Paravalvular Regurgitation after TAVR

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Definitions

TAVR
• Transcatheter aortic valve replacement

Paravalvular Regurgitation (PVR)
• Regurgitation OUTSIDE the circumference of the stent valve

Meeting Goals

• TTE v TEE
• Mechanism of Paravalvular Regurgitation
• Severity Algorithm – New guideline paper
• Diagnose definitely MILD or SEVERE
  • Color Doppler Quantification
  • Spectral Doppler Quantification

Introduction

Transcatheter aortic valve replacement (TAVR) has increased.
• TAVR is an accepted alternative to SAVR
  • High & intermediate-risk as well as inoperable patients
  • April 2019: Severe AS in low-surgical risk patients

Balloon Expandable Vs. Self Expanding Valves

How does this affect you?

• Post TAVR – assess for regurgitation via echo
• Residual regurgitation predictor of mortality
  • Moderate or severe regurg. ↑ mortality

• Sonographer:
  • Assess and quantify regurgitation after TAVR
  • Provide a guide to the cardiac team
TAVR Follow Up

Uncomplicated
Clinical Deterioration

TAVR Follow Up – Uncomplicated TAVR
Pts w/ uncomplicated TAVR implantation:
• Complete TTE soon after implantation to establish baseline valvular function
• 1-3 months
• 1 year
Clinical Deterioration: As needed (underlying cause?)

The baseline post TAVR TTE is integral to accurate follow-up

Balloon Expandable – Edwards SAPIEN
Balloon assisted expansion

Self Expandable - Medtronic Corevalves/Evolut
Spontaneously expand on release

Paravalvular Regurgitation Post TAVR
Causes
**Cause: Poor Positioning (Malapposition)**

**Definition:** The separation of at least one stent strut from the surface of the wall with evidence of blood behind the strut.

**Malapposition: Causes**

1. Under-expanded
2. Placed too low
3. Placed too high

**Mechanism: Incomplete**

**Causes**

**Examples**

**Incomplete Positioning**

**Causes:**

1. Under expansion of the prosthesis
2. Heavy calcification

**Examples:**

- Flow is outside the circumference of the prosthetic stent frame (paravalvular)
- PVR originates from space between Stent & Annulus

**Example: Incomplete Positioning**

- TEE PSAX
- Device is not co-axial to the root
- Space between prosthetic valve and left annulus
- Edwards SAPIEN 26mm
- Balloon Expandable Device

**Example: Under-Expanded**

- Under-expanded
- TEE short axis: Assess shape (circular or non-circular)
- Oval-shaped waist
- Medtronic CoreValve 29mm
- Self Expandable
**Valve Measurement**

- Example: TEE long axis
- Diameters of 24 to 26 mm indicating reasonable expansion in the presence of PVR
- Edwards SAPIEN XT 26-mm
- Balloon Expandable Device

**Mechanism: Supra-skirt**

- Low implant ("too ventricular")
- Prosthesis is deployed at a depth that exceeds the height of its tissue skirt
- Regurgitant jet passes above the skirt outside the circumference of the stent (PVR)
- Flow Pattern:
  - Aortic portion \(\rightarrow\) paravalvular space
  - \(\rightarrow\) LVOT

**Too Low “Supra-Skirt” PVR**

**Mechanism: Infra-skirt**

- High implant ("too aortic")
- Partially above the native annulus
- Flow Pattern outside the circumference of the stent (PVR):
  - Paravalvular space \(\rightarrow\) irregular inflow edge
  - \(\rightarrow\) LVOT
Too High “Infra-Skirt”

Transvalvular Regurgitation Post TAVR

Definition
Example

Transvalvular Aortic Regurgitation

• Easy to differentiate from PVR
• WITHIN the circumference of prosthetic stent frame (central jet)
• Transvalvular AR - Assess valve leaflets
  • Structural damage vs. insufficient diastolic pressure to close them?

Example: Transvalvular Aortic Regurgitation

• TEE long-axis view
• Both: Transvalvular central jet
• PVR Posterior Jet
• Edwards SAPIEN 23-mm
• Balloon Expandable Device

Jet Location Tips

• The jet must enter the LV to be considered true regurgitation
  • Image just below the edge of the stent to confirm true PVR

• Color flow around valve within S of V, but above the annular valve skirt should not be mistaken for PVR.
  • This low velocity flow (not aliased) does not connect with the LVOT in diastole
• Scan through the long axis of the valve to distinguish sinus flow from PVR.

