Tricuspid and Pulmonary Valve Disease

Lawrence Rudski MD FRCPC FACC FASE
Professor of Medicine
Director, Division of Cardiology
Jewish General Hospital
McGill University

Tricuspid Regurgitation
So What?

- Right Sided Failure
  - Edema
  - Gut congestion
  - Atrial fibrillation
  - DEATH – associated with increased risk of death

Dyspnea!!!

Little TR – OK (useful for us, in fact)
Lots of TR - BAD
TR predicts survival (n=5,223)

Nath et al (VA, Palo Alto), JACC 2004
“Complex” Anatomy (literally)

- Leaflet(s) – One continuous leaflet with indentations into Anterior, Septal, Posterior
- Annulus – D-shaped, with flatter portion along the central fibrous body - contractile
- Chordae
- Papillary muscles – usually 3
- Underlying Right Ventricular Myocardium

View from Above
Incremental Value of the En Face View of the Tricuspid Valve by Two-Dimensional and Three-Dimensional Echocardiography for Accurate Identification of Tricuspid Valve Leaflets

Ivan Stankovic, MD, Ana Mara Darzba, MD, Ruta Jasaityte, MD, Aleksandar N. Nesicovic, MD, PhD, Peter Claus, PhD, and Jeno-Uwe Voigt, MD, PhD, Leveon, Beograd, Serbia

Journal of the American Society of Echocardiography
Volume 27 Number 4

Comprehensive Two-Dimensional Interrogation of the Tricuspid Valve Using Knowledge Derived from Three-Dimensional Echocardiography

Karima Addetia, MD, Megan Yamat, RDMS, Anuj Mediratta, MD, Diego Medvedofsky, MD, Mita Patel, MD, Preston Ferrara, RDMS, Victor Mor-Avi, PhD, and Roberto M. Lang, MD, Chicago, Illinois

JASE 2015
Why is this important?
What Can Go Wrong?

• Leaky
  – Stretched
  – Infected, with long-term sequelae
  – Perforated
  – Skewered
  – Ripped

• Narrowed
  – Rheumatic
  – Evil Humors

Etiologies of TR

• Functional TR
  – PAH
  – Vol. Overload e.g. ASD
  – Cor Pulmonale
  – Left heart Disease
  – RV myocardial Disease
    • RV dysplasia
    • RV ischemia
    • Post-transplant

• Primary TR
  – Rheumatic
  – Myxomatous
  – Ebstein’s Anomaly
  – Endocarditis
  – Carcinoid/Infiltrative
  – Traumatic – anterior structure-MVA
  – Iatrogenic
    • Pacer/ICD wires
    • RV biopsy

No reason why Carpentier’s Classification can’t apply
Primary or Secondary?
PA Pressure - As a *general rule*...

- In setting of severe TR, PAPs > 55 mmHg is often associated with anatomically normal tricuspid valves, while PAPs < 55 mmHg usually associated with an abnormality of the tricuspid valve apparatus.

Tricuspid Valve Assessment
- Leaflets
  - Thickening, doming, restriction
  - Coaptation
  - Flail
- Annulus diameter
- Mean gradient
- TR severity
- RA + RV dilatation, septal flattening
- RV systolic function
- PA pressure
Leaflets
Bicuspid TV Valve

Pacemaker Lead Impingement

Courtesy of Dr. Roberto Lang
Not TV Dinner, but TV Kebab

- (a) Valve obstruction caused by lead placed in between leaflets.
- (b) Lead adherence due to fibrosis and scar formation to valve causing incomplete closure.
- (c) Lead entrapment in the tricuspid valve apparatus
- (d) Valve perforation or laceration.
- (e) Annular dilatation.


Functional TR

**RV Remodeling**
- RV dysfunction and dilatation
- Papillary Muscle Displacement
- Leaflet tethering and resultant tenting
- **Annular Dilatation**

**RA Remodeling**
- Atrial Fibrillation
- LA-RA enlargement
- **Annular and Ventricular Base Dilatation**

Surkova et al – Abstract EACVI 2016
FTR ≠ FTR

Clinical Context and Mechanism of Functional Tricuspid Regurgitation in Patients With and Without Pulmonary Hypertension

Yan Topilsky, MD; Amber Khanna, MD; Thierry Le Tourneau, MD; Soon Park, MD; Hector Michelena, MD; Rakesh Suri, MD, DPhil; Douglas W. Mahoney, MS; Maurice Enriquez-Sarano, MD

(Circ Cardiovasc Imaging, 2012;5:314-323.)

