Flow Pattern Analysis Inside the Heart

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How to Describe Intracardiac Flow?

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Assessment of Cardiac Flow

conventional echo

Doppler
... only for valve assessment

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Assessment of Cardiac Flow

conventional echo

Doppler
... only for valve assessment
... cannot display complex 2D/3D blood motion patterns

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Particle Imaging Velocimetry

by echo: following speckles in the blood

frame 24
frame 25
frame 26
to estimate velocity, direction and pattern of blood flow

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Particle Imaging Velocimetry

contrast echo
flow vectors

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Particle Imaging Velocimetry

data analysis

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PIV - Phantom Validation

sample volume
velocity
angle

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Phantom Measurements

estimated vs. true velocity

true velocity profile
tracking

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Phantom Measurements

angle estimate vs. true velocity

reasonable estimates despite high velocities

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Assessment of Cardiac Function

Normal LV Flow Patterns

courtesy: G. Pedrezzetti

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Vortical Flow in the Heart

simulation
flow re-direction

courtesy: G. Pedrezzetti
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Energy Storage by Vortices

effective re-direction of blood flow

mid-ventricular main vortex

Intracavitary Flow Patterns

time sequence

Assessment of Cardiac Function

Flow Patterns in the RV

determined by ventricular size

normal
dilated

normal
dilated
Determinants of Vortex Characteristics

ventricular size vs. vortex area

\[ y = 8.0482\ln(x) - 15.146 \]

\[ R^2 = 0.9242 \]

Abnormal Flow Patterns

Wall - Flow - Interaction

Conduction Abnormalities

normal  LBBB

Conduction Abnormalities

AAI stimulation  DDD stimulation

Conduction Abnormalities

AAI stimulation  DDD stimulation

Doppler strain
**Relative Vortex Size**

<table>
<thead>
<tr>
<th>AAI stimulation</th>
<th>DDD stimulation</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1.png" alt="Graph" /></td>
<td><img src="image2.png" alt="Graph" /></td>
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</tbody>
</table>

**Time of Vortex Occurrence**

<table>
<thead>
<tr>
<th>Cardiac Cycle</th>
<th>AAI</th>
<th>DDD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Early filling</td>
<td><img src="image3.png" alt="Graph" /></td>
<td><img src="image4.png" alt="Graph" /></td>
</tr>
<tr>
<td>Dias</td>
<td><img src="image5.png" alt="Graph" /></td>
<td><img src="image6.png" alt="Graph" /></td>
</tr>
<tr>
<td>Late fill.</td>
<td><img src="image7.png" alt="Graph" /></td>
<td><img src="image8.png" alt="Graph" /></td>
</tr>
<tr>
<td>IVC</td>
<td><img src="image9.png" alt="Graph" /></td>
<td><img src="image10.png" alt="Graph" /></td>
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</tbody>
</table>

**Energy Storage by Vortices**

\[
R_S = \frac{\int_{\Omega} \omega_1(x, y) dx dy}{\int_{\Omega} \omega_0(x, y) dx dy}
\]

**Conduction Abnormalities**

<table>
<thead>
<tr>
<th>Diastolic Energy Dissipation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal</td>
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<tr>
<td><img src="image11.png" alt="Graph" /></td>
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</tbody>
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**Assessment of Cardiac Function**

**Abnormal Flow Patterns**

- Infarcts

**Abnormal Flow Patterns**

- Study: normals vs. apical infarcts

- Normal
- Infarct
Abnormal Flow Patterns
study: normals vs. apical infarcts
normal

infarct

Assessment of Cardiac Function
Abnormal Flow Patterns
Mitral Valve Replacement

Mitral Valve Replacement
umerical simulations
normal
prosthesis

ca. 30% increased energy dissipation during 1 heart beat
prosthesis
normal
Modern speckle tracking technology allows to follow the motion of contrast enhanced blood in the heart. Flow patterns can be displayed and quantified using parameters such as vorticity.

This echocardiographic particle imaging velocimetry (PIV) offers new insights into intraventricular hemodynamics and, thus, the energetics of cardiac function.

The clinical importance of this technique remains to be determined.