Quantification of Tricuspid Valve Tenting in Patients with Primary Pulmonary hypertension by Transthoracic Real-time 3-dimensional Echocardiography

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Pulmonary Arterial Hypertension (PAH)

- Pulmonary vascular resistance increase
- Pulmonary artery pressure increase
- RV afterload increase
- RV dilatation
- Tricuspid regurgitation (TR)
- RV failure and death
- RV free wall tension increase
- RV hypertrophy
- RV ischemia
- RV output reduce

Parameters of disease severity and prognosis:
- Brain natriuretic peptide (BNP)
- Right atrial (RA) pressure
- Cardiac index (CI)

RV: right ventricular
Severity of Pulmonary Artery Hypertension

The velocity of TR jet provided by Doppler echocardiography can be used to estimate RV or pulmonary artery systolic pressure (PASP).

In patients with PAH complicated severe RV failure,
- cardiac output reduces
- RA pressure increase → RV-RA pressure gradient decrease
  the velocity of TR underestimates PASP.


The Doppler-derived PASP is inaccurate in some patients with PAH.
We need other useful noninvasive parameters to determine the severity of functional TR and RV dysfunction in patients with PAH.
The same geometric changes in Tricuspid Valve (TV) as functional MR (annular dilatation and leaflet tenting), and functional TR occur in patients with PAH, and may affect RV dysfunction and prognosis.
Functional TR appears in patients with PAH resulting from RV dilatation and Geometric changes in TV, and functional TR itself leads to further RV dilatation and RV dysfunction.
Superior Evaluation of Tricuspid Valve Using 3D Echocardiography

- The shape of the tricuspid annulus is not circular but oval.
- The tricuspid valve has three leaflets of unequal size.

2D Echocardiography (2DE) is inadequate for accurate evaluation of TV.

We use 3D Echocardiography (3DE) to evaluate the geometric changes in TV.
Objective

The aim of this study;

(1) evaluate the geometric changes in TV which causes functional TR in patients with PAH using 3DE analysis software quantitatively.

(2) investigate whether or not the geometric changes in TV are associated with the severity of RV dysfunction in PAH patients.
Study Patients

Pulmonary arterial hypertension (Group PAH):

64 patients
14 males, 50 females
mean age ; 34±10 years

Healthy control subjects (Group N):

36 subjects
7 males, 29 females
mean age ; 30±9 years

PAH has been defined as an increase in mean pulmonary arterial pressure ≥25mmHg at rest as assessed by right heart catheterization.

All patients were in sinus rhythm, and had no left heart disease and organic TV disease.
Methods

Two Dimensional Transthoracic Echocardiography (2DE)

iE33 (Philips Medical Systems, Andover, Mass): 2DE scan was performed using S3 probe.

- **TR jet pressure gradient** by Doppler echocardiography
- Right ventricular end-diastolic area index ($RVEDAI$)
- Right ventricular end-systolic area index ($RVESA_{AI}$)
- RV fractional area change ($\%RVFAC$)
  \[ = 100 \times \frac{RVEDA - RVESA}{RVEDA} \]
- Right atrial volume index ($RAVI$)
  \[ = \frac{\text{Right atrial volume}}{\text{body mass index}} \]
- the size of the inferior vena cava ($IVC$) and the changes in its size during respiration
Tricuspid Regurgitation (TR)

All patients underwent color doppler echocardiography for an assessment of TR severity, TR severity was graded on a scale from 1+ to 4+, based on the size of the TR jet by color flow imaging.

1+ = mild (including trivial)
2+ = mild to moderate
3+ = moderate
4+ = severe

PASP was calculated as the sum of the peak TR systolic pressure gradient (measured by continuous-wave Doppler echocardiography) and RA pressure. RA pressure was estimated according to the size of the inferior vena cava and the changes in its size during respiration.

Methods

Real-time Three Dimensional Transthoracic Echocardiography (3DE)

iE33 (Philips Medical Systems, Andover, Mass): 3DE scan was performed using X4 probe.

Apical RV full-volume image was acquired.
Methods

Quantitative Analysis of 3D Tricuspid Valve Image

3D analysis software: REALVIEW (YD, LDT, Nara, Japan)

- The tricuspid annulus and the TV leaflet were semi-automatically traced in mid-systole.
- 3D morphology of tricuspid complex was reconstructed, and annular area, tenting volume, maximum tenting length, and 3D tenting surface area were quantified.

**tenting length**: was defined as the distance from the annular plane to the most tethered leaflet site in the 3D data.

**tenting volume**: was calculated as the volume enclosed between the annular plane and tricuspid leaflets.

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All patients underwent right heart catheterization and echocardiography within the same day.