Annular Dimension

70 mm

Annulus Diameter

40 mm or 21 mm/m²

Functional TR – Putting it all Together
Quantitation?
Quantification of TR by Color Doppler

- Simplest and quickest way to evaluate TR severity but limitations and uncertainties

**Analogous to MR Assessment by color Doppler**

- A large color jet represents more significant tricuspid regurgitation than a small jet
- Visualisation of the color jet depends on:
  - Hemodynamic/Loading Conditions
    - Hyper/Hypotension
    - RA Pressure and pressure gradient between RV-RA
    - RA size and capacitance
    - Phase of respiration
  - Cause of regurgitation
    - Excentric Jet (Coanda effect)-use multiple views
    - Vs. Central Jet
  - Technical Limitations
    - Sub-optimal views
    - Gain settings
SEVERE : > 10 cm²

Vena Contracta

<table>
<thead>
<tr>
<th>MILD</th>
<th>MODERATE</th>
<th>SEVERE</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;0.3</td>
<td>0.3-0.69</td>
<td>≥0.7</td>
</tr>
</tbody>
</table>
Quantitation – Vena Contracta

Severe: VC > 0.7 cm
Nyquist 50-60 cm/s

3D Vena Contracta
**TR Severity by PISA**

**EROA** = \(6.28 \times 0.9^2 \times 32 / 386 = 0.4 \text{ cm}^2\)

**RVol** = \(0.4 \times 109 = 44 \text{ mL}\)

<table>
<thead>
<tr>
<th>Quantitative</th>
<th>Mild</th>
<th>Moderate</th>
<th>Severe</th>
</tr>
</thead>
<tbody>
<tr>
<td>EROA (cm²)</td>
<td>&lt;0.20</td>
<td>0.20-0.39</td>
<td>≥0.40</td>
</tr>
<tr>
<td>RVol (2D PISA) (mL)</td>
<td>&lt;30</td>
<td>30-44</td>
<td>≥45</td>
</tr>
<tr>
<td>PISA radius (cm)²</td>
<td>≥0.5</td>
<td>0.5-0.9</td>
<td>&gt;0.9</td>
</tr>
</tbody>
</table>

**EOA** = \(2\pi R^2 \times V_{\text{alias}} / V_{\text{max}}\)

Nyquist Radius

- 28 – 0.9cm
- 25 – 1.0cm
- 31 – 0.8cm
- 37 – 0.68cm
- 43 – 0.59cm
### Pulsed Doppler Hepatic Vein Reversal

<table>
<thead>
<tr>
<th>Optimization</th>
<th>Example</th>
<th>Advantages</th>
<th>Pitfalls</th>
</tr>
</thead>
</table>
| Align insonation beam with the flow in the hepatic vein | ![Example Image](image1.png) | Simple supportive sign of severe TR  
Can be obtained with both TTE and TEE | Depends on compliance of the right atrium  
May not be reliable in patients with atrial fibrillation, paced rhythm with retrograde atrial conduction |

### Hepatic Vein Reversal

![Example Images](image2.png)
TR signal – density and shape

- Align insolation beam with the flow
- Simple
- Density is proportional to the number of red blood cells reflecting the signal
- Faint or incomplete jet is compatible with mild TR

- Qualitative
- Perfectly central jets may appear denser than eccentric jets of higher severity
- Overlap between moderate and severe TR

TR signal – density and shape

- Align insolation beam with the flow
- Simple
- Specific sign of pressure equalization in low velocity, early peaking dense TR jet

- Qualitative
- Affected by changes that modify RV and RA pressures
Effect on RV (and vice versa)

