Similarities and differences in Tricuspid vs. Mitral Valve Anatomy and Imaging. Echo evaluation of TR severity and procedural guidance for tricuspid interventions

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Attending, Department of Transcatheter Heart Valves
Overview of the atrioventricular valves

Mitral Valve
- Left atrium
- Mitral leaflets
- Mitral annulus
- Chordae and papillary muscles
- Left ventricle

Tricuspid Valve
- Right atrium
- Tricuspid leaflets
- Tricuspid annulus
- Chordae and papillary muscles
- Right ventricle
The Atria

**Left atrium**
- Thicker wall than RA
- Smooth atrial cavity
- Long and narrow trabeculated LAA
- Pulmonary vein orifices

**Right atrium**
- Thinner, more distensible walls
- Crista terminalis
- Wide and blunted RAA
- Orifices of SVC, IVC, coronary sinus (CS)
Tricuspid valve leaflets

• 3 leaflets
• Thinner, more translucent, more fragile compared to mitral
• 3 commissures (*)
• Coaptation zone between
  • septal-anterior
  • septal-posterior
  • anterior-posterior
Mitral Valve Leaflets

- Anterior ("aortic" leaflet) occupies 2/3 of mitral orifice area
- Posterior ("mural" leaflet) attaches to the posterior 3/5 of the annulus
- 3 scallops in posterior (P1 lateral, P2 middle, P3 medial) leaflet with corresponding areas in anterior leaflet (A1-A2-A3)
- 2 Commissures (anterolateral / posteromedial); *single* coaptation zone
Tricuspid valve annulus

- Largest orifice of all valves 7-9cm²
- Contiguity with Koch triangle, RCA (anteroposterior) and aortic cusps
- Annulus attached to only one fibrous trigone (posteromedial)
- Easily distensible with thinner and almost virtual fibrous structure
Changes in Anatomy of the Tricuspid Valve in Functional Tricuspid Regurgitation

Heart 2015;101:1840–1848
Mitral Valve and Adjacent Structures

- AV node
- Coronary sinus
- Left circumflex a.
- Right coronary a.

J Am Coll Cardiol 2010;56:617–26
Mitral and Tricuspid Annulus: Relation with coronary arteries

- Tricuspid annulus in proximity to the right coronary artery
  - Anterior and posterior side
  - Risk during annuloplasty procedures

- Mitral annulus in proximity with the left circumflex
  - In the lateral commissure and P1 region
  - Risk during annuloplasty procedures
Mitral Annulus

- Fibromuscular 3D structure
- Saddle shaped → reduces strain on valve
- Anterior and posterior portions

J Am Coll Cardiol 2010;56:617–26
Anterior Mitral Annulus

• Coupled with aortic annulus

• Attached to 2 fibrous trigones

• More resistant to dilatation
Posterior Mitral Annulus

More muscular with areas of fatty tissue

More susceptible to dilatation and calcification (MAC)

American Heart J 2009;158:887-95
Conduction system (AV node / His bundle)

From right side

From left side
Papillary muscles and chordae

Mitral

Tricuspid
Papillary muscles and chordae

Mitral
• Two papillary muscles
• Thicker more resistant chords
• Extend from papillary muscle heads
• Primary (marginal) to free edges
• Secondary to ventricular surface of leaflets
Papillary muscles and chords

**Tricuspid**
- 3 papillary muscles
- Anterior is the dominant
- Posterior and septal multiple with thinner heads
- Chords thinner, more fragile, single attachment to free edge
- May originate directly from RV wall
Tricuspid commissural chords

• Risk of entrapment and impinging the commissural chordae, once valve is crossed

• Higher risk in the anteroseptal commissural region of the tricuspid valve
Right ventricle and RVOT

- Thinner more distensible walls
- Moderator band and significant trabeculations
- *Tricuspid and pulmonic valve are widely separated*
Left ventricle and LVOT

• Thicker walls than RV

• Absence of moderator band

• Mitral valve is in continuity with the aortic valve
Imaging
Real Time 3-D Imaging of Mitral Valve
Real Time 3-D Imaging of Mitral Valve

Aorta = Anterior
LAA = Lateral
Interatrial septum = Medial
Posterior
Real Time 3-D Imaging of Mitral Valve

