Evaluation of Diastolic Dysfunction Using Cardiac MRI

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Learning Objectives

1. To highlight the importance and study the patho-physiology of diastolic dysfunction.
2. To study the parameters in diagnosing diastolic dysfunction including their individual strengths and weaknesses.
3. To investigate the role of CMR in evaluation of these parameters.

Outline

• What is Diastology?
  – Epidemiology and Pathophysiology of Diastolic Dysfunction.
• Which parameters to study on MRI and how?
  – Morphological: Indexed LA volume and Indexed LV mass.
  – Mitral valve flow-velocity: E/A ratio, Deceleration time.
  – Pulmonary vein: Systolic and diastolic flow peaks, S/D ratio & A-wave reversal.
• Which parameter to rely on?
  – Strengths and weaknesses of individual parameter.
• What more can be done?
  – Recent advances: Strain imaging.

Understanding Normal Cardiac Function

The cardiac cycle consists of four phases shown in the diagram.

Notice the pressure-vol. changes during the cycle, in particular during IVRT and ventricular filling.

Understanding Diastolic Function

• Diastole, in turn, is divided into four stages:
  1. Isovolumetric relaxation
  2. Early rapid diastolic filling
  3. Diastasis
  4. Late diastolic atrial filling
• Notice that the Trans-mitral Pressure Gradient (TMPG) is the actual determinant of LV filling.
• TMPG is influenced by:
  – LV relaxation
  – LV compliance (which affects LA pressures)

Understanding the Terminology: What is Diastolic Dysfunction?

The inability to fill the left ventricle, during rest or exercise, to a normal end diastolic volume without an abnormal increase in LV end-diastolic or mean left atrial pressure

Or, a failure to increase LVEDV, & therefore cardiac output during exercise represents diastolic dysfunction.

While diastolic heart failure refers to the clinical syndrome of heart failure in the setting of a normal ejection fraction, DD refers to the abnormality of diastolic function regardless of the clinical status of the patient [1].
Understanding the Problem at Hand: Epidemiology

- Both DD and diastolic heart failure are very common, particularly in the elderly population [2].
  - The prevalence of asymptomatic DD in individuals > 45 years is approximately 25-30% [3].
  - Up to 40% of heart failure patients have DD which is a cause of significant morbidity in this group [4]. The condition often precedes the progression of systolic dysfunction and is a major determinant of the symptoms of patients with systolic heart failure.
- Hence assessment of diastolic LV function and estimation of filling pressures is an important part of the management of patients with heart disease.

Understanding the Pathophysiology of Diastolic dysfunction

- Impaired Relaxation
  - Aging
  - Ischemia
  - Cardiomyopathy
- Reduced Compliance
  - LV Hypertrophy (HTn, Valvular and Cong. Heart Diseases
  - Myocardial fibrosis (Infarction)
  - Restrictive Cardiomyopathy
- Extrinsic Compression
  - Constrictive pericarditis
  - Pericardial Tamponade

Interplay of Reduced LV compliance and Impaired Relaxation on Grading of Diastolic Dysfunction

<table>
<thead>
<tr>
<th>LA Pressure (mm Hg)</th>
<th>Normal</th>
<th>Grade 1 (Impaired Relaxation)</th>
<th>Grade 2 (Pseudo-normal)</th>
<th>Grade 3 (Restrictive)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 15</td>
<td>&lt;15</td>
<td>15-25</td>
<td>&gt; 25</td>
<td></td>
</tr>
<tr>
<td>EA ratio &gt;1</td>
<td>&gt;1</td>
<td>1-1.5</td>
<td>&gt; 2</td>
<td></td>
</tr>
<tr>
<td>DT (ms.) 150-220</td>
<td>&gt; 250</td>
<td>&gt; 150</td>
<td>&lt; 25</td>
<td></td>
</tr>
<tr>
<td>IVRT (ms.) &lt;90</td>
<td>&lt;90</td>
<td>&lt;90</td>
<td>&lt; 70</td>
<td></td>
</tr>
<tr>
<td>PVs/PVd &gt;1</td>
<td>&gt;1</td>
<td>&lt;1</td>
<td>&lt;=1</td>
<td></td>
</tr>
</tbody>
</table>

Legend: DT- Deceleration time; IVRT- Isovolumetric relaxation time; PVs- 2nd systolic pulmonary vein peak; PVd- Pulmonary vein diastolic peak

Parameters in evaluation of Diastolic Dysfunction

- Morphological
  - Indexed Left Atrial Volume
  - Indexed Left Ventricular mass
- Mitral flow and velocity
  - EA ratio (Ratio of peaks of E and A waves)
  - DT: Deceleration time.
  - E wave upslope:
- Pulmonary vein flow
  - SD ratio (Ratio of peaks of the S and D waves)
  - A wave amplitude and duration.