Paradoxical Septum – D-Diastole
### RA Size

Table 14: Grading the severity of chronic TR by echocardiography

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Mild</th>
<th>Moderate</th>
<th>Severe</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Structural</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TV morphology</td>
<td>Normal/mildly abnormal leaflets</td>
<td>Moderately abnormal leaflets</td>
<td>Severe valve lesions (e.g., flail leaflet, severe retraction, large perforation)</td>
</tr>
<tr>
<td>RV and RA size</td>
<td>Usually normal</td>
<td>Normal/mild dilatation</td>
<td>Usually dilated</td>
</tr>
<tr>
<td>Inferior vena cava diameter</td>
<td>Normal &lt; 2 cm</td>
<td>Normal/mildly dilated 2.1-2.5 cm</td>
<td>Dilated &gt; 2.5 cm</td>
</tr>
<tr>
<td><strong>Qualitative Doppler</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Color flow jet area¹</td>
<td>Small/narrow, central</td>
<td>Moderate central</td>
<td>Large central jet or eccentric wall-impinging jet of variable size</td>
</tr>
<tr>
<td>Flow convergence zone</td>
<td>Not visible, transient or small</td>
<td>Intermediate in size and duration</td>
<td>Large throughout systole</td>
</tr>
<tr>
<td>CW Doppler jet</td>
<td>Faint/partial/parabolic</td>
<td>Dense, parabolic or triangular</td>
<td>Dense, often triangular</td>
</tr>
<tr>
<td><strong>Semi-quantitative</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Color flow jet area (cm²)¹</td>
<td>Not defined</td>
<td>Not defined</td>
<td>&gt;10</td>
</tr>
<tr>
<td>VCW (cm)¹</td>
<td>&lt;0.3</td>
<td>0.3-0.69</td>
<td>&gt;0.7</td>
</tr>
<tr>
<td>PISA radius (cm)¹</td>
<td>&gt;0.5</td>
<td>0.6-0.9</td>
<td>&gt;0.9</td>
</tr>
<tr>
<td>Hepatic vein flow⁵</td>
<td>Systolic dominance</td>
<td>Systolic blunting</td>
<td>Systolic flow reversal</td>
</tr>
<tr>
<td>Tricuspid inflow⁶</td>
<td>A-wave dominant</td>
<td>Variable</td>
<td>E-wave &gt;1.0 m/sec</td>
</tr>
<tr>
<td><strong>Quantitative</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EROA (cm²)¹</td>
<td>&lt;0.20</td>
<td>0.2-0.30</td>
<td>&gt;0.40</td>
</tr>
<tr>
<td>RVol (2D PISA) (mL)</td>
<td>&lt;30</td>
<td>30-44</td>
<td>&gt;45</td>
</tr>
</tbody>
</table>

RA, Right atrium.

¹Boiled signs are considered specific for their TR grade.

²RV and RA size can be within the “normal” range in patients with acute severe TR.

³With Nyquist limit >50-70 cm/sec.

⁴With baseline Nyquist limit shift of 28 cm/sec.

⁵Signs are nonspecific and are influenced by many other factors (RV diastolic function, atrial fibrillation, RA pressure).

⁶There are little data to support further separation of these values.
Key Points

- Physiologic mild TR is common in normal individuals.
- In patients with more than mild TR, identifying the mechanism of TR is important. TR is classified as primary or secondary (functional), and the precise mechanism of TR should be specified and reported (Table 12).
- No single Doppler and echocardiographic measurement or parameter is precise enough to quantify TR severity. Integration of multiple parameters is required (Tables 13 and 14). When multiple parameters are concordant, TR grade can be determined with high probability (especially for mild or severe TR).
- There is less experience with quantitation of TR severity with PISA or volumetric flow compared with MR and AR.
- Severe, wide-open TR may have low velocity, without aliasing or turbulence, and thus may be difficult to see as a distinct jet by color Doppler.
- The size of the right atrium and RV should be considered. Chronic severe TR almost always leads to dilated RV and right atrium. Conversely, normal chamber volumes are unusual with chronic severe TR.
- CMR assessment of TR is less established compared with other regurgitant valvular lesions. Few indirect quantitative techniques can be used.
- Additional testing with TEE or CMR is indicated when the TTE examination does not provide a mechanism for significant TR, the echo/Doppler parameters are discordant or inconclusive regarding the severity of TR, or there is discrepancy of echocardiographic findings with the clinical setting.
Tricuspid Stenosis

Etiology

Rheumatic

Infiltration – Carcinoid

Compression – Rare – external (clot/tumor)/aorta

TS Gradients and TV Area

VTI 63-74 cm

- TVA cm$^2$ = 190/PHT
Calculation of TVA

- $A_1 = \text{LVOT CSA or RVOT CSA}$
- $V_1 = \text{LVOT V1 or RVOT V1 (PW)}$
- $V_2 = \text{Vmax of Tricuspid Inflow by CW Doppler}$

\[
A_2 = \frac{A_1 \cdot V_1}{V_2}
\]

