TAVR Hemodynamics Post Implantation: Is Echo Enough?

Amr E Abbas, MD, FACC, FSCAI, FASE, FSVM, RPVI
Director, Cardiovascular Research
Beaumont Health, Royal Oak, MI
Professor of Medicine
OUWB School of Medicine
Disclosures

Edwards Life Sciences:
Speaker Bureau
Research Grants
Case 1

• 83 year old female with H/O bio-prosthetic aortic valve
• Presented with NYHA Class III
• TEE suggestive of severe AR
• Underwent successful TF-TAVR ViV with 23 mm Evolut R
• Simultaneous CATH ECHO MG obtained
• Discharged with no complications
Simultaneous Post TAVR ECHO/CATH

ECHO MG 6 mmHg

CATH MG 0 mmHg
Case 2

• 79 year old man with H/O bio-prosthetic aortic valve
• Presented with acute congestive heart failure requiring intubation
• TEE suggestive of severe AS with MG 40 mmHg, AVA 0.71 and severe AI
• Underwent successful **TF-TAVR ViV with 20mm SAPIEN 3 valve**
• Simultaneous CATH ECHO MG obtained
Simultaneous Post TAVR ECHO/CATH

ECHO MG 40 mmHg

CATH MG 11 mmHg

5/23/2019
Topics of Discussion

• Why was there a CATH ECHO discordance?
• Is the Bernoulli equation valid post implant in normal valves?
  • Clinical Data
  • Bench Data
  • Physics: Bernoulli assumptions and Pressure Recovery
  • Sequel and Clinical implications
Post TAVR: CATH Vs. ECHO

- Post TAVR ECHO and CATH MG were obtained simultaneously
- **314 TAVR**
  - 278 Native & 36 ViV
- **278 Native**
  - 217 BE
    - 77 small: < 26 mm & 140 large: > 26 mm
  - 61 SE
    - 21 small: ≤ 26 mm & 40 large: > 26 mm
- **36 ViV**
  - 29 BE & 7 SE
Simultaneous Immediate Post TAVR ECHO/CATH Gradients

MEAN 0.96 +/- 3.3
MEDIAN 0
RANGE 0 - 37

MEAN 6.2 +/- 4.7
MEDIAN 5
RANGE 1 - 40

CATH MG
ECHO MG

p < 0.0000001, Z = - 19.48

Native Vs. ViV: CATH Vs. ECHO MG

Native Large Vs. Small BE/SE CATH vs. ECHO MG

ECHO MG

CATH MG

0 mmHg

ECHO MG

CATH MG

0 mmHg

Small BE-TAVR CATH MG
Mean 0.83 +/- 2.57
Median 0, Range 0-14 mmHg

Large BE-TAVR CATH MG
Mean 0.26 +/- 0.9
Median 0, Range 0-6 mmHg

Small BE-TAVR ECHO MG
Mean 7.03 +/- 4.36
Median 6, Range 2-30 mmHg

Large BE-TAVR ECHO MG
Mean 4.78 +/- 2.46
Median 4, Range 1-12 mmHg

Small SE-TAVR CATH MG
Mean 0.71 +/- 1.74
Median 0, Range 0-6 mmHg

Large SE-TAVR CATH MG
Mean 0.77 +/- 3.82
Median 0, Range 2-24 mmHg

Small SE-TAVR ECHO MG
Mean 6.56 +/- 4.49
Median 5, Range 2-20 mmHg

Large SE-TAVR ECHO MG
Mean 4.68 +/- 2.2
Median 4, Range 2-11 mmHg
Native Large vs. Small BE/SE CATH vs. ECHO MG

- SMALL SE-TAVR POST ECHO/CATH DISCORDANCE: 29, > 10 mmHg: 14, > 5 mmHg: 29
- LARGE SE-TAVR POST ECHO/CATH DISCORDANCE: 40, > 10 mmHg: 5, > 5 mmHg: 35
- SMALL BE-TAVR POST ECHO/CATH DISCORDANCE: 48, > 10 mmHg: 17, > 5 mmHg: 31
- LARGE BE-TAVR POST ECHO/CATH DISCORDANCE: 34, > 10 mmHg: 6, > 5 mmHg: 28
ViV ECHO MG > Day 1 compared to Post TAVR ECHO