Aorta = Anterior

LAA = Lateral

Interatrial septum

A1
A2
A3
P1
P2
P3
“Surgical” view of the tricuspid valve
Orientation in the right atrium for TV interventions

“SURGICAL” VIEW OF THE TRICUSPID VALVE

CADAVERIC HUMAN HEART

EuroIntervention. 2017 Feb 3;12(15):e1825-e1827
Tricuspid Valve: Live 3-D from transgastric short axis
Tricuspid Valve: 3-D from transgastric short axis

Tricuspid valve (diastole) as viewed from the ventricular side
Transesophageal interrogation of the tricuspid valve

Multimodality Tricuspid Valve Imaging

TEE - TRANSGASTRIC SHORT AXIS VIEW

EEG GATED COMPUTED TOMOGRAPHY

3D-TEE MID-ESOPHAGEAL VIEW

LAO FLUOROSCOPIC VIEW

Eur Heart J Cardiovasc Imaging. 2017 Jul 1;18(7):823
Transthoracic MV Interrogation: Parasternal short axis at base
Transthoracic MV Interrogation:
Parasternal short axis at base with Color Flow Doppler

Localization of mitral regurgitation jet origin along the coaptation line

Functional MR jet extending across the coaptation line
Transthoracic MV Interrogation:
Parasternal long axis with color flow

Functional MR jet involving the A2-P2 region
Transthoracic MV interrogation from parasternal long axis view
Transthoracic MV Interrogation: Apical 2-Chamber view – Commissural
### 2D TRANSTHORACIC ECHOCARDIOGRAPHY

#### PARASTERNAL LONG AXIS VIEW OF THE RV INFLOW
- Obtained from the parasternal long axis view by tilting the probe downwards.
- Displays the anterior leaflet and either the septal or posterior leaflet (tilt vertically probe 15° or more from the initial position).

#### PARASTERNAL SHORT AXIS VIEW AT THE AORTIC LEVEL
- Displays the posterior leaflet and either (more often) the septal leaflet attached near the RCA trajet or the anterior leaflet.

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#### RV FOCUSED (MEDIAL)
**APICAL 4 CHAMBER VIEW**
- Obtained from the apical 4C view by tilting the probe to the right towards the sternum.
- Displays anterior and septal leaflet.
- Recommended view for TA diameter measure.

**RV MODIFIED (LATERAL)**
- Obtained from the apical 4C view by moving the transducer laterally.

#### APICAL 4 CHAMBER VIEW FOCUSED ON THE RV
- Obtained by rotating the probe 90° counter-clockwise from the 4C view centered on RV.
- Displays posterior and anterior leaflets.

#### RV SUBCOSTAL 4 CHAMBER VIEW
- Displays anterior and septal leaflets.

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#### RV SUBCOSTAL EN FACE VIEW
- Obtained by rotating the probe 90° counter-clockwise from the subcostal 4C view centered on RV.
- Displays the 3 leaflets in an en face view.
- Displays posterior and septal/anterior leaflets.
- Interesting for the measurement of dilated TA.
Transthoracic Tricuspid Valve
Transthoracic Tricuspid Regurgitation in 3D
Etiology of Tricuspid Regurgitation: Secondary

<table>
<thead>
<tr>
<th>Morphologic Classification</th>
<th>Disease Subgroup</th>
<th>Specific Abnormality</th>
</tr>
</thead>
<tbody>
<tr>
<td>Secondary (‘Functional’) - 75%</td>
<td>Left heart disease</td>
<td>LV dysfunction or valve disease</td>
</tr>
<tr>
<td></td>
<td>Right ventricular dysfunction</td>
<td>RV ischemia</td>
</tr>
<tr>
<td></td>
<td></td>
<td>RV volume overload</td>
</tr>
<tr>
<td></td>
<td></td>
<td>RV cardiomyopathy (eg. ARVD)</td>
</tr>
<tr>
<td>Pulmonary Hypertension</td>
<td>Chronic lung disease</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Pulmonary thromboembolism</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Left-to-right shunt</td>
<td></td>
</tr>
<tr>
<td>Right atrial abnormalities</td>
<td>Atrial fibrillation</td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td>Post-operative</td>
<td>Recurrent TR post-surgical intervention</td>
</tr>
</tbody>
</table>
# TR Severity: CW and PW