TTE vs. TEE

Advantages and Disadvantages
Echo Quantification of PVR After TAVR

4 Principles:
- Color Doppler
- CW and PW Doppler
- Quantification (Rvol & RF)

4 Principles: Evaluation of PVR with Echo

1. Comprehensive Exam – 2D, color, CW, PW, TTE, TEE, 3D
2. Individualization to the patient (mechanism, location of PVR)
3. Integration of multiple parameters
4. Precise & standardized language to describe findings (TEE/TTE)
   - Severity
   - Location

Location Description: Clock Face

Place the tricuspid valve at 9 o’clock
**Vena Contracta Width**

- **Vena contracta**: Narrowest region between the proximal laminar flow and the distal turbulent regurgitant jet spray

**Advantages**
- Valid in eccentric jets
- Independent of flow rate and driving pressure
- Less dependent on technical factors – simple & reproducible
- Good at identifying mild or severe AR
- Rapid qualitative assessment

**Disadvantages**
- Smaller jets - difficult to evaluate severity
- Problematic with multiple jets
- Irregular shaped jets: Over or underestimate severity

**VC Width – Correct Technique**
- Select image plane that optimizes the Vena Contracta – not always PLAX
- Zoom Image
- Narrowest area of jet
- Avoid surrounding blurred color signals
  - Remove color from frozen image (color suppression)
VC Width – Tips
- Sweep Valve to ensure smallest VC
- Flow convergence ➔ VC ➔, to jet spray
- Maximize Nyquist limit (>65 cm/sec):
  - Distinguish high vs. low velocity

Vena Contracta Width Values

<table>
<thead>
<tr>
<th>AR Vena Contracta Width (VCW)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Mild</td>
<td>&lt; 0.3 cm</td>
</tr>
<tr>
<td>Moderate</td>
<td>0.3 – 0.6 cm</td>
</tr>
<tr>
<td>Severe</td>
<td>&gt; 0.6 cm</td>
</tr>
</tbody>
</table>

Vena Contracta Area (VCA)

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
<th>Blooming Artifacts</th>
<th>Technique</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

VC Area: Advantages
- May allow addition of multiple jets
- Strong correlation existed between 2D VCA and 3D VCA
- Good for VC jet shapes that are irregular or ellipsoid

VC Area: Disadvantages
- Accuracy limited by spatial resolution for small jets
- User Error
- Prone to blooming artifacts
  - Color extends beyond true boundaries
  - Mainly distal portion
  - Lower the color gain to reduce color bleed!

VC Area – Correct Techniques
- Trace each jet and add together
- Narrow color flow sector
  - ↑ resolution
  - Mid-diastole
  - Minimize effect of cardiac motion

VC Area – Correct Techniques

<table>
<thead>
<tr>
<th>VC Area – Correct Techniques</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>VCA ≈ 0.12 cm²</td>
<td></td>
</tr>
<tr>
<td>VCA ≈ 0.10 cm²</td>
<td></td>
</tr>
<tr>
<td>VCA ≈ 0.05 cm²</td>
<td></td>
</tr>
</tbody>
</table>
### Vena Contracta Area

<table>
<thead>
<tr>
<th>AR Vena Contracta Area (VCA)</th>
<th>Mild</th>
<th>Moderate</th>
<th>Severe</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>&lt; 10 cm²</td>
<td>0.10 – 0.29 cm²</td>
<td>&gt; 0.30 cm²</td>
</tr>
</tbody>
</table>

### Circumferential Extent %

**Assess the extent of the PVR around stent**

1. Trace Circumference (C)
2. Measure length of jet along valve curvature

**Single Jet:** \( \frac{a}{c} \times 100 \)

**Multiple Jets:** \( \frac{a + b}{c} \times 100 \)

**Multiple jets:** Measure each jet

### Circumferential Extent: Technique

- **Measure:** Parasternal Short Axis
- **Scan and Check:** PLAX, Apical 5 and Apical 3
- **Some jets may not be detected in PSAV:**
  - Shadowing from the prosthesis (PSAX)
- **Complete interrogation:**
  - Transducer rotation & tilting upward or sideways
  - Off-axis planes

