Hemodynamics by Echocardiography

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What is the rationale?

The answer is: Imaging the hemodynamics!
Agenda

1- Historical background.
2- Stroke volumes and cardiac output.
3- Role of Doppler in hemodynamics.
4- Estimation of RV pressure and PAP.
5- IVC size and RA pressure.
6- LV pressures.
7- Vortex flow analysis.
- Christian Johann Doppler (1842) -

Christian Doppler was an Austrian mathematician who lived between 1803-1853. He is known for the principle he first proposed in *Concerning the coloured light of double stars* in 1842. He hypothesised that the pitch of a sound would change if the source of the sound was moving. He didn't test this hypothesis until 1845.

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**Doppler Echocardiography History**

- **1959 Satomura**
  detected arterial flow

- **1961 Franklin**
  measurement of flow velocity

- **1973 Johnson**
  located place of cardiac murmur

- **1978 Hatle**
  measured PG between LA and LV

- **1982 Namekawa**
  real-time color Doppler using autocorrelator technique
1-Historical background.
2-Stroke volumes and cardiac output.
3-Role of Doppler in hemodynamics
4- Estimation of RV pressure And PAP.
5-IVC size and RA pressure.
6-LV pressures.
7-Vortex flow analysis.
Stroke Volume, Cardiac Output, Cardiac Index

- $SV_{cc} = TVI_{cm} \times CSA_{cm^2}$
- $CO_{liters/min} = SV_{cc} \times HR_{beats/min}$
- $CI_{liters/min/m^2} = CO_{liters/min} \times BSA_{m^2}$

Hemodynamic data that can be obtained with Doppler echocardiography

- **Volumetric measurements**
  - Stroke volume and cardiac output
  - Regurgitant volume and fraction
  - Pulmonary-systemic flow ratio (Qp/Qs)
- **Pressure gradients**
  - Maximal instantaneous gradient
  - Mean gradient
- **Valve area**
  - Stenotic valve area
  - Regurgitant orifice area
- **Intracardiac pressure**
  - Pulmonary artery pressure, LA pressure, LVEDP
Quantification of pressure gradients

Simplified Bernoulli equation:
Pressure gradient (in mmHg) = \(4(V_{\text{max}})^2\)

1-Historical background.
2-Stroke volumes and cardiac output.
3-Role of Doppler in hemodynamics.
4- Estimation of RV pressure And PAP.
5-IVC size and RA pressure.
6-LV pressures.
7-Vortex flow analysis.
Evaluation of RV Systolic Pressure

RV systolic pressure = TR gradient + RA pressure

Assessing Hemodynamics
RA pressure (using IVC size)

Clinical: CVP

<table>
<thead>
<tr>
<th>RAP (mm Hg)</th>
<th>Diameter (cm)</th>
<th>Inspiratory Collapse</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volume Depletion</td>
<td>&lt;1.2</td>
<td>Total</td>
</tr>
<tr>
<td>0-5 Normal RAP</td>
<td>1.2 - 1.7</td>
<td>≥ 50%</td>
</tr>
<tr>
<td>6-10</td>
<td>&gt; 1.7</td>
<td>&lt; 50%</td>
</tr>
<tr>
<td>11-15</td>
<td>&gt; 1.7</td>
<td>None</td>
</tr>
<tr>
<td>&gt; 15</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Normal IVC Size 1.6 cm
>50% Respiratory Variation

RV Pressures
RV systolic = RA pressure (6) + TR gradient (40) = 46 mm Hg

In the absence of TS, RV diastolic pressure = RA pressure
PA Pressure

Systolic = RV systolic (46)

Diastolic = PR gradient (20) + RA pressure (6) = 26 mmHg

Evaluation of RV Diastolic Pressure

In the absence of TS:
RV diastolic pressure = RA pressure

In the presence of TS:
RV diastolic pressure = RA pressure - TS gradient
Evaluation of PA Systolic Pressure

PA systolic pressure = TR gradient + RA pressure

In the presence of PS:
PA systolic pressure = RV systolic pressure - PS gradient

Evaluation of PA end-diastolic pressure

PA end-diastolic pressure = PR gradient + RA(V) end-diastolic pressure
1-Historical background.
2-Stroke volumes and cardiac output.
3-Role of Doppler in hemodynamics.
4- Estimation of RV pressure And PAP.
5-IVC size and RA pressure.
6-L.V pressures.
7-Vortex flow analysis.