<table>
<thead>
<tr>
<th></th>
<th>Mild</th>
<th>Moderate</th>
<th>Severe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tricuspid Inflow</td>
<td>A-wave dominance</td>
<td>Variable</td>
<td>E-wave &gt; 1.0 m/s</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>
</tbody>
</table>

Zoghbi WA et al. JASE 2017
# TR Severity: Color Doppler

<table>
<thead>
<tr>
<th></th>
<th>Mild</th>
<th>Moderate</th>
<th>Severe</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Flow Convergence</strong></td>
<td>Not visible, transient or small</td>
<td>Intermediate size/duration</td>
<td>Large throughout systole</td>
</tr>
<tr>
<td><strong>Central jet area</strong></td>
<td>$&lt; 5 \text{ cm}^2$ (Not defined)</td>
<td>5-10 cm$^2$ (Not defined)</td>
<td>$&gt; 10 \text{ cm}^2$</td>
</tr>
<tr>
<td><strong>Vena contracta</strong></td>
<td>$&lt; 0.3 \text{ cm}$</td>
<td>0.3-0.69 cm</td>
<td>$&gt; 0.7 \text{ cm}$</td>
</tr>
</tbody>
</table>

Color Doppler Flow Mapping (at least 2 orthogonal planes)  

Zoghbi WA et al. JASE 2017
# TR Severity

<table>
<thead>
<tr>
<th></th>
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<th>Moderate</th>
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</tr>
</thead>
<tbody>
<tr>
<td>IVC</td>
<td>Normal &lt;2.0 cm</td>
<td>Normal or mild $\uparrow$ (2.1-2.5 cm)</td>
<td>Dilated &gt;2.5 cm</td>
</tr>
<tr>
<td>Hepatic vein flow</td>
<td>Systolic dominance</td>
<td>Systolic blunting</td>
<td>Systolic reversal</td>
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Zoghbi WA et al. JASE 2017
## TR Severity: PISA

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<th>Severe</th>
</tr>
</thead>
<tbody>
<tr>
<td>PISA radius (shift to 28 cm/s)</td>
<td>≤0.5 cm</td>
<td>0.6-0.9 cm</td>
<td>&gt;0.9 cm</td>
</tr>
<tr>
<td>PISA EROA</td>
<td>&lt; 20 mm²</td>
<td>20-39 mm²</td>
<td>&gt;40 mm²</td>
</tr>
<tr>
<td>PISA RegVol (2D)</td>
<td>&lt;30 cc</td>
<td>30-44 cc</td>
<td>≥45 cc</td>
</tr>
</tbody>
</table>

The shape of the tricuspid regurgitant orifice is often elliptical or stellate which may result in significant underestimation of the ROA by this method.
Grading of severity of tricuspid regurgitation

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Mild</th>
<th>Moderate</th>
<th>Severe</th>
</tr>
</thead>
<tbody>
<tr>
<td>RV</td>
<td>Normal</td>
<td>Normal</td>
<td>Dilated, diastolic septal flattening</td>
</tr>
<tr>
<td>RA</td>
<td>Normal or mild ↑</td>
<td>Normal or mild ↑ (2.1-2.5 cm)</td>
<td>Dilated &gt;2.5 cm</td>
</tr>
<tr>
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<td>Normal or mild ↑</td>
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<td>Not defined</td>
<td>Not defined</td>
<td>&gt;10 cm²</td>
</tr>
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<td>Hepatic vein flow</td>
<td>Systolic dominance</td>
<td>Systolic blunting</td>
<td>Systolic reversal</td>
</tr>
<tr>
<td>Tricuspid Inflow</td>
<td>A-wave dominance</td>
<td>Variable</td>
<td>E-wave &gt;1.0 m/s</td>
</tr>
</tbody>
</table>
### 2D/Doppler Measurements of TR Severity

- Severe TR was present in the presence of a suggestive color Doppler jet and if any one or more of the following combinations of criteria were present:
  - 1) IVC diameter >2.5 cm AND RA area >18 cm² (in the absence of ASE of pulmonic valvular disease);
  - 2) jet area >10 cm² AND vena contracta width >7 mm;
  - 3) systolic flow reversal in the hepatic veins in the absence of AV dissociation, ventricular pacing, or atrial arrhythmia;
  - 4) triangular continuous wave Doppler signal with density equal to or greater than that of tricuspid inflow

