Advanced imaging of the left atrium - strain, CT, 3D, MRI -

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Declaration of interest: I have nothing to declare
Case presentation

F, 54 yr
LVMi = 105 g/m²
Grad = 113 mmHg

M, 66 yr
LVMi = 113 g/m²
Grad = 117 mmHg
GLS = -13.2%

GLS = -11.2%
LAVi = 73 ml/m²

LAε = 10%

LAVi = 72 ml/m²

LAε = 7.8%
ASr = -0.49 s⁻¹

NYHA II
Sinus rhythm after 1 year follow-up

ASr = -0.83 s⁻¹

NYHA III
Atrial fibrillation after 1 year follow-up

ASr = -0.49 s⁻¹
Symptoms of heart failure were related to the severity of LA dysfunction.

Rosca et al. JASE 2010;23:1090
The utility of left atrium imaging

Left atrium (LA), in a close interdependence with left ventricle (LV), plays a key role in maintaining an optimal cardiac performance.

The atrium contributes up to 30% of total LV stroke volume in normal individuals (with an increased contribution when LV is dysfunctional).

The loss of the atrial contribution to LV filling and stroke volume with atrial fibrillation often leads to symptomatic deterioration.

A thorough assessment of the LA (size, function and structure) may have important clinical, prognostic and therapeutic implications.
Multimodality LA imaging

LA assessment
- Size
- Function
- Structure/anatomy

Multimodality imaging
- Echocardiography
- TDI, STE, 3DE
- MRI/CT
LA size

- increases with conditions of pressure/ volume overload
- reflects the average effect of LV filling pressures over time
  (marker of both chronicity and severity of LV diastolic dysfunction)
- provides strong prognostic information
  (in general population and different pathological conditions)


To estimate LA size, **volume** is preferred over linear dimension
because the former enables accurate assessment of the
asymmetric remodeling of the LA.

*Evangelista A, et al. EJE 2008;9:438*
LA size assessment by echocardiography

Because the majority of prior research and clinical studies have used the **biplane area–length formula**, this is the recommended method.

**Limitations:**
- assumptions that may be inaccurate
- underestimation of LA volume as compared with CT/MRI

*Lang RM. JASE 2005;18:1440*
LA size assessment by echocardiography

The feasibility of 3DE for the assessment of LA volumes has been demonstrated and the technique has been validated against MRI


3DE allows an accurate assessment of LA volume, with a low test–retest variation, and lower intra- and interobserver variability as compared to 2DE

LA size assessment by echocardiography

The obtained 3DE LA volumes are higher than 2DE LA volumes

2DE biplane LA maximum volume = 45 ml

3DE LA maximum volume = 52 ml

Limitations:
- dependent on 2D image quality
- lack of cut-offs
LA size assessment by MRI/CT

More accurate (MRI = gold standard)

Limitations of MRI:
Low availability, high cost, gadolinium contrast

Limitations of CT:
Radiation risk, iodinated contrast

This techniques are not recommended in daily clinical practice.
Frank-Starling mechanism is also operative in the LA (LA output increases as atrial diameter increases, which contributes to maintaining a normal stroke volume)


LA active emptying might decrease in the presence of severe LA dilation as the optimal Frank-Starling relationship is exceeded

Pathophysiological bases

Reservoir function
Modulated by:
- LV contraction
- RV systolic pressure
- LA relaxation
- LA chamber stiffness

Conduit function
Modulated by:
- LV relaxation
- LA afterload

Contractile function
Modulated by:
- LV compliance
- LA afterload (LV filling pressures)
- LA preload
- intrinsic LA contractility
LA function assessment

Invasive assessment
LA pressure-volume relationship
– gold standard

Echocardiographic assessment
Conventional parameters
New techniques (TDI/STE/3D ecocardiography)

Conventional LA echocardiographic parameters

LA expansion index = \( \frac{\text{Vol}_{\text{max}} - \text{Vol}_{\text{min}}}{\text{Vol}_{\text{min}}} \times 100 \) - reservoir

LA passive emptying fraction = \( \frac{\text{Vol}_{\text{max}} - \text{Vol}_p}{\text{Vol}_{\text{max}}} \times 100 \) - conduit

LA active emptying fraction = \( \frac{\text{Vol}_p - \text{Vol}_{\text{min}}}{\text{Vol}_p} \times 100 \) - contractile

Limitations: influenced by loading conditions
3D echocardiography

Due to the availability of the 3D dataset at different phases of the cardiac cycle, the assessment of LA phasic functions by 3DE is improved.

Limitations: influenced by loading conditions

Myocardial velocities

TDI allows the quantification of longitudinal myocardial velocities, providing a relatively load independent measure of both LV systolic and diastolic function.