Table 10: Findings indicative of haemodynamically significant tricuspid stenosis

<table>
<thead>
<tr>
<th>Specific findings</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean pressure gradient</td>
<td>$\geq 5 \text{ mmHg}$</td>
</tr>
<tr>
<td>Inflow time–velocity integral $T_{1/2}$</td>
<td>$\geq 60 \text{ cm}$</td>
</tr>
<tr>
<td>Valve area by continuity equation$^a$</td>
<td>$\geq 190 \text{ ms}$  $\leq 1 \text{ cm}^2$</td>
</tr>
<tr>
<td>Supportive findings</td>
<td></td>
</tr>
<tr>
<td>Enlarged right atrium $\geq$ moderate</td>
<td></td>
</tr>
<tr>
<td>Dilated inferior vena cava</td>
<td></td>
</tr>
</tbody>
</table>

$^a$ Stroke volume derived from left or right ventricular outflow. In the presence of more than mild TR, the derived valve area will be underestimated. Nevertheless, a value $\leq 1 \text{ cm}^2$ implies a significant haemodynamic burden imposed by the combined lesion.
Pulmonic Valve << Tricuspid Valve

• Stenosis – Valvar, Sub-, Supra
  – Congenital
  – Infiltrative
  – Iatrogenic – post Ross e.g.

• Regurgitation
  – PH
  – Congenital Surgery – Repaired Tetralogy
  – Endocarditis
  – Infiltrative

Normal PV
Color Doppler

### Doppler Signs of PR Severity

<table>
<thead>
<tr>
<th>Modality</th>
<th>Optimization</th>
<th>Example</th>
<th>Advantages</th>
<th>Pitfalls</th>
</tr>
</thead>
<tbody>
<tr>
<td>VC</td>
<td>Parasternal short-axis or subcostal views</td>
<td></td>
<td>Surrogate for effective regurgitant orifice area</td>
<td>Not usable with multiple jets</td>
</tr>
<tr>
<td></td>
<td>Zoomed view</td>
<td></td>
<td>Independent of flow rate and driving pressure for a fixed orifice</td>
<td>The direction of the jet (in relation to the imaging beam) will influence the appearance of the jet</td>
</tr>
<tr>
<td></td>
<td>Should visualize proximal flow convergence, distal jet, and the “narrow” neck in a single view</td>
<td></td>
<td>Less dependent on technical factors</td>
<td>Cutoffs for various grades of PR not validated</td>
</tr>
<tr>
<td></td>
<td>Measured in diastole immediately below PV</td>
<td></td>
<td></td>
<td>Not easy to perform</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>VC/PV annular diameter ratio</th>
<th>Parasternal short-axis view</th>
<th>Zoomed view</th>
<th>Optimizes visualization of proximal PA</th>
<th>Simple sensitive screen for PR</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Rapid qualitative assessment</td>
<td>Underestimates PR in eccentric jets</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Overestimates PR in control jets</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>PR jet may expand unpredictably below the orifice</td>
</tr>
</tbody>
</table>
Regurgitant Volume and Fraction

**Figure 33.** CWD of pulmonic flow. Calculation of pulmonic regurgitation index (PR index = A/B) is shown, an index of PR severity, quantitating early termination of diastolic regurgitant flow.

<table>
<thead>
<tr>
<th>Quantitative Doppler</th>
<th>RVol and fraction</th>
</tr>
</thead>
<tbody>
<tr>
<td>RW4 = ( SV_{RVOT} - SV_{LVOI} )</td>
<td><em>Pulmonic annulus from PSAX view, measured during early ejection just below PV.</em></td>
</tr>
<tr>
<td>RF = RW4/SV_{RVOT}</td>
<td><em>Pulsed Doppler in RVOT from PSAX.</em></td>
</tr>
<tr>
<td></td>
<td><em>Aortic annulus measured in early systolic from PLA.</em></td>
</tr>
<tr>
<td></td>
<td><em>Pulsed Doppler in LVOI from apical window.</em></td>
</tr>
</tbody>
</table>

- **Quantitative, valid with multiple jets and eccentric jets.** Provides lesion severity (RF) and volume overload (RVol; ERGA not validated).
- **Difficulties measuring RVOT diameter.**
- In case of AR, would need to use the mitral annulus site.
- Experience is scant.