<table>
<thead>
<tr>
<th>Criteria diagnostic of Severe Tricuspid Regurgitation*</th>
</tr>
</thead>
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<td>1) IVC diameter &gt;2.5 cm AND RA area &gt;18 cm² (in the absence of ASE of pulmonic valvular disease)</td>
</tr>
<tr>
<td>2) Jet area &gt;10 cm² AND vena contracta width &gt;7 mm</td>
</tr>
<tr>
<td>3) Systolic flow reversal in the hepatic veins in the absence of AV dissociation, ventricular pacing, or atrial arrhythmia</td>
</tr>
<tr>
<td>4) Triangular CW Doppler signal with density equal to or greater than that of tricuspid inflow</td>
</tr>
</tbody>
</table>


Grant AD et al J Am Soc Echo 2014;27(3):277-284

Correlated best with expert-reads and magnetic resonance imaging determined regurgitant volume and fraction (using >48% to define severe) and improved interobserver agreement
TR Quantitation

<table>
<thead>
<tr>
<th></th>
<th>Mild</th>
<th>Moderate</th>
<th>Severe</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>3D Vena</strong></td>
<td>Not defined</td>
<td>Not defined</td>
<td>&gt;40 mm²</td>
</tr>
<tr>
<td><strong>Contracta</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*The Nyquist limit was controlled at 45 to 65 cm/sec for JA/RAA ratio VCW*

The cutoff for 3D VCA (0.36 cm²) was similar to the cutoff for mean of 2D and 3D methods (0.35 cm²), although the latter had better sensitivity and specificity.


From current available data a VCA > 0.4 cm² is a reasonable cutoff value for severe TR. (Zoghbi et al)
3D Color Vena Contracta Area: 2.04 cm²
The need for a new tricuspid regurgitation grading scheme

Rebecca T. Hahn¹ and Jose L. Zamorano²∗

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mild</th>
<th>Moderate</th>
<th>Severe</th>
<th>Massive</th>
<th>Torrential</th>
</tr>
</thead>
<tbody>
<tr>
<td>VC (biplane)</td>
<td>&lt;3 mm</td>
<td>3-6.9 mm</td>
<td>7-13 mm</td>
<td>14-20 mm</td>
<td>≥21 mm</td>
</tr>
<tr>
<td>EROA (PISA)</td>
<td>&lt;20 mm²</td>
<td>20-39 mm²</td>
<td>40-59 mm²</td>
<td>60-79 mm²</td>
<td>≥80 mm²</td>
</tr>
<tr>
<td>3D VCA or quantitative</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EROA</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Evaluation of right ventricular size and function: A critical aspect of tricuspid regurgitation

<table>
<thead>
<tr>
<th>(A) Echocardiography</th>
<th>Abnormal</th>
</tr>
</thead>
<tbody>
<tr>
<td>RV diameter (mm)</td>
<td></td>
</tr>
<tr>
<td>Base*</td>
<td>&gt;41</td>
</tr>
<tr>
<td>Midventricular level*</td>
<td>&gt;35</td>
</tr>
<tr>
<td>Length*</td>
<td>&gt;83</td>
</tr>
<tr>
<td>RV wall thickness (subcostal view) (mm)</td>
<td>&gt;5</td>
</tr>
<tr>
<td>RA end-systolic area (mm²)</td>
<td>&gt;18</td>
</tr>
<tr>
<td>RA volume (mL/m²)</td>
<td>&gt;30</td>
</tr>
<tr>
<td>Systolic function</td>
<td></td>
</tr>
<tr>
<td>TAPSE (mm)</td>
<td>&lt;17</td>
</tr>
<tr>
<td>Pulsed Doppler peak S’ (m/s)</td>
<td>&lt;9.5</td>
</tr>
<tr>
<td>RV fractional area change (%)</td>
<td>&lt;35</td>
</tr>
<tr>
<td>RV 3D EF (%)</td>
<td>&lt;45</td>
</tr>
<tr>
<td>Diastolic function</td>
<td></td>
</tr>
<tr>
<td>E/E’ ratio</td>
<td>&gt;6</td>
</tr>
<tr>
<td>Tissue Doppler MPI</td>
<td>&gt;0.54</td>
</tr>
</tbody>
</table>