P < 0.0001

11 mmHg

18 mmHg

P NS

P NS
Bernoulli Equation

\[ P_1 - P_2 = \frac{1}{2} \rho (V_2^2 - V_1^2) \]

Convective acceleration

\[ \rho \int_{\text{max}} (\frac{\text{dv}}{\text{dt}}) \times ds \]

Decreased AVA

Flow acceleration

\[ \text{Systole} \]

Viscous/Friction Losses

\[ P_1 - P_2 = 4(V_2^2) - 4(V_1^2) \]

P1 & V1 = proximal to obstruction
P2 & V2 = distal to obstruction
\( \rho \) = mass density of blood
\( R \) = viscous resistance
\( \mu \) = viscosity

SCAI
Society for Cardiovascular Angiography & Interventions
Bernoulli Components

- Convective Acceleration: River flow when narrows
  - **With steady non-pulsatile flow**, a decrease in area leads to an increase in velocity of blood flow
  - **Steady Flow** = $\text{Area} \times \text{velocity}$
Bernoulli Components

- Flow Acceleration: Intermittent water pump
  - Change in flow velocity with systole: at a constant area, an increase in flow leads to increased velocity

- Pulsatile Flow = \textbf{Constant} Area $\times$ velocity

![Diagram showing Bernoulli components with notations for flow, area, pressure, and velocity changes.](image-url)
Bernoulli Components

- Viscous Forces $R (\mu)$: Movement of molasses
  - Viscous $R$: Energy losses due to friction between **fluid layers** and adjacent wall
  - Viscosity: $(\mu)$ lower viscosity leads to higher gradients (anemia)
Bernoulli Components

- Energy dissipation: Rubbing your hands together
  - Heat generation
  - Viscous $R$:
    - Energy losses due to friction between fluid layers and adjacent wall
  - Valve inertia: energy absorbed to open the valve
Pressure Recovery

ECHO MG: 60 mmHg $\Delta P_{max}$

Doppler/ Catheter Discordance: 20 mmHg

Combined Flow

Central Flow

Eddy Currents

Combined Flow

CATH MG: 40 mmHg $\Delta P_{net}$

Lost 40 mmHg: energy loss

Heat & Friction 40 mmHg

Eddy Currents

Central Flow

Combined Flow
Why ECHO CATH DISCORDANCE?

• We did not adjust for LVOT MG
• We did not adjust for pressure recovery
  • ECHO MG x 2 x AVA/AsAoA x (1-AVA/AsAoA).
• Or
• Should we even use the Simplified Bernoulli Equation? It was designed for stenotic valves. Misleading when used to determine post TAVR Echo MGs in normal functioning valves
• Is there a difference between valves?
ECHO vs. CATH: LVOT and PR Native TAVR

CATH/ECHO Discordance
Before & After Adjusting for LVOT Gradient and “Pressure Recovery”

Simplified Bernoulli Assumptions

- Laminar/steady flow:
  - Negligible Flow Acceleration

- Short tube:
  - Negligible viscous loss

- No Pressure Recovery

- Neglect \(4V_1^2\) (In AS: \(V_2 \gg V_1\))
Bernoulli: Laminar vs. Turbulent Flow

An in vitro evaluation of turbulence after transcatheter aortic valve implantation

Hoda Hatoum, MS, a Atieh Yousefi, BS, a Scott Lilly, MD, PhD, b Pablo Maureira, MD, PhD, c Juan Crestanello, MD, b and Lakshmi P. Dasi, PhD a,b

CATH VS. ECHO MG

- CATH MG
- Bernoulli Equation
- Pressure Recovery

- CATH MG
- Convective Acceleration
  \[ 4V_2^2 \]
- LVOT Pressure
  \[ 4V_1^2 \]
- Viscous
- Flow Acceleration

ECHO MG
- Simplified Bernoulli
- ECHO CATH DISCORDANCE
  \[ 4V_2^2 - \text{CATH} \]
Aortic Stenosis