Answer: Pulmonary hypertension
Note the end-diastolic gradient of 2.5 m/sec, indicating a gradient of 25 mmHg between the PA and RV
Evaluation of LV Systolic Pressure

In pts without valve disease:
LV systolic pressure = **systolic BP**

In pts with AS or LVOT obstr.:
LV systolic pressure = **systolic BP + Peak-to-Peak gradient**

Aortic Valve Gradients

1. Peak-to-Peak Gradient (PP)
2. Maximum Instantaneous Gradient (MIG)
3. Mean Gradient

The PP gradient is 70% of the MIG

In pts with AS or LVOT obstr.:
LV systolic pressure =
systolic BP + Peak-to-Peak gradient

In pts with AR:
LV end-diastolic pressure =
diastolic BP - AR gradient
CW Doppler of Aortic Valve Flow
BP is 150/80 mmHg

The LV pressure is:
1. 84/16 mmHg
2. 214/44
3. 214/16
4. 195/16

ANSWER: 4. 195/16 mmHg

LV (sys) = Sys. BP (150) + 70% Ao gradient (45) = 195 mmHg

LV (dias) = Dias. BP (80) - Ao dias. gradient (64) = 16 mmHg
Left Atrial pressures

Calculation of LA pressure

\[ \text{LAP} = \frac{E}{e'} + 4 \]

\[ \text{LAP} = \frac{55}{6} + 4 = 13 \text{ mmHg} \]

- \( e' = 6 \text{ cm/sec} \)
- \( E/e' = 9.2 \)

- \( E = 55 \text{ cm/sec} \)

- \( E/e' = 8: \text{LA pressure nl} \)
- \( E/e' = 15: \text{LA pressure high} \)
Calculation of LA pressure

\[ LAP = E/e' + 4 \]

- \( e' = 6 \text{ cm/sec} \)
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\[ LAP = \frac{55}{6} + 4 = 13 \text{ mmHg} \]

- \( E/e' = 8: \text{ LA pressure nl} \)
- \( E/e' = 15: \text{ LA pressure high} \)

Estimating LA Pressure by \( E/e' \) may be inaccurate in:

- Mitral stenosis
- Mitral annular calcification
- Prosthetic MV
- Mitral regurgitation
- Diffuse severe LV dysfunction
Assessment of LA pressure in pts with MS

LA diastolic pressure = LVDP + transmitral gradient

MV gradient 16mmHg

MV gradient 4mmHg

LA pressure = LV diastolic (10) + MV mean gradient (13) = 23 mmHg
dP/dt

How to measure dP/dt?

1. Optimize CW MR jet with clear initial slope (high-filter setting
2. Decrease velocity range to max envelope from baseline to 4 m/s
3. Increase sweep speed to 100 mm/s
4. Draw horizontal lines at 1 m/s and 3 m/s
5. Draw vertical line from intercept at MR to these points
6. Measure “time” (ms)

Measurement of LV dP/dt from MR jet

\[
\frac{\Delta P \text{ mmHg} \times 1.000}{\Delta t \text{ (msec)}} = \frac{4 (V^2 - V_0^2) \times 1.000}{\Delta t \text{ (msec)}} = \frac{4 (3^2-1^2) \times 1.000}{\Delta t \text{ (msec)}} = \frac{32.000}{\Delta t \text{ (msec)}}
\]

Normal LV dP/dt = > 1000 mmHg/sec
Normal t < 32 msec
Time to reach MR velocity from 1 to 3 m/sec is 25 msec.

\[ \frac{dP}{dt} = \frac{32.000}{25 \text{ msec}} = 1200 \text{ mmHg/sec} \]

Evaluation of LV Diastolic Pressure

In the absence of MS:
LVDP = approx. LA pressure

In pts with AR:
LV end-diastolic pressure = diastolic BP - AR gradient
New Advanced technology
For assessment of hemodynamics

New Advanced Technology in Echo

- Evaluation of LV Mechanics
  - 2D Strain and Strain rate
  - Twist and torsion
- Real time 3D Echo
  - Single beat 3D Echo
- LV vortex flow analysis with contrast Echocardiography
3D Echocardiography

Real time 3-Dimensional Echocardiographic Volume Measurements

End Diastolic Volume

2D

y = 0.76x + 17.1
R² = 0.79

RT3D

y = 0.89x + 4.3
R² = 0.93

Jacobs L et al., European Heart Journal 27: 460-468, 2006
End Systolic Volume

2D

$y = 0.79x + 4.3$

$R^2 = 0.85$

RT3D

$y = 0.88x + 4.7$

$R^2 = 0.94$

Jacobs L et al., European Heart Journal 27: 460-468, 2006

LV Vortex Flow Analysis by Contrast Echo

Severance Cardiovascular Hospital
Yonsei University College of Medicine
LV Vortex flow analysis