Peak A’ wave velocity
– marker of atrial function

Limitations
- angle dependent, influenced by translation and tethering

Contractile function
A’ was recorded in 96 patients with LV systolic dysfunction who were followed up for 29±10 months.

A’ < 5 cm/s was the most powerful predictor of cardiac death or hospitalization for worsening heart failure compared with clinical, hemodynamic, and the other echocardiographic variables.

Yamamoto et al. JASE 2003;16:333
Segmental LA function – color TDI

Parameters
- velocities of different atrial segments
- atrial electomechanical delay

Limitations
- inability to distinguish atrial contraction from mitral annular and ventricular motion
**Atrial strain and strain rate imaging - TDI**

**A good site specificity**
- The longitudinal shortening and lengthening of the atrium are discordant with ventricular longitudinal motion

**Limitations**
- angle dependent
- time-consuming (wall-by-wall sampling limits the use in clinical practice)
Atrial strain and strain rate imaging - STE

Angle-independent tool for a thorough assessment of LA performance

Limitations
- dependent on image quality
- STE has not been validated for LA function assessment
Atrial strain and strain rate imaging

The feasibility of TDI and STE for the assessment of LA longitudinal deformation has been documented, and normal values for atrial deformation in different segments have been reported

Sirbu et al. EJE 2006;7:199
Vianna-Pinton et al. JASE 2009;22:299

The values obtained by TDI are higher than those obtained by STE

The variability reported for STE derived parameters is lower than for TDI parameters
LA strain parameters

Atrial function assessed by myocardial velocity, strain and strain rate is reduced in patients with atrial fibrillation (AF)

# LA strain parameters

<table>
<thead>
<tr>
<th></th>
<th>MSR Patients (n=25)</th>
<th>AFR Patients (n=40)</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, y</td>
<td>60±11</td>
<td>57±11</td>
<td>0.6</td>
</tr>
<tr>
<td>Male sex, %</td>
<td>72</td>
<td>77</td>
<td>0.8</td>
</tr>
<tr>
<td>BSA, m²</td>
<td>1.8±0.2</td>
<td>1.9±0.2</td>
<td>0.7</td>
</tr>
<tr>
<td>AF duration, wk</td>
<td>8.2±2.9</td>
<td>8.6±2.6</td>
<td>0.5</td>
</tr>
<tr>
<td>Previous history of AF, %</td>
<td>65</td>
<td>64</td>
<td>0.3</td>
</tr>
<tr>
<td>Systolic blood pressure, mm Hg</td>
<td>136±12</td>
<td>134±9</td>
<td>0.4</td>
</tr>
<tr>
<td>Diastolic blood pressure, mm Hg</td>
<td>81±8</td>
<td>79±7</td>
<td>0.3</td>
</tr>
<tr>
<td>Heart rate, bpm</td>
<td>93±24</td>
<td>85±19</td>
<td>0.1</td>
</tr>
<tr>
<td>IVS end-diastole, cm</td>
<td>1.1±0.1</td>
<td>1.1±0.1</td>
<td>&gt;0.9</td>
</tr>
<tr>
<td>LV end-diastole, cm</td>
<td>5.0±0.4</td>
<td>5.0±0.5</td>
<td>&gt;0.9</td>
</tr>
<tr>
<td>PW end-diastole, cm</td>
<td>1.1±0.1</td>
<td>1.1±0.1</td>
<td>&gt;0.9</td>
</tr>
<tr>
<td>LV ejection fraction, %</td>
<td>54±3</td>
<td>54±5</td>
<td>&gt;0.9</td>
</tr>
<tr>
<td>LV mass index, g/m</td>
<td>135±22</td>
<td>131±16</td>
<td>0.4</td>
</tr>
<tr>
<td>LA, cm</td>
<td>4.5±0.3</td>
<td>4.4±0.5</td>
<td>0.4</td>
</tr>
<tr>
<td>LA maximal volume, mL</td>
<td>66.5±16</td>
<td>62.7±18</td>
<td>0.4</td>
</tr>
<tr>
<td>LA compliance index, %</td>
<td>32±7</td>
<td>29±10</td>
<td>0.2</td>
</tr>
<tr>
<td>Pulmonary artery wedge pressure, mm Hg</td>
<td>7±6</td>
<td>8±7</td>
<td>0.6</td>
</tr>
<tr>
<td>LA appendage peak velocity flow, cm/s</td>
<td>39±12</td>
<td>32±15</td>
<td>&lt;0.01</td>
</tr>
</tbody>
</table>

