration time and left ventricular chamber stiffness. A value > 0.27 provides diagnostic evidence for diastolic left ventricular dysfunction.

Muscle stiffness is the slope of the myocardial stress–strain relation and represents the resistance to stretch when the myocardium is subjected to
stress. A value > 16 provides diagnostic evidence for diastolic left ventricular dysfunction.

There are four configurations of diastolic function following acute myocardial infarction:
- abnormal left ventricle relaxation;
- pseudonormalization of the mitral and pulmonary flow;
- restrictive with reversibility;
- restrictive without reversibility.

Evolution of these patterns is due to evolution of physiopathological process or changes in loading conditions.

Assessment of diastolic dysfunction in patients with acute myocardial infarction revealed:
- increase τ value;
- IVRT > 200 ms;
- E/A < 1 and decrease DT due to increase pressure in left atrium.

The prevalence of diastolic dysfunction in patients with a history of myocardial infarction or coronary disease is approximately 25%. The most often is slow left ventricular relaxation, but this pattern may change during acute phase.

Patients with large anterior acute myocardial infarction may present an increased chamber stiffness with increasing E/A > 2 and shortening DT.

Relaxation and stiffness may ameliorate with reperfusion therapy and after 6 months restrictive pattern becomes pseudonormal. Reperfusion is associated with diastolic stunning.

Patients with large anterior acute myocardial infarction without reperfusion may present early acute dilatation due to increased left ventricle pressure. These are consequences of contractile mass loss and increased pressure in left atrium for stroke volume maintenance.

There are studies who showed that left ventricle remodeling is influenced by dimensions of the necrosis zone; this influences transmitral filling pattern which becomes restrictive in large myocardial infarctions. CK-MB peak was increased in patients with short DT.

Diastolic properties and expansion possibility are also influenced by transmural necrosis extension: the second predictor factor of dilatation was wall contractility recovery in infarcted zone.

In the next 24 hours, the chamber stiffness can continue to increase, returning to normal in the next days. This situation can occur as a primary abnormality in infarcted myocardium. Thus, in patients with extensive myocardial infarction the effect of ischemia on the compliance is a restrictive pattern, as in the restrictive conditions such as constrictive pericarditis or restrictive cardiomyopathy. In the early phase, the infarcted tissue is characterized by edema and cellular infiltration, causing the reduced extensibility. The increased ventricular stiffness produces a growth in left atrium pressure, with a rapid increase in ventricular pressure during the rapid filling, contributing to the reduced TDE (restrictive pattern). The biphasic filling pattern suggests an early increase in chamber stiffness, which then returns to normal. Nevertheless, this could be explained more by remodeling and scar formation than by gradual recovery of the diastolic function after reperfusion.

The increase of collagen deposits in subacute phase correlates with dilation, restrictive pattern and systolic dysfunction. After a few weeks, with progression of remodeling, the compliance decreases again. With scar formation, advancement the ventricle becomes more compliant and dilated, with prolonged TDE. The transmitral flow pattern is the consequence of scar formation with increased rigidity and ventricular remodeling with hypertrophy and delayed relaxation. Thus, the serial evolution of post-myocardial infarction filling pattern is parallel to the evolution of the dimensions. Additional factors are TDE which is age-dependent and the interaction of intrinsic diastolic properties and hemodynamic and pericardial restrictive alterations post-myocardial infarction, factors that are difficult to control in clinical studies.

The asynchronism of relaxation in the long axis of the LV is frequent in patients with ischemia, and can be the major cause of reduced E wave velocity and delayed relaxation pattern. This is the most common filling pattern at one year after the myocardial infarction and could be due to remodeling (compensatory hypertrophy, scarring of the infarction area).

Ventricular remodeling is a main determinant of long term survival after myocardial infarction. Important aspects are those related to diastolic function alterations, caused by scar formation that increases stiffness, and the appearance of hypertrophy in non-infarcted areas that will show delayed relaxation.

Left ventricular filling pressure may influence the subsequent dilation due to alterations in wall stress. In chronic coronary artery disease, with prior myocardial infarction, compensatory hypertrophy and remodeling, the appearance of ischemia in non-infarcted myocardium and un-uniform relaxation associate with delayed relaxation pattern of the mitral flow. Patients with myocardial infarction that show diastolic dysfunction during exercise appear to have coronary stenosis in non-infarcted territory. Those
with depressed systolic function (LVEF < 35%) have a reduced exercise capacity if they associate diastolic dysfunction.

Heart failure during hospitalization appears in patients with very early signs of diastolic dysfunction. TDE < 140 ms identifies best the patients with high risk of developing heart failure and mortality. A value of TDE < 136 ms predicts the 6-month mortality with a sensitivity of 75% and a specificity of 97%. Dilation may appear even after uncomplicated myocardial infarction.

An initial restrictive filling pattern which persists at discharge, identifies patients with severe alteration with high risk of remodeling at 6 months and risk of death at 6 years (GISSI 3 echo substudy). Restrictive and pseudonormal patterns correlate with progressive dilation of the ventricle and are predictors of mortality after the first myocardial infarction. In these patients the LVEDVI and LVESVI are significantly higher after 3 months; 12 months mortality is also higher.

**Tissue Doppler imaging (TDI)**

Is a method of assessment of the diastolic function that measures myocardial movement in relation to time (pulsed TDI) or by color-coding (color TDI). The data seem to be independent of loading conditions. A volume sample (2-5 mm) is positioned in the septal of lateral edge of the mitral ring in the 2 or 4 section image. When the sample is positioned at the ventricular wall we can analyze the regional ventricular function. Tissue Doppler imaging is the most used method to record mitral velocity flow and it has three components: Sm (in systole), Em and Am (in diastole). The value of Em is adjusted to age, is influenced by preload and correlates directly to τ and dp/dt and indirectly to left ventricular pressure. Am correlates to dp/dt, is influenced by LVEDP and ventricular relaxation.