*LPA, Left pulmonary artery; PHT, Pressure half-time; PSAX, Parasternal short axis; RPA, Right pulmonary artery.*
### Table 18  Echocardiographic and Doppler parameters useful in grading PR severity

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Mild</th>
<th>Moderate</th>
<th>Severe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pulmonic valve</td>
<td>Normal</td>
<td>Normal or abnormal</td>
<td>Abnormal and may not be visible</td>
</tr>
<tr>
<td>RV size</td>
<td>Normal*</td>
<td>Normal or dilated</td>
<td>Dilated*</td>
</tr>
<tr>
<td>Jet size, color Doppler*:</td>
<td>Thin usually &lt;10 mm in length with a narrow origin</td>
<td>Intermediate</td>
<td>Broad origin; variable depth of penetration</td>
</tr>
<tr>
<td>Ratio of PR jet width/pulmonary annulus</td>
<td>&gt;0.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Jet density and contour (OW)</td>
<td>Soft</td>
<td>Dense</td>
<td>Dense; early termination of diastolic flow</td>
</tr>
<tr>
<td>Deceleration time of the PR spectral Doppler signal</td>
<td></td>
<td>Short, &lt;260 msec</td>
<td></td>
</tr>
<tr>
<td>Pressure half-time of PR jet</td>
<td></td>
<td>&lt;100 msec</td>
<td></td>
</tr>
<tr>
<td>PR index¹</td>
<td>&lt;0.77</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diastolic flow reversal in the main or branch PAs (PW)</td>
<td></td>
<td>Prominent</td>
<td></td>
</tr>
<tr>
<td>Pulmonary systolic flow (NT) compared to systemic flow (LVOT VTI by PW)</td>
<td>Slightly increased</td>
<td>Intermediate</td>
<td>Greatly increased</td>
</tr>
<tr>
<td>RP*²</td>
<td>&lt;20%</td>
<td>20%-40%</td>
<td>&gt;40%</td>
</tr>
</tbody>
</table>

*PW, Pulsed wave Doppler.
*Unless there are other reasons for RV enlargement.
¹Exceptions: acute PR.
²A-S-Naqiel limit of 50-70 cm/sec.
³Identifies a CMR-derived PR fraction >40%.
⁴Defined as the duration of the PR signal divided by the total duration of diastole, with this cutoff identifying a CMR-derived PR fraction > 25%.
⁵Not reliable in the presence of high RV end diastolic pressure.
⁶Cutoff values for RVol and fraction are not well validated.
⁷Steep deceleration is not specific for severe PR.
⁸RF data primarily derived from CMR with limited application with echocardiography.
Pulmonic Stenosis
Pulmonic Valve Disease-Carcinoid

Table 11 Grading of pulmonary stenosis

<table>
<thead>
<tr>
<th></th>
<th>Mild</th>
<th>Moderate</th>
<th>Severe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak velocity (m/s)</td>
<td>&lt;3</td>
<td>3–4</td>
<td>&gt;4</td>
</tr>
<tr>
<td>Peak gradient (mmHg)</td>
<td>&lt;36</td>
<td>36–64</td>
<td>&gt;64</td>
</tr>
</tbody>
</table>
Impact

• Same as for TR
  – Assess RV size, RA size, RV function

– PAP Calculation Caveat – Subtract the PS Gradient**
– SPAP = (TR gradient + RAP) – PV PG
  = (43 + 15) – 32 = 26 mmHg

Key Points
- Physiologic, mild PR is common in normal individuals.
- In patients with more than mild PR, identifying the mechanism of PR is important. PR is classified as primary or secondary (functional). Primary PR is more common in congenital heart disease.
- No single Doppler and echocardiographic parameter is precise enough to quantify PR severity. Integration of multiple parameters is required (Tables 15 and 16 and Figure 39). When multiple parameters are concordant, PR grade can be determined with high probability (especially for mild or severe PR).
- There is little experience with quantification of PS severity with Doppler echocardiography.
- Severe, primary PR with normal pulmonary pressures may be of very short duration and have low velocity, thus it may be difficult to see as a distinct jet by color Doppler.
- The size of the RV should also be considered. Chronic severe PR almost always results in dilation of the RV. Conversely, normal chamber volumes are unusual in chronic severe PR. In patients with PR secondary to pulmonary hypertension, the size and function of the RV are variable.
- CWD is an excellent modality for evaluation of the PV, PA and for quantification of RV severity, using the direct phase-contrast method. It is the preferred method for quantification of RV volume and function.
- Additional testing with CWD is indicated when the TTE examination does not provide sufficient information. For example, if the Doppler parameters are discordant or inconclusive regarding the severity of PR, or there is discrepancy of echocardiographic findings and the clinical setting. This information is particularly relevant in patients with suspected or known congenital heart disease. TTE is not a preferred modality when information beyond TTE is needed.
**Summary**