Transcatheter Options for Tricuspid Valve Repair

**ANNULOPLASTY**
- Cardioband
- TriAlign
- Tricinch

**EDGE TO EDGE**
- MitraClip
- Pascal

**VALVE IN VALVE / RING**
- Sapien
- Melody

**TRANSCATHETER TRICUSPID VALVE IMPLANTATION**
- NaviGate Valve

**SPACER IMPLANTATION**
- Edwards FORMA

**CAVAL VALVE IMPLANTATION (CAVI)**
Transcatheter Options for Tricuspid Valve Repair

• Most devices are in early feasibility trials, some have progressed to CE mark trials
• Patient population commonly high risk, inoperable patients with functional tricuspid regurgitation, often massive or torrential TR, with advanced heart failure
• All devices require MULTIMODALITY imaging (TTE, TEE, 3D/4D, cardiac CT with reconstructions, occasionally 3D printing)
• Encouraging results in short term, however long term efficacy and survival advantage remain to be seen
Interventional Tricuspid Valve Therapies: The TriValve Registry
**2D Transeosophageal Echocardiography**

<table>
<thead>
<tr>
<th>MID-ESOPHAGEAL 4 CHAMBER (0-30°)</th>
<th>RV-FOCUSED MID-ESOPHAGEAL 4 CHAMBER (0-30°)</th>
</tr>
</thead>
<tbody>
<tr>
<td>- probe is turned to the right until the TV is seen</td>
<td>- Flex right the transducer to place the right ventricle in the center of the image</td>
</tr>
<tr>
<td>- displays anterior and septal leaflets</td>
<td>- displays anterior and septal leaflets</td>
</tr>
<tr>
<td>- recommended view for TA diameter measure</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>MID-ESOPHAGEAL RV INFLOW-OUTFLOW VIEW (60-90°)</th>
<th>LOW-ESOPHAGEAL RV VIEW (90-150°)</th>
</tr>
</thead>
<tbody>
<tr>
<td>- multiplane angle is then rotated forward to 60-90° to develop the aortic short axis view</td>
<td>- obtained from the bicaval view by pushing slightly the probe</td>
</tr>
<tr>
<td>- displays posterior and either anterior (more frequently) or septal leaflets</td>
<td>- displays anterior and posterior leaflets</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>TRANSFASTRIC RV BASAL SHORT AXIS (0°-30°)</th>
<th>TRANSFASTRIC RV INFLOW (100-120°)</th>
</tr>
</thead>
<tbody>
<tr>
<td>- probe is slightly withdrawn toward the base of the heart until the TV is in the center and multiplane angle is rotated to around 30°</td>
<td>- multiplane angle is rotated to 100° until the apex of the RV appears on the left</td>
</tr>
<tr>
<td>- displays en face view with the 3 TV leaflets</td>
<td>- displays posterior and anterior leaflets</td>
</tr>
<tr>
<td></td>
<td>- provides the best images of the subvalvular apparatus</td>
</tr>
</tbody>
</table>
Transesophageal interrogation of the tricuspid valve
Fusion Imaging (3D-Echo with Fluoroscopy) for Edge-to-Edge repair with Mitraclip
Intra-cardiac Echo (ICE) for Tricuspid Edge-to-Edge

- Local anesthesia
- SGC via right femoral vein
- 10 Fr ViewFlex™ Xtra ICE probe (St. Jude Medical) via left femoral vein
- Four Mitraclips deployed in anterior-septal commissure under clear visualization with ICE
- TR reduction to moderate
Imaging for the FORMA Spacer
Animation

Edwards FORMA Repair System
In Summary

- Tricuspid valve transcatheter interventions are evolving
- Complex anatomy with inherent difficulties in imaging
- Multimodality approach in evaluation and procedural guidance
  (fusion imaging, intracardiac echocardiography)
“Surgical” view of the tricuspid valve
Tricuspid Valve: 3-D Color

(3D from mid-esophageal view)
Tricuspid Valve: 3-D Color

(3D from mid-esophageal view)
3-Dimensional vena contracta area (VCA) of TR jet
FORMA spacer advanced in RV near tip of anchor rail: No entanglement with chords
FORMA SPACER in position