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Morphological parameters: How to calculate LA Vol. on CMR?

Biplane Area-Length method used for MR evaluation of Left atrial volume on Cine-false FISP 4-CH and 2-CH views.

\[ \text{LA Volume} = \frac{0.85 \times A1 \times A2}{L} \]

- \( L \): LA length
- \( A1 \): LA area in 2-CH view
- \( A2 \): LA area in 4-CH view

Morphological parameters: How to calculate LV mass on CMR?

Calculation of LV mass on Cine short-axis views in end diastole.

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Mitral Valve evaluation: How to obtain Mitral Flow and Velocity Curves on CMR?

Mitral valve evaluation: How to calculate EA ratio, DT and E-wave upslope from the flow / velocity curves?

Parameters in evaluation of Diastolic Dysfunction

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Pulmonary vein evaluation: How to obtain pulmonary vein flow curve on CMR?

Phase contrast cine MR image through the pulmonary vein

Pulmonary vein evaluation: How to calculate pulmonary vein SD ratio, A wave amplitude & duration on CMR?

Left Atrial Volume

- LA volume is regarded as a barometer of chronicity of diastolic dysfunction.
- In echo literature, Left atrial volume is graded relative to risk,
  - Mild =28 to 33ml/m²;
  - Moderate = 34 to 39 ml/m²;
  - Severe = 40ml/m²

Understanding individual parameters: Strengths & weaknesses

Left Atrial Volume

- Strength
  - Provides morphologic and physiologic evidence for chronic elevation in filling pressure
  - Severity scale based on clinical outcomes

- Weakness
  - May be enlarged in other medical conditions including chronic anemia, athletic heart, chronic valvular disease without increase in LV filling pressure.

Mitral valvular flow (E/A ratio and E-wave upslope)

- **E wave (E):** represents early mitral inflow velocity and is influenced by the relative pressures between the LA and LV.
- **A wave (A):** represents the atrial contractile component of mitral filling and is influenced by LV compliance and LA contractility.
- **E-wave upslope:** Reflects the rapid growth of early diastolic atrio-ventricular pressure gradient.
### Mitral valvular flow (DT)

**Deceleration time (DT):** Interval from E wave peak to a point of intersection of the deceleration of flow with the baseline.

It correlates with time of pressure equalization between the LA and LV. As the early LA and LV filling pressures either evolve toward or away from equivalence, so will the DT either shorten or lengthen respectively.

### Mitral valvular flow:

<table>
<thead>
<tr>
<th>E/A ratio, E-wave upslope and DT</th>
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<tbody>
<tr>
<td><strong>Strength</strong></td>
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<tr>
<td>Can be obtained in all patients</td>
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<tr>
<td>Provides diagnostic and prognostic information</td>
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### Pulmonary Vein Flow

- **Pulmonary venous pattern:**
  - The S-wave, occurring during LV systole, depends on atrial relaxation and mitral annulus motion.
  - The D-wave occurring during LV diastole reflects LV filling, and
  - The A-wave, which is opposite to the other waves and occurs during atrial contraction, reflects changes in LV compliance.

### Pulmonary Vein Flow

| - Complements mitral flow parameters especially when fusion of E and A wave (differentiating normal vs. pseudo-normal pattern). |
| The relationship of PV-A reversal (PVAR) duration to mitral A duration is the only marker specific for elevation in LVEDP |

### Myocardial Strain Imaging

- Used to measure torsion and its rate of recoil.
- Noninvasive markers or ‘Tags’ are imprinted on the myocardium by selective RF saturation of planes perpendicular to the imaging plane.
- These change the magnetization of the protons in the tagged plane compared with the neighboring non-tagged regions, resulting in a difference in signal intensity.
- When placed at end diastole and then imaged throughout the cardiac cycle, tags reveal the deformation and displacement of the myocardium on which they were placed.
- Tags may be positioned in:
  - A radial pattern, which is ideal for the measurement of torsion, or,
  - A grid pattern, which is commonly used for calculation of a full strain field.

### Myocardial Strain Imaging

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<th>Diastole</th>
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<tr>
<td>Systole</td>
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Phase contrast MR Flow patterns (Top two rows) and Doppler Echo images (Bottom two rows) through the mitral valves and pulmonary veins in patients with Grade 1 (left), Grade 2 (Middle) and Grade 3 Diastolic Dysfunction.

CMR versus Echocardiography

- Very low inter and intra observer variability of MRI parameters in diastolic dysfunction.
- Body habitus is not a limiting factor in assessment.
- Comprehensive LV assessment available for etiology during the same study.

References