CATH MG
45 mmHg

Bernoulli Equation
45 mmHg

Pressure Recovery
4 mmHg

CATH MG
45 - 4 = 41 mmHg

Convective Acceleration
$4V_2^2$
47 mmHg

LVOT Pressure
$4V_1^2$
4 mmHg

Viscous
1 mmHg

Flow Acceleration
1 mmHg

ECHO MG
47 mmHg
Simplified Bernoulli

ECHO CATH DISCORDANCE
Simplified
47 – 41 = 6 mmHg

47 - 4 – 41 = 2 mmHg
Post TAVR Laminar Pressure Recovery

CATH MG 14 mmHg

- Bernoulli Equation 14 mmHg
- Pressure Recovery 10 mmHg

CATH MG 14 - 10 = 4 mmHg

- Convective Acceleration
  \[4V_2^2\]
  14 mmHg

- LVOT Pressure
  \[4V_1^2\]
  4 mmHg

- Viscous
  3 mmHg

- Flow Acceleration
  1 mmHg

ECHO MG 14 mmHg

Simplified Bernoulli

ECHO CATH DISCORDANCE

Simplified

14 - 4 = 10 mmHg

LVOT Pressure 4 mmHg
POST TAVR Turbulent Less Pressure Recovery

CATH MG

- 14 mmHg
  - Bernoulli Equation
    - 14 mmHg
  - Pressure Recovery
    - 8 mmHg
  - CATH MG
    - 14 – 8 = 6 mmHg

ECHO MG

11 mmHg
  - Simplified Bernoulli

Convective Acceleration
  - $4V_2^2$
  - 11 mmHg

LVOT Pressure
  - $4V_1^2$
  - 3 mmHg

Viscous
  - 1 mmHg

Flow Acceleration
  - 5 mmHg

= ECHO CATH DISCORDANCE

- Modified
  - 11 - 3 - 6 = 2 mmHg
ECHO CATH DISCORDANCE

• A result of
  • Bernoulli Assumptions
  • Pressure Recovery

• Lead to
  • Prosthesis patient mismatch
  • TAVR valve choice
  • Valve fractures
How Gradient and Area Interact

- **AV VELOCITY**
  - Continuity Equation: Aortic valve area
    - \( \text{AREA}_{LVOT} \times \text{Velocity}_{LVOT}/\text{Velocity}_{AV} \)
  - Bernoulli Equation: Gradient
    - 4 (AV Velocity)²
Prosthesis Patient Mismatch

<table>
<thead>
<tr>
<th></th>
<th>All (N = 62,125)</th>
<th>Severe PPM (n = 7,514)</th>
<th>Moderate PPM (n = 15,271)</th>
<th>None (n = 39,340)</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>BSA, m²</td>
<td>1.87 (1.69–2.04)</td>
<td>1.98 (1.80–2.17)</td>
<td>1.93 (1.76–2.10)</td>
<td>1.83 (1.66–1.99)</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Mean aortic gradient, mm Hg</td>
<td>42 (34–50)</td>
<td>42 (33–51)</td>
<td>42 (34–50)</td>
<td>42 (34–50)</td>
<td>NS</td>
</tr>
</tbody>
</table>

Procedural factors

- **VIV procedure**
  - 5.6
  - 14.7
  - 6.1
  - 3.6
  - <0.0001

- **Prosthesis ≤23-mm diameter**
  - 27.9
  - 40.0
  - 32.1
  - 24.0
  - <0.0001

- **Post-AVA, cm²**
  - 1.76 (1.40–2.14)
  - 1.10 (1.00–1.23)
  - 1.45 (1.30–1.60)
  - 2.00 (1.78–2.40)
  - <0.0001

- **Post mean gradient, mm Hg**
  - 9 (7–13)
  - 13 (9–18)
  - 11 (8–14)
  - 8 (6–11)
  - <0.0001

- **Post-AR, moderate/severe**
  - 2.8

Central Illustration: Incidence and Effect on Survival of Severe Prosthesis-Patient Mismatch After Transcatheter Aortic Valve Replacement

5 mmHg difference between severe and no PPM
"CHOICE OF VALVE"