If we use a single measurement we prefer lateral Em, because septal Em is influenced by preload and diastolic function of the right ventricle. Segmental hypokynesia will produce the decrease of mitral ring velocity and thus it is necessary to obtain a mean value. At the ventricular wall we measure: myocardial precontraction time (PTCm), myocardial contraction time (Ctm), myocardial relaxation time (RTm). With altered relaxation, Em/Am < 1 and RTm > 90 ms may appear at lateral mitral ring and are associated with global left ventricular diastolic dysfunction or limited to one wall but with normal mitral flow pattern. This marks the early regional diastolic dysfunction.

In heart failure Em is progressively delayed to E and it decreases progressively to dilation, invasive studies showing it correlates to τ, it is much more susceptible to preload and remains low in patients with advanced diastolic dysfunction. The lowest value is recorded in patients with restrictive filling.

Naqueh et al. demonstrated that the E/Em using lateral transmitral flow can indicate a PCWP > 12 mmHg. Using septal Em, Omman et al. found that PCWP is normal if E/Em < 8 and increased if E/Em > 15. A mean value of the two velocities, lateral Em and septal Em, is more precise in the presence of regional dysfunction an LVEF > 50%. In post-myocardial infarction patients with atrial fibrillation Sm, Em are decreased, with increased E/Em. This seems to be useful in the evaluation of the risk of atrial fibrillation after the myocardial infarction. In addition, E/Em > 9 was predictor for left ventricular thrombus formation after myocardial infarction, with a predictive negative value of 84%; Sm, Em and E/Em were decreased.

**Color M mode**

From the four chamber section, with the M mode sampling oriented parallel to the left ventricle inflow, we can measure the speed vp; E/vp correlated to the filling pressure and the pulmonary capillary wedge pressure, in the condition of low LVEF and dilation. In the acute phase of the myocardial infarction E/vp > 1.5 is a powerful predictor of in-hospital heart failure, and is important in the prediction of 30-day mortality. It can be predictor of a PCWP > 18 mmHg with a sensitivity of 95% and a specificity of 98%.

New echocardiographic techniques for assessing diastolic function

Exercise left ventricular filling: an ideal test for the confirmation of the diagnosis of diastolic heart failure is the objectivation of limited exercise capacity, with the confirmation of the increased left atrial pressure by E/Em at rest and after maximum exercise; this method needs supplementary investigations. Exercise limitation is associated with the conversion of altered relaxation at rest to pseudonormalisation after exercise. There are studies that showed that at equal ejection fractions, patients with restrictive mitral flow pattern had lower exercise tolerance than those with delayed relaxation pattern.

**Tissue Doppler characteristics:** more sensitive echocardiographic techniques for the characterization of myocardial structure and function imply strain imaging. The measurement of strain and strain rate of the myocardial segments deformation uses color TDI for

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determining the gradient of adjacent myocardial velocities.

All the above techniques allow the assessment of the global diastolic function. It is not yet known which extent of segmental diastolic dysfunction is needed to alter the parameters of global function. When regional hypokynesia is present, with preserved LVEF (eg. hypokynesia of the inferior wall) we may assume that inferior segments will have altered relaxation and compliance; nevertheless, it is possible that the global function is normal, or abnormal, depending on the extent of the segmental diastolic dysfunction and the function of non-infarcted segments. The extent of regional asynchronism in the myocardial relaxation timing may affect significantly the measurement of global diastolic performance. Supplementary information can be obtained through strain imaging and magnetic resonance imaging.

**Conclusions**

The multiple parameters used for the assessment of the diastolic function have imperfect sensitivity and specificity; discordant results may be obtained in the same patient.

Doppler parameters of diastolic function are influenced by physiological factors: heart rate, loading conditions, contractility.

Diastolic dysfunction seem to be an important prognosis marker, because diastolic properties correlate to the progression of left ventricular dilation, heart failure, and post-myocardial infarction mortality.

**Abbreviations**

- LVEF = left ventricular ejection fraction;
- LVEDDI = left ventricular end-diastolic internal dimension index;
- LVEDVI = left ventricular end-diastolic volume index;
- LVdp/dtmin = peak negative left ventricular dP/dt;
- IVRT = isovolumic relaxation time indexed for age groups;
- τ = time constant of LV pressure decay;
- PFR = peak LV filling rate indexed for age groups;
- EDV = end-diastolic volume;
- E/A = ratio of peak early to peak atrial Doppler flow velocity indexed for age groups;
- S/D = ratio of pulmonary vein systolic and diastolic flow velocities indexed for age groups;
- LVEDP = left ventricular end-diastolic pressure;
- PCW = pulmonary capillary wedge pressure;
- A pulmonary flow = pulmonary venous atrial flow velocity;
- A atrial flow = mitral atrial flow velocity;
- A/H = ratio of atrial wave to total signal excursion on the apex-cardiogram;
- b = constant of LV chamber stiffness;
- b* = constant of muscle stiffness.

**References**

13. Gibson G. Derek, Francis P. Darrel, Clinical assessment of left ventricular disfunction, Heart, 2003; 89: 231-238
15. Leite-Moreira F. Adelino, Current perspectives in diastolic disfunction and diastolic heart failure, Heart, 2006; 92: 712-718


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