- **Pulmonary artery systolic pressure (PASP)**
- **Right atrial pressure (RAP)**
- **Pulmonary vascular resistance (PVR)**
- **Cardiac index (CI)**
Increased Brain natriuretic peptide (BNP) serum levels reflect severity of RV dysfunction and indicate unfavorable prognosis in patients with PAH. This biochemical maker is an attractive non-invasive tool for assessment and monitoring of RV dysfunction in patients with PAH.

The serum BNP concentration was measured. Natural log (Ln) transformation was performed on BNP values because of skewed distribution.
## Patients Characteristics

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Group PAH</th>
<th>Group N</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number</td>
<td>64</td>
<td>36</td>
<td></td>
</tr>
<tr>
<td>Age (years)</td>
<td>34 ±10</td>
<td>30 ±9</td>
<td>0.07</td>
</tr>
<tr>
<td>Female(%)</td>
<td>50 (78%)</td>
<td>22 (61%)</td>
<td>0.07</td>
</tr>
<tr>
<td>Heart rate (b.p.m.)</td>
<td>81 ±17</td>
<td>66 ±10</td>
<td>&lt;0.01</td>
</tr>
</tbody>
</table>

### 2DE data

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Group PAH</th>
<th>Group N</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>TR pressure gradient</td>
<td>70 ±25</td>
<td>20 ±10</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>RAVI (ml/m²)</td>
<td>49 ±11</td>
<td>11 ±7</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>RVEDAI (cm/m²)</td>
<td>20 ±5</td>
<td>11 ±2</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>RVESAI (cm/m²)</td>
<td>13 ±5</td>
<td>6 ±1</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>%RVFAC (%)</td>
<td>31 ±1</td>
<td>45 ±4</td>
<td>&lt;0.01</td>
</tr>
</tbody>
</table>
Visualization of Analyzed Tricuspid Valve Geometry

**Group N**

- **Annular Area:** 4.40 cm²
- **Annular Circumference:** 75.65 mm
- **Annular Height:** 1.16 mm
- **Maximum tenting length:** 3.70 mm
- **Mean tenting length:** 1.70 mm
- **Tenting volume:** 0.49 cm³
- **Diameter:**
  - AP=25.66 mm
  - ML=22.63 mm

**Group PAH**

- **Annular Area:** 15.47 cm²
- **Annular Circumference:** 148.87 mm
- **Annular Height:** 2.26 mm
- **Maximum tenting length:** 19.56 mm
- **Mean tenting length:** 8.55 mm
- **Tenting volume:** 10.63 cm³
- **Diameter:**
  - AP=47.70 mm
  - ML=41.41 mm
Comparison of Geometric Changes of Tricuspid Valve in Group PAH and Group N

Results
Results

Relation Between TR Severity by Color Doppler Echocardiography and TV Geometric Changes

TV Annular area (cm²)

Maximum tenting length (cm)

Tenting volume (cm³)

*: p<0.01 vs. other groups
**: p<0.05 vs. Group TR3+,4+
**Results**

**Classification of PAH Patients using Appearance of Heart Failure**

- **Group PAH**
  - 64 patients

- **Group PAH-HF**
  - 19 patients
  - Patients with right heart failure (NYHA III or IV)

- **Group PAH-N**
  - 45 patients
## Results

### Patient Characteristics in Two PAH Groups

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Group PAH-HF</th>
<th>Group PAH-N</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>number</td>
<td>19</td>
<td>45</td>
<td></td>
</tr>
<tr>
<td>Age (years)</td>
<td>35±11</td>
<td>35±10</td>
<td>0.88</td>
</tr>
<tr>
<td>Heart rate (b.p.m.)</td>
<td>86±15</td>
<td>79±19</td>
<td>0.06</td>
</tr>
<tr>
<td><strong>2DE data</strong></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>TR pressure gradient</td>
<td>79±27</td>
<td>70±21</td>
<td>0.10</td>
</tr>
<tr>
<td>PASP by Doppler</td>
<td>91±26</td>
<td>80±21</td>
<td>0.05</td>
</tr>
<tr>
<td>RAVI (ml/m²)</td>
<td>70±5</td>
<td>34±5</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>RVEDAI (cm/m²)</td>
<td>23±5</td>
<td>17±4</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>RVESAI (cm/m²)</td>
<td>18±5</td>
<td>11±4</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>%RVFAC (%)</td>
<td>25±2</td>
<td>35±2</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>BNP</td>
<td>342±32</td>
<td>43±28</td>
<td>&lt;0.01</td>
</tr>
</tbody>
</table>
## Results