### Circumferential Extent: PLAX

### Circumferential Extent: Apical 5
Circumferential Extent: Apical 3

Circumferential Extent

<table>
<thead>
<tr>
<th>Severity of PVR</th>
<th>Circumferential %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trace</td>
<td>Pinpoint Jet</td>
</tr>
<tr>
<td>Mild</td>
<td>&lt; 10%</td>
</tr>
<tr>
<td>Moderate</td>
<td>(10 – 30%)</td>
</tr>
<tr>
<td>Severe</td>
<td>&gt; 30%</td>
</tr>
</tbody>
</table>

Circumferential Extent: Reporting

Circumferential Extent & VCA

MILD Circumferential Extent: 8%
MILD VCA: 0.1 cm²

MILD Circumferential Extent: 10%
MODERATE VCA: 0.2 cm²

Circumferential Extent & VCA

- Circumferential Extent \text{DOES NOT factor in VCA}
- Only measures the length of the jet in relation to circumference NOT JET THICKNESS
- Similar Circumferential Extent BUT larger VCA = greater PVR
- $\uparrow$ VCA = $\uparrow$ jet thickness = $\uparrow$ severity
- Severity of PVR is affected by both circumferential extent and thickness of the PVR

Circumferential Extent: Reporting

Circumferential Extent %: Caution

VCA Factor
Correct Imaging Plane
Circumferential Extent: Correct Plane

Jet/LVOT ratio not used post TAVR

- PVR jets are frequently eccentric & constrained by the LVOT, leading to rapid jet broadening
- TTE, anterior eccentric jet

Qualitative Color Doppler
Proximal Flow Convergence

Advantages / Disadvantages
Technique

Large flow convergence - indicative of severe PVR
Rapid qualitative assessment

Disadvantages:
- Multiple jets

Proximal Flow Convergence: Technique

- Zoomed view
- Change baseline of Nyquist limit in the direction of the jet
- Adjust lower Nyquist limit to obtain the most hemispheric flow convergence
- Align direction of flow parallel to US beam to avoid distortion of hemisphere
Proximal Flow Convergence: Severity

<table>
<thead>
<tr>
<th>Severity</th>
<th>Proximal Flow Convergence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mild</td>
<td>Absent</td>
</tr>
<tr>
<td>Moderate</td>
<td>May be present</td>
</tr>
<tr>
<td>Severe</td>
<td>Often present</td>
</tr>
</tbody>
</table>

Color Doppler Summary

Key Points

Tips and Artifacts

Severity Chart

PVR Color Severity: Semi-Quantitative/Qualitative

<table>
<thead>
<tr>
<th>TAVR: Color Flow Severity of AR</th>
<th>Semi Quantitative</th>
<th>Mild</th>
<th>Moderate</th>
<th>Severe</th>
</tr>
</thead>
<tbody>
<tr>
<td>VCW</td>
<td>≤ 0.3 cm</td>
<td>0.3 – 0.6 cm</td>
<td>&gt; 0.6 cm</td>
<td></td>
</tr>
<tr>
<td>VCA</td>
<td>≤ 0 cm²</td>
<td>0.10 – 0.29 cm²</td>
<td>&gt; 0.30 cm²</td>
<td></td>
</tr>
<tr>
<td>Circumferential</td>
<td>≤10%</td>
<td>10 – 29%</td>
<td>≥ 30%</td>
<td></td>
</tr>
<tr>
<td>Qualitative</td>
<td>Mild</td>
<td>Moderate</td>
<td>Severe</td>
<td></td>
</tr>
<tr>
<td>Prox. Flow Convergence</td>
<td>Absent</td>
<td>May be present</td>
<td>Often present</td>
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</tr>
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</table>

Summary: Color Doppler

Scan entire Valve: Distal - Prox (Aortic - LVOT) to identify jet:
1. Width (VCW/VCA)
2. # of Jets / Circumferential extent of jet
3. Location (o'clock, ant/post) (Mechanism: supra-skirt / infra-skirt)
4. Direction (eccentric)
   • Short-axis imaging below the valve may overestimate PVR severity in eccentric jets
   • Attenuation hinders visualization of regurgitation
     • Anterior (TEE)
     • Posterior (TTE)