**More than eyeball of color jet**

- **Tricuspid**
  - Morphology, Degree of dysfunction, Impact on cardiac size and function

- **Pulmonic**
  - Same as above

- **Implications for Clinical therapy**
  - When to intervene in primary and secondary TR, PR
  - When to intervene for TS and PS

---

**CMR – So 1990’s**

- **Echo**, echocardiography; **RAP**, right atrial pressure; **TR**, tricuspid regurgitation.

- **Watch RAP!**
Images can be deceptive! – Integrate detail with the BIG PICTURE

Table 12: Etiology of TR

<table>
<thead>
<tr>
<th>Morphologic classification</th>
<th>Disease subgroup</th>
<th>Specific abnormality</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary leaflet abnormality</td>
<td>Acquired disease</td>
<td>Degenerative, myxomatous, rheumatic, endocarditis, cardiovascular fitness, toxins, trauma, ischemic (pacing leads, RV biopsy), other (e.g., ischemic papillary muscle rupture)</td>
</tr>
<tr>
<td></td>
<td>Congenital</td>
<td>Ebstein's anomaly, TV dysplasia, TV tethering associated with perimembranous ventricular septal defect and ventricular septal aneurysm, repaired tetralogy of Fallot, congenitally corrected transposition of the great arteries, other (papillary fibroelastosis)</td>
</tr>
<tr>
<td>Secondary (functional)</td>
<td>Left heart disease</td>
<td>LV dysfunction or valve disease</td>
</tr>
<tr>
<td></td>
<td>RV dysfunction</td>
<td>RV ischemia, RV volume overload, RV cardiomyopathy</td>
</tr>
<tr>
<td></td>
<td>Pulmonary hypertension</td>
<td>Chronic lung disease, pulmonary thromboembolism, left-to-right shunt</td>
</tr>
<tr>
<td></td>
<td>Right atrial abnormalities</td>
<td>Atrial fibrillation</td>
</tr>
</tbody>
</table>
### Evaluate Tricuspid Valve
### Evaluate Right Heart Chambers