### Right Heart Catheterization

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Group PAH-HF</th>
<th>Group PAH-N</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pulmonary capillary wedge pressure (PCWP)</td>
<td>9.5 ± 3.6</td>
<td>8.8 ± 3.6</td>
<td>0.520</td>
</tr>
<tr>
<td>Pulmonary artery systolic pressure (PASP)</td>
<td>80.9 ± 19.6</td>
<td>73.2 ± 20.1</td>
<td>0.049</td>
</tr>
<tr>
<td>Right atrial pressure (RAP)</td>
<td>11.3 ± 1.1</td>
<td>6.4 ± 1.0</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Pulmonary vascular resistance (PVR)</td>
<td>14.0 ± 6.4</td>
<td>9.7 ± 6.3</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Cardiac index (CI)</td>
<td>2.1 ± 0.2</td>
<td>3.0 ± 0.2</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>
Results

**Tricuspid Valve Annular Area**

- **Group PAH-HF**
- **Group PAH-N**

- TV Annular area (cm²)

- P<0.001

- r=0.65
  - P<0.01

- r=0.69
  - P<0.01
Results

Correlation among TV Annular Area and BNP, Cardiac Index, and RA Pressure

- $r = 0.444$, $p < 0.001$
- $r = 0.424$, $p = 0.002$
- $r = 0.414$, $p = 0.002$
Results

Maximum Tenting Length

Group PAH-HF

Group PAH-N

P<0.001

r=0.74
P<0.01

r=0.71
P<0.01
Correlation among Maximum Tenting Length and BNP, Cardiac Index, and RA Pressure

Results

\[ r = 0.565 \quad P < 0.001 \]

\[ R = -0.348 \quad p = 0.014 \]

\[ r = 0.514 \quad P < 0.001 \]
Tenting Volume

Group PAH-HF

Group PAH-N

P<0.001

r=0.72
P<0.01

r=0.76
P<0.01
Correlation among Tenting Volume and BNP, Cardiac Index, and RA Pressure

- $r = 0.606$  
P < 0.001

- $R = -0.285$  
$R^2 = 0.050$

- $r = 0.456$  
P < 0.001
Conclusion

Three-dimensional echocardiographic analysis is beneficial in the quantitative evaluation of the geometric changes in TV; such as tricuspid annular dilatation and TV leaflet tenting.

The geometric changes in TV correlate to functional TR and RV dysfunction in patients with PAH. The severity of RV dysfunction progresses according to the increase of geometric changes in TV.

The quantitative evaluation of TV geometric changes can be parameters to determine the severity of RV dysfunction in patients with PAH.
BACKGROUND: Primary pulmonary hypertension (PPH) causes right ventricular dilation with various degrees of tricuspid regurgitation (TR), leading to right heart failure.

OBJECTS: We sought to investigate the geometric changes of tricuspid valve (TV) in patients with PPH using three-dimensional echocardiography (3DE).

METHODS: We performed 3DE using iE33 (Philips Medical Systems, Bothell, WA) in 46 patients with PPH (Group PH) and 22 control subjects (Group N). Using a real-time 3D echocardiographic system, we obtained transthoracic volumetric images (full-volume mode) with the apical view in all the subjects. Eighteen (Group PH-HF) of 46 patients in Group PH were complicated with right heart failure, and other 28 patients (Group PH-N) were not complicated. TV images were analyzed using 3D analysis software system (REAL VIEW, YD, NARA). The 3D images of the leaflets and annulus were reconstructed for the quantitative measurements.

RESULTS: Annular area of TV (12.2 ± 2.9cm² vs. 8.4 ± 2.5 cm², p <0.0001) and tenting volume (3.9 ± 2.0cm² vs. 1.2 ± 0.9 cm² , p <;0.0001) were larger in Group PH than Group N. Maximum tenting length was longer in Group PH than Group N (10.3 ± 4.0 mm vs. 5.8 ± 1.9 mm, p < 0.0001). Maximum tenting length was longer (12.9 ± 0.8 mm vs. 8.3 ± 0.6 mm , p <0.0001), and tenting volume (5.1 ± 2.3cm² vs. 2.6 ±1.2 cm² , p <0.0001) was larger in Group PH-HF than Group PH-N. In patients with PPH, Maximum tenting length (r=0.580, p <0.001) and tenting volume (r=0.570, p <0.001) had closely correlation with BNP.

CONCLUSIONS: 3DE was useful for evaluate the geometric changes causes TR and cardiac dysfunction in PPH patients. The geometric changes, especially tethering of TV affect the severity of RV failure.