## Peak Systolic Value

<table>
<thead>
<tr>
<th></th>
<th>MSR Patients (n=25)</th>
<th>AFR Patients (n=40)</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atrial septum</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Velocity, cm/s</td>
<td>3.9±1.9</td>
<td>3.4±1.4</td>
<td>0.2</td>
</tr>
<tr>
<td>S, %</td>
<td>37±18</td>
<td>19±14</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>SR, s⁻¹</td>
<td>2.7±0.7</td>
<td>1.4±0.8</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>LA lateral wall</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Velocity, cm/s</td>
<td>3.2±1.9</td>
<td>2.7±1.4</td>
<td>0.2</td>
</tr>
<tr>
<td>S, %</td>
<td>39±26</td>
<td>18±13</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>SR, s⁻¹</td>
<td>3±1.7</td>
<td>1.3±0.9</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>RA free wall</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Velocity, cm/s</td>
<td>5±2.3</td>
<td>4.3±2</td>
<td>0.2</td>
</tr>
<tr>
<td>S, %</td>
<td>58±44</td>
<td>33±23</td>
<td>0.003</td>
</tr>
<tr>
<td>SR, s⁻¹</td>
<td>3.8±1.6</td>
<td>2.3±1.6</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>LA inferior wall</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Velocity, cm/s</td>
<td>3.7±1.8</td>
<td>2.9±1.9</td>
<td>0.2</td>
</tr>
<tr>
<td>S, %</td>
<td>33±27</td>
<td>17±9</td>
<td>0.0007</td>
</tr>
<tr>
<td>SR, s⁻¹</td>
<td>2.7±1</td>
<td>1.6±0.6</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>LA anterior wall</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Velocity, cm/s</td>
<td>3.9±2</td>
<td>3±1.6</td>
<td>0.1</td>
</tr>
<tr>
<td>S, %</td>
<td>24±13</td>
<td>13±10</td>
<td>0.0002</td>
</tr>
<tr>
<td>SR, s⁻¹</td>
<td>2.1±0.6</td>
<td>1.4±0.8</td>
<td>0.0003</td>
</tr>
</tbody>
</table>

LA wall fibrosis by delayed-enhancement MRI is inversely related to LA strain and strain rate, and these are related to the AF burden.

Noninvasive imaging of LA fibrosis may be helpful in:
- predicting the risk of AF
- guiding therapeutic strategies
- predicting the outcomes in patients with AF

LA structure assessment by MRI

The MRI with late gadolinium enhancement allows tissue characterization and fibrosis or scar imaging.

This study presents an imaging methodology for obtaining DE-MRI scans with sufficient spatial resolution and signal to noise ratio for visualization and analysis of LA tissue.

LA structure assessment by MRI

Pre-ablation DE-MRI could identify responders to AF ablation and may provide a measure of overall disease progression

LA structure assessment by MRI

DE-MRI can be used for imaging LA wall injury (scar) after pulmonary vein isolation in patients with AF

McGann CJ, et al. JACC 2008;52:1263
LA assessment by CT

Cardiac CT acquires a 3D dataset that accurately depicts LA and pulmonary venous anatomy

As a result, cardiac CT has become the investigation of choice before and after atrial fibrillation ablation

Volume-rendered image of the LA viewing posteriorly with the 3D dataset acquired by CT

To ACY, et al. J Am Coll Cardiol Img 2011;4:788
LA assessment by CT
LA assessment by CT

Image integration of the CT 3D images of the LA and pulmonary veins with the realtime electroanatomical mapping data during the ablation

<table>
<thead>
<tr>
<th>3D CT model</th>
<th>Fluoroscopy image</th>
<th>Registered image</th>
</tr>
</thead>
<tbody>
<tr>
<td>RSPV</td>
<td>Transeptal sheath</td>
<td>RSPV</td>
</tr>
<tr>
<td>MV</td>
<td>RA</td>
<td>MV</td>
</tr>
<tr>
<td></td>
<td>His</td>
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<tr>
<td></td>
<td>RV</td>
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<tr>
<td></td>
<td>CS</td>
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</tbody>
</table>

Successful registration of the 3D left atrial image from the CT with projection image from fluoroscopy

LA assessment by CT

Multiplanar reconstruction images of a patient, 3 months after atrial fibrillation ablation, showing left inferior pulmonary vein stenosis that was subsequently stented

To ACY, et al. J Am Coll Cardiol Img 2011;4:788
Conclusions

Recent advancing in cardiac imaging allow an accurate assessment of LA remodeling

**Echocardiography** remains the investigation of clinical choice for measuring LA volumes

It is likely that in the near future **3D echo** will emerge as the best method to calculate LA volumes

The new echocardiographic techniques (**TDI, STE**) provide valuable information on atrial mechanics

**MRI** has an unique ability to characterize the LA structure (fibrosis, scars)

**CT** remains the gold standard for accurately depicting LA and pulmonary venous anatomy