Continuous Wave (CW)/ Pulse Wave (PW)

Spectral Doppler (CW)/ PW

Limitations
Desc. Aorta flow reversal

Native Valves:
• Pressure half-time
• Jet density (CW)
• Desc. Aortic Flow Reversal

TAVR:
These values have limited application – multiple jets
Pressure Half Time

PHT & LV Compliance
Jet Density

PVR: Pressure Half Time Limitations

- Multiple Jets
- LV Compliance affects PHT
  \[ \text{Stiffness} = \frac{1}{\text{PHT (over-estimate)}} \]

Pressure half-time in extremes may be helpful

<table>
<thead>
<tr>
<th>Pressure Half Time</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Mild</td>
<td>&gt; 500 ms</td>
</tr>
<tr>
<td>Severe</td>
<td>&lt; 200 ms</td>
</tr>
</tbody>
</table>

PVR: Jet Density

- Multiple PVR jets limits CW spectral density from a single jet
- Jet Density: Very dense waveform signals at least moderate AR

PVR: Desc. Aorta Flow Reversal

Exceptions
Severity

False Readings: Desc. Aorta Flow Reversal

1. NO Holodiastolic flow reversal ... in the presence of SEVERE REGURG.
   - Severe bradycardia

2. Flow reversal...with NO regurgitation
   - HTN patients
   - Pre-TAVR assessment of descending aortic flow is essential

Desc. Aorta Flow Reversal

In the absence of baseline flow reversal:
- Severe PVR: End-diastolic flow >20 cm/s (Normal HR)

Flow reversal in the abdominal aorta is a more specific indication of significant regurgitation
### TAVR: Desc. Aorta Flow Reversal

<table>
<thead>
<tr>
<th></th>
<th>Mild</th>
<th>Moderate</th>
<th>Severe</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Desc. Aorta</strong></td>
<td>Brief</td>
<td>May be</td>
<td>Holodiastolic &gt; 20cm/s (prox)</td>
</tr>
<tr>
<td><strong>Abdominal Aorta</strong></td>
<td>Absent</td>
<td>Absent</td>
<td>Present</td>
</tr>
</tbody>
</table>

### Integrated Approach

**Mild AR**  

- **Integrated Approach**  
  - Meet 4 or more Criteria: Definitively MILD  
  - No Need To Perform Additional Quantification

<table>
<thead>
<tr>
<th>Metric</th>
<th>Value</th>
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</thead>
<tbody>
<tr>
<td>VCW</td>
<td>&lt; 0.3 cm</td>
</tr>
<tr>
<td>VCA</td>
<td>&lt; 0.10 cm²</td>
</tr>
<tr>
<td>Circumferential Extent</td>
<td>&lt; 10%</td>
</tr>
<tr>
<td>Flow Convergence</td>
<td>None / Small</td>
</tr>
<tr>
<td>PHT</td>
<td>&gt; 500 ms</td>
</tr>
<tr>
<td>Desc. Aorta Flow Reversal</td>
<td>None / Brief</td>
</tr>
</tbody>
</table>

### Severe AR

- **Meet 4 or more Criteria**: Definitively SEVERE  
- No Need To Perform Additional Quantification

<table>
<thead>
<tr>
<th>Metric</th>
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<tbody>
<tr>
<td>VCW</td>
<td>&gt; 0.6 cm</td>
</tr>
<tr>
<td>VCA</td>
<td>&gt; 0.30 cm²</td>
</tr>
<tr>
<td>Circumferential Extent</td>
<td>≥ 30%</td>
</tr>
<tr>
<td>Flow Convergence</td>
<td>Large</td>
</tr>
<tr>
<td>PHT</td>
<td>&lt; 200ms</td>
</tr>
<tr>
<td>Desc. Aorta Flow Reversal</td>
<td>Holodiastolic ≥ 20cm/s</td>
</tr>
</tbody>
</table>
Advanced Quantification

\[ \text{Rvol} = \text{LV SV} - \text{Systemic SV} \]

\[ \text{RF} = \frac{\text{Rvol}}{\text{SV}_{\text{LVOT}}} \]