#### Table 15: Doppler echocardiography in evaluating severity of PR

<table>
<thead>
<tr>
<th>Modality</th>
<th>Optimization</th>
<th>Example</th>
<th>Advantages</th>
<th>Pitfalls</th>
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<tbody>
<tr>
<td>Color flow Doppler (B)</td>
<td>Parasternal short-axis or subcostal view</td>
<td></td>
<td>- Accurate for effective regurgitant orifice size</td>
<td>- Not usable with multiple jets</td>
</tr>
<tr>
<td></td>
<td>Diametral view</td>
<td><img src="image1.png" alt="Image" /></td>
<td>- Independent of flow rate and driving pressure for a fixed orifice</td>
<td>- The direction of the jet in relation to the transducer may influence</td>
</tr>
<tr>
<td></td>
<td>Should exclude proximal flow convergence, distal jet, and the “hourglass”</td>
<td><img src="image2.png" alt="Image" /></td>
<td>- Less dependent on technical factors</td>
<td>- Obscures the jet</td>
</tr>
<tr>
<td></td>
<td>view in a single view</td>
<td><img src="image3.png" alt="Image" /></td>
<td>- Not usable with multiple jets</td>
<td>- Not easy to perform</td>
</tr>
<tr>
<td>VCE/PV similar</td>
<td>Parasternal short-axis view</td>
<td><img src="image4.png" alt="Image" /></td>
<td>- Simple sensitive screen for PR</td>
<td>- Underestimates/mitigates jets</td>
</tr>
<tr>
<td>diameter ratio</td>
<td>Diametral view</td>
<td><img src="image5.png" alt="Image" /></td>
<td>- Rapid qualitative assessment</td>
<td>- Overestimates PR in ventricle jets</td>
</tr>
<tr>
<td>Pulsed wave Doppler (PW)</td>
<td>Align insonation beam with the flow in the RPA and IMA</td>
<td><img src="image6.png" alt="Image" /></td>
<td>- Simple suprasternal sign of severe PR</td>
<td>- PR jet may expand abnormally below the aortic valve</td>
</tr>
<tr>
<td>flow reversal in the</td>
<td><img src="image7.png" alt="Image" /></td>
<td><img src="image8.png" alt="Image" /></td>
<td>- Depends on compliance of the PA</td>
<td>- Flow velocity reversal is normal</td>
</tr>
<tr>
<td>branching PA</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CW Doppler</td>
<td>Align insonation beam with the flow in the PW and RV</td>
<td><img src="image9.png" alt="Image" /></td>
<td>- Simple</td>
<td>- Qualitative</td>
</tr>
<tr>
<td>Density of regurgitant</td>
<td>Simple</td>
<td><img src="image10.png" alt="Image" /></td>
<td></td>
<td>- Mild mitral regurgitation may appear denser</td>
</tr>
<tr>
<td>jet</td>
<td>- Dense</td>
<td><img src="image11.png" alt="Image" /></td>
<td></td>
<td>- Consistent with presence of higher severity</td>
</tr>
<tr>
<td></td>
<td>- Dense is proportional to the number of pixels cells reflecting the signal</td>
<td><img src="image12.png" alt="Image" /></td>
<td></td>
<td>- Overlap between severe and moderate PR</td>
</tr>
<tr>
<td></td>
<td>- Part or incomplete jet is compatible with mild PR</td>
<td><img src="image13.png" alt="Image" /></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Modality</td>
<td>Optimization</td>
<td>Example</td>
<td>Advantages</td>
<td>Pitfalls</td>
</tr>
<tr>
<td>----------</td>
<td>--------------</td>
<td>---------</td>
<td>------------</td>
<td>----------</td>
</tr>
<tr>
<td>Jet deceleration rate (pressure half-time)</td>
<td>Align insufflation beam with the flow or subcostal views.</td>
<td>Simple. Specific sign of pressure equilibration. Values &lt; 100 msec consistent with severe PR.</td>
<td>Poor alignment of Doppler beam may result in eccentric jets providing low PHT. Affected by RV and PA pressure difference, e.g., RV diastolic dysfunction.</td>
<td></td>
</tr>
<tr>
<td>The PR index (PR)</td>
<td>Align insufflation beam with the flow or subcostal views. Ensure complete forward and regurgitant flow.</td>
<td>Uses combination of PR duration and duration of diastole. Accounts for pressure differences between PA and RV.</td>
<td>Affected by RV diastolic dysfunction and RV diastolic pressures.</td>
<td></td>
</tr>
<tr>
<td>Quantitative Doppler: ( RV = \frac{SA_{RVOT}}{SA_{RVOT}} )</td>
<td>Pulmonic annulus from PSAX view, measured during early systole just below PV.</td>
<td>Quantitative, valid with multiple jets and eccentric jets. Provides lesion severity (PR) and volume overload (RV); EROA not validated.</td>
<td>Difficulties measuring RVOT diameter. In case of AR, would need to use the mitral annulus site. Experience is scant.</td>
<td></td>
</tr>
</tbody>
</table>

LPA: Left pulmonary artery; PHT: Pressure half-time; PSAX: Parasternal short axis; RPA: Right pulmonary artery.

<table>
<thead>
<tr>
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<th>Optimization</th>
<th>Example</th>
<th>Advantages</th>
<th>Pitfalls</th>
</tr>
</thead>
<tbody>
<tr>
<td>Color flow Doppler 2D</td>
<td>Align direction of flow with occlusive begin to avoid detection of hemisphere from nonocclusive imaging.</td>
<td>Rapid qualitative assessment. Multiple jets. Homogeneous shape.</td>
<td>Problems in the presence of multiple jets. In order to measure the convergence, one needs to be visualized.</td>
<td></td>
</tr>
<tr>
<td>VC</td>
<td>Zoom in view.</td>
<td>Apparatus for regurgitant office side.</td>
<td>Independent of flow rate and driving pressure for a fixed office. Less dependent on technical factors. Good at identifying leaflets EP.</td>
<td>Dependent on the driving pressure and jet direction. Direction and shape of jet may overestimate potential extraneous or underestimate eccentric, wall imaging pitch area.</td>
</tr>
<tr>
<td>Jet area</td>
<td>Four-chamber, RV inflow or subcostal views.</td>
<td>Qualitative.</td>
<td>Dependent on the driving pressure and jet direction. Direction and shape of jet may overestimate potential extraneous or underestimate eccentric, wall imaging pitch area.</td>
<td></td>
</tr>
<tr>
<td>Color flow Doppler 3D</td>
<td>Color flow sector should be narrow to avoid turbulence or aliasing of the jets.</td>
<td>Multiple jets of differing directions may be measured.</td>
<td>Dynamic jets may be over or underestimated. Time consuming. Observational resolution will need to be overestimated.</td>
<td></td>
</tr>
</tbody>
</table>
### PR Severity