**Table 4: Thirty-Day Hemodynamic Outcomes of Patients With Large or Small Aortic Valve Annulus Stratified According to Transcatheter Heart Valve Implanted (Results From the CHOICE-Extend Registry)**

<table>
<thead>
<tr>
<th></th>
<th>Large Annulus (n = 312)</th>
<th>Small Annulus (n = 122)</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Evolut R</strong></td>
<td>(n = 50)</td>
<td>(n = 262)</td>
<td></td>
</tr>
<tr>
<td>Effective orifice area index, cm²/m²</td>
<td>1.08 ± 0.33</td>
<td>0.86 ± 0.22</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Prosthesis-patient mismatch</td>
<td>10 (21.7)</td>
<td>98 (43.2)</td>
<td>0.008</td>
</tr>
<tr>
<td>Transvalvular peak PG, mm Hg</td>
<td>12.7 ± 5.1</td>
<td>19.8 ± 6.0</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Transvalvular mean PG, mm Hg</td>
<td>6.8 ± 2.8</td>
<td>10.9 ± 3.9</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Aortic regurgitation (echocardiography)</td>
<td>0.346</td>
<td>0.836</td>
<td></td>
</tr>
<tr>
<td>None</td>
<td>28 (58.3)</td>
<td>158 (67.5)</td>
<td></td>
</tr>
<tr>
<td>Mild</td>
<td>20 (41.7)</td>
<td>74 (31.6)</td>
<td></td>
</tr>
<tr>
<td>Moderate</td>
<td>0</td>
<td>2 (0.9)</td>
<td></td>
</tr>
<tr>
<td>MRI assessment</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MRI regurgitation fraction, %</td>
<td>5.0 ± 3.8</td>
<td>5.0 ± 6.1</td>
<td>0.996</td>
</tr>
<tr>
<td><strong>SAPIEN 3</strong></td>
<td>(n = 262)</td>
<td>(n = 70)</td>
<td></td>
</tr>
<tr>
<td>Effective orifice area index, cm²/m²</td>
<td>1.04 ± 0.28</td>
<td>0.80 ± 0.19</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Prosthesis-patient mismatch</td>
<td>10 (33.3)</td>
<td>42 (59.2)</td>
<td>0.029</td>
</tr>
<tr>
<td>Transvalvular peak PG, mm Hg</td>
<td>11.6 ± 4.8</td>
<td>23.5 ± 7.2</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Transvalvular mean PG, mm Hg</td>
<td>6.6 ± 3.1</td>
<td>13.3 ± 4.3</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Aortic regurgitation (echocardiography)</td>
<td>0.346</td>
<td>0.836</td>
<td></td>
</tr>
<tr>
<td>None</td>
<td>18 (52.9)</td>
<td>41 (56.2)</td>
<td></td>
</tr>
<tr>
<td>Mild</td>
<td>16 (47.1)</td>
<td>32 (43.8)</td>
<td></td>
</tr>
<tr>
<td>Moderate</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

**Bioprosthetic Valve Performance After Transcatheter Aortic Valve Replacement With Self-Expanding Versus Balloon-Expandable Valves in Large Versus Small Aortic Valve Annuli**

Insights From the CHOICE Trial and the CHOICE-Extend Registry

Mohamed Abdelghani, MD,‡ MS; Nader Mankarious, MS; Abdallah Alali, MD; Martin Loschi, MD; Jhaldejir Kaur, MD; Timothy A. Sullivan, MD; Constantin Mita, MD; Susanne Gachen, MD; Ishshela Mehdi, MD; Franco Iudice Santarelli, MD; Christian Freude, MD; Thomas Kuri, MD; Mohamed El-Mowafy, MD; Gert Richard, MD; Mohamed Abdel Wahab, MD
Conclusions

- Post TAVR ECHO-CATH discordant MGs caused by
  - Bernoulli simplification and assumptions
  - Pressure recovery
- What does a high ECHO MG mean? CATH in All?
- How frequent is prosthesis patients mismatch (PPM)? CONFLICTING OUTCOME?
- Compare TAVR valves by ECHO MG ONLY?
- Should we fracture valves just by ECHO MG ONLY?
- Does this happen with surgical valves as well?
THANK YOU