Principle of LV Vortex analysis

• 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.
LV Vortex Flow Analysis

LV vortex flow in normal

Steady streaming
Pulsatility intensity

Change of vortex size during cardiac cycle

Hong et al. J Am Coll Cardiol Img 2008;1: 705-717

LV Vortex Flow Analysis

LV vortex flow in heart failure

Steady streaming
Pulsatility intensity

Change of vortex size during cardiac cycle

Hong et al. J Am Coll Cardiol Img 2008;1: 705-717
LV vortex flow in LV diastolic function

Normal M/45 EF=65%
LAVI / E/E': 20 / 5.5

Mild DD M/54 EF=62%
LAVI / E/E': 25 / 8.4

Severe DD M/57 EF=72%
LAVI / E/E': 32 / 16

Hong et al. ACC 2008 (abstract)

Vorticity Imaging
Phasic Changes- Normal vs SHF vs DHF
LV Vortex Flow Analysis in HF

Correlation to symptomatic status in NYHA I-II compensated HF
M/53, DOE (-), EF=29%, E/E’=11, LAVI=28
M/32 DOE (+), EF=27%, E/E’=13, LAVI=30

LV Vortex Flow Analysis in HF

Comparison of conventional and vorticity parameters to symptomatic status in NYHA I-II compensated HF

<table>
<thead>
<tr>
<th>Parameter</th>
<th>DOE (-) (n=7)</th>
<th>DOE (+) (n=6)</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>EF (%)</td>
<td>35.8 ± 5.7</td>
<td>32.5 ± 6.4</td>
<td>NS</td>
</tr>
<tr>
<td>LAVI (ml/m²)</td>
<td>28.4 ± 4.7</td>
<td>30.5 ± 5.7</td>
<td>NS</td>
</tr>
<tr>
<td>E/E’</td>
<td>10.8 ± 3.7</td>
<td>12.3 ± 4.5</td>
<td>NS</td>
</tr>
<tr>
<td>LVEDP</td>
<td>10.5 ± 3.2</td>
<td>13.8 ± 5.2</td>
<td>0.07</td>
</tr>
<tr>
<td>CI (l/min/m²)</td>
<td>2.9 ± 0.8</td>
<td>1.9 ± 0.7</td>
<td>0.02</td>
</tr>
<tr>
<td>RS</td>
<td>1.65 ± 0.3</td>
<td>1.18 ± 0.2</td>
<td>0.01</td>
</tr>
<tr>
<td>VRS</td>
<td>0.81 ± 0.2</td>
<td>0.59 ± 0.2</td>
<td>0.01</td>
</tr>
<tr>
<td>VPC</td>
<td>0.84 ± 0.2</td>
<td>0.67 ± 0.1</td>
<td>0.01</td>
</tr>
</tbody>
</table>

Hong et al. 2007 AHA (abstract) & In Submission
LV Vortex Flow Analysis

LV vortex flow in ischemic cardiomyopathy

Clinical Usefulness of LV Vortex Flow Analysis for Predicting Apical Thrombus Formation in Patients with LV Dysfunction

Jang-Won Son, Geu-Ru Hong, Sang-Hee Lee, Jong-Seon Park, Dong-Gu Shin, Young-Jo Kim, Bong-Sup Shim

Division of Cardiology, Yeungnam University, Daegu, Korea

Presented at 2011 AHA, and In Revision
Apical thrombus with LV dysfunction

Thrombus (+)
M/73, LVEF 27%
LVEDD 67mm, LVMI 162g/m²

Thrombus (-)
F/70, LVEF 20%
LVEDD 63mm, LVMI 160g/m²

LA Vortex Flow Analysis

Normal

Af
New Environment: Equipment

Advantage of Echo

- Inexpensive
- Safe
- Portable
- Repeat
- Hemodynamic information
  - Do not require offline analysis
Take Home message

- Normal and abnormal hemodynamics can be evaluated non invasively by Doppler echocardiography.

- Invasive evaluation may be needed in certain cases

- Echocardiography provides important data for therapeutic decision making in the field of cardiology.

- The new techniques for the ventricular mechanics, vortex flow analysis and 3D Echo hold great promise for improving the quality of patient care and accurate assessment.
Thank you