<table>
<thead>
<tr>
<th>Modality</th>
<th>Optimization</th>
<th>Sample</th>
<th>Advantages</th>
<th>Pitfalls</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pulsed wave Doppler</td>
<td>High intensity signal with the entire mitral valve</td>
<td><img src="image1.png" alt="Image" /></td>
<td>Single supravalvular jet of interest with both TTE and TEE</td>
<td>Depends on cardiac disease of the patients, May not be visible in patients with atrial fibrillation, possible right bundle branch block</td>
</tr>
<tr>
<td>CW Doppler</td>
<td>Align interrogation beam with the flow</td>
<td><img src="image2.png" alt="Image" /></td>
<td>Simple, highly reflective, proportional to the number of red blood cells reflecting the signal, faint or invisible jets visible with mild TR</td>
<td>Qualitative, jet may appear more pronounced with eccentric jets of higher pressure, overlap between mitral and aortic jets, severe TR</td>
</tr>
<tr>
<td>Jet contour</td>
<td>Align interrogation beam with the flow</td>
<td><img src="image3.png" alt="Image" /></td>
<td>Simple, specific shape of the mitral valve, often visible, easily visible on simultaneous Doppler and PW Doppler with low velocities, mostly left atrial pressures</td>
<td>Qualitative, jet may appear more pronounced with eccentric jets of higher pressure, overlap between mitral and aortic jets, severe TR</td>
</tr>
</tbody>
</table>

**PESA**
- Align interrogation beam with flow, lower the probe, Doppler baseline in the direction of the jet, look for the characteristic shape of the left atrial appendage, not visible in eccentric jets with severe TR or LM systolic pressure. Not valid for multiple jets, may overlap in eccentric jets, limited sensitivity, typically lower LV pressure than LGE, less contrast.
Not many numbers
RV enlargement with PR jet and not much else
Very broad vena contracta
Short PHT
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Mild</th>
<th>Moderate</th>
<th>Severe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tricuspid valve</td>
<td>Usually normal</td>
<td>Normal or abnormal</td>
<td>Abnormal/ flail leaflet/ poor coaptation</td>
</tr>
<tr>
<td>RV/RA/IVC size</td>
<td>Normal</td>
<td>Normal or dilated</td>
<td>Usually dilated</td>
</tr>
<tr>
<td>Jet area-central jets (cm²)*</td>
<td>&lt;5</td>
<td>5-10</td>
<td>&gt;10</td>
</tr>
<tr>
<td>VC width (cm)*</td>
<td>Not defined</td>
<td>&lt; 0.7</td>
<td>&gt; 0.7</td>
</tr>
<tr>
<td>PISA radius (cm)**</td>
<td>&lt;0.5</td>
<td>0.6-0.9</td>
<td>&gt;0.9 *</td>
</tr>
<tr>
<td>Jet density and contour-CW</td>
<td>Soft and parabolic</td>
<td>Dense, variable contour early peaking</td>
<td>Systolic</td>
</tr>
<tr>
<td>Hepatic vein flow</td>
<td>Systolic dominance</td>
<td>Systolic blunting</td>
<td>Systolic reversal</td>
</tr>
</tbody>
</table>

IVC - inferior vena cava; RA - right atrium; RV - right ventricle; VC - vena contracta width; PISA - Proximal isovelocity surface area.
TR by PISA

• Set Nyquist Limit to aliasing velocity of 28 cm/s
• A Radius of > 9mm correlates with severe TR
• 6-9mm moderate TR
• < 5mm, usually with mild TR