- Post TAVR patients have smaller Rvol
  - LVH, Smaller LV cavity, Abnormal LV compliance
  - (explaining why even mild regurg. post TAVR impacts clinical outcomes)
- Native AR cut-off for severe (Rvol of > 60 mL) seems inappropriate early after TAVR

\[ \text{RF} < 30\% \]
\[ 30\% - 49\% \]
\[ > 50\% \]

\[ \text{RVol} < 30 \text{ mL} \]
\[ 30 - 59 \text{ mL} \]
\[ > 60 \text{ mL} \text{ in low flow} \]

\[ \text{EROA} < 0.10 \text{ cm}^2 \]
\[ 0.10 - 0.29 \text{ cm}^2 \]
\[ > 0.30 \text{ cm}^2 \]

**TAVR population:** CMR RF in PVR showed a reduced survival with a RF of 30%

**Regurgitant Volume (Rvol)**

- LV Stroke Volume
- Systemic Stroke Volume

**Regurgitation Volume (Rvol)**

- LVOT Stroke Volume
- MV Stroke Volume
- Volumetric LV Stroke Volume
- RVOT Stroke Volume

**LV Stroke Volume**

- LVOT Stroke Volume
- Volumetric Stroke Volume

**PVR Color Severity: Quantitative**

<table>
<thead>
<tr>
<th>Quantitative</th>
<th>Mild</th>
<th>Moderate</th>
<th>Severe</th>
</tr>
</thead>
<tbody>
<tr>
<td>RF</td>
<td>&lt; 30%</td>
<td>30 – 49%</td>
<td>&gt; 50%</td>
</tr>
<tr>
<td>RVol</td>
<td>&lt; 30 mL</td>
<td>30 – 59 mL</td>
<td>&gt; 60 mL (in low flow)</td>
</tr>
<tr>
<td>EROA</td>
<td>&lt; 0.10 cm$^2$</td>
<td>0.10 – 0.29 cm$^2$</td>
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(TAVR population: CMR RF in PVR showed a reduced survival with a RF of 30%)
LVOT Stroke Volume

Method

Challenges

LVOT Measurement Challenges:

• Valve protrudes into the LVOT (unlike sutured surgical valve)
• Match PW LVOT sample with LVOT diameter of valve

LVOT Diameter: Preferred Method

Outer-to-outer border of the valve
Ventricular tip
PW sample: Apical to the valve

LVOT Diameter: Deep Valve Placement

• In-stent diameter, mid-stent, level of leaflets
• Inner-to-inner

PW sample volume IN STENT
Proximal to the valve

Volumetric Stroke Volume

Method
LV Stroke Volume: Volumetric Method

Bi-Plane LV Volumes
- End Diastole & End Systole
- 4 Chamber & 2 Chamber
- Use contrast if needed

Systemic Stroke Volume

MV Stroke Volume
- MV Annulus Diameter
- PW MV – same location

RVOT Stroke Volume
- RVOT Annulus Diameter
- PW PV – same location
Contradicting Data

• Advanced quantification required if do NOT meet ≥ 4 criteria
• If assessment is difficult and indeterminate or provides contradicting data:
  • Look carefully for technical and physiologic reasons to explain these discrepancies
  • Rely on the components that have the best quality / most accurate considering the underlying clinical condition

Further testing with either TEE or CMR:

Summary

Integration of Multiple Parameters

PVR after TAVR should be a comprehensive and integrative process
• More challenging compared to native AR
• Color flow Doppler – Most essential modality

Scan entire Valve: Distal - Prox (Aortic - LVOT) to identify jet:
1. Width (VCW/VCA)
2. # of Jets / Circumferential extent of jet
3. Location (o'clock, ant/post) (Mechanism: supra-skirt / infra-skirt)
4. Direction (eccentric)

Color Doppler – Key Points

• Short-axis imaging below the valve may overestimate AR severity in eccentric jets
• Attenuation hinders visualization of regurgitation
  • Anterior (TEE)
  • Posterior (TTE)
• Valvular regurgitation severity classification:
  • Mild, moderate, severe

If the AR is definitely determined as mild or severe, no further quantification is required

Thank you
References

- https://www.cardioserv.net/MCSS
- https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4425861/figure/Fig1/
- https://radiopaedia.org/articles/blooming-artifact-ultrasound