22nd Annual Conference of the Saudi Heart Association
Riyadh, Saudi Arabia

Echocardiographic Evaluation of Right Ventricular Function in Congenital Heart Disease

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No Disclosures
Assessment of RV Function

Objectives

- Review common non-invasive methods of RV functional assessment
  - 2-dimensional & 3-dimensional imaging
  - Doppler-derived indices
- Advantages & limitations of quantitative RV assessment
- Emerging techniques to improve functional assessment of RV performance
Right Ventricular Function

Background

• Knowledge of RV function lags behind LV

• Increased recognition of importance of RV dysfunction in CV disease

• Challenges in the quantitative assessment of RV structure & function

• Publications (to present)
  • LV function (23,769)
  • RV function (2,927)

Redington A, Cardiol Clin 2002
Right Ventricular Function

Background

- **RV Anatomy & Function**
  - Chamber geometry is complex
    - Inlet (sinus)
    - Outlet (conus)
  - Longitudinal > radial shortening
  - RV - LV interactions
    - Shared wall → IVS
    - Mutually encircling epicardial fibers
    - Share pericardial space
Right Ventricular Function

Background

- **RV Physiology**
  - RV cardiac output = LV cardiac output
  - Very different vascular beds
  - RV external work is 25% of LV work
  - Different pressure - volume relationships
    - RV is very efficient system
    - Critically dependent upon low hydraulic impedance of normal pulmonary vascular bed
Right Ventricular Function

Background

- LV is a “square wave” pump
- RV performs under different pressure-volume conditions
  - RV ejection very efficient
    - Begins early during pressure rise
    - Occurs beyond development of peak RV pressure
    - Continues as RV pressure falls

Redington A, Cardiol Clin 2002
Right Ventricular Function
Echocardiographic Assessment

- Unique challenges with morphologic RV
  - Geometry
  - Anatomic location
  - Different hemodynamics compared to LV
    - Beat-to-beat changes with respiration
    - Pulmonary vs systemic vascular bed
  - Right - left heart interaction
Evaluation of Ventricular Function

Congenital Heart Disease

Challenges in congenital heart disease

• Complex anatomy
• Variable loading conditions
• Regional myocardial function
• RV function as relevant as LV function
Assessment of RV Function
Qualitative Visual Assessment
**Evaluation of Congenital Heart Disease**

**Segmental Approach**

- **Situs & Position**
- **Systemic & Pulmonary Venous Connections**
- **Atrial & AV Connection**
- **Ventricular morphology**
- **VA Connection**
- **Great Arteries**

*Hypoplastic Left Heart*
### Assessment of Left Ventricular Function

#### Segmental Approach

<table>
<thead>
<tr>
<th>LV systolic function</th>
<th>LV global function</th>
</tr>
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<tbody>
<tr>
<td>• LVSF % and LVEF %</td>
<td>• Myocardial</td>
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<tr>
<td>• Stress-velocity index</td>
<td>performance index</td>
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<tr>
<td>• LV dP / dt</td>
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<table>
<thead>
<tr>
<th>LV diastolic function</th>
<th>LV longitudinal function</th>
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<tbody>
<tr>
<td>• Mitral inflow Doppler</td>
<td>• Tissue Doppler</td>
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<td>• Pulmonary venous Doppler</td>
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<td>• Color flow propagation</td>
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<table>
<thead>
<tr>
<th>LV regional function</th>
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<tbody>
<tr>
<td>• Strain and strain rate</td>
<td>Myocardial twist &amp; torsion</td>
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</tbody>
</table>
Assessment of Right Ventricular Function
Segmental Approach

**RV systolic function**
- RV FAC and RVEF %
- RV dP / dt
- TAPSE

**RV diastolic function**
- Tricuspid inflow Doppler
- Hepatic venous Doppler
- RVOT Doppler

**RV global function**
- Myocardial performance index
- 3-D Echo

**RV longitudinal function**
- Tissue Doppler

**RV regional function**
- Strain and strain rate

Cardiac MRI
Evaluation of RV Function

RV Fractional Area & Volume Change

- 2-Dimensional Analysis
  - Single plane method
  - Biplane volume methods
    - Area - length method
    - Simpson’s method
    - A4C + Subcostal 4C
- Limitations = many
  - Geometric
  - Anterior RV free wall
  - Inclusion of RVOT
Assessment of RV Function
3-Dimensional Echocardiography

- **RV Assessment**
  - Volume
  - EDV
  - ESV
  - Stroke volume
  - RV EF %

Courtesy Phillips & G Shirali
Assessment of RV Function
3-Dimensional Echocardiography

**Advantages**
- Quantitative
- Global function
- Incorporates RV inflow & outflow
- No geometric limitations
- Reproducible
- Close correlation with MRI volumes

**Limitations**
- Availability
- Image quality
- Learning curve
- Load dependent
- Regional function
Assessment of RV Function
Doppler Echocardiography

- Challenges in Assessment of RV physiology
  - **Respiratory variation**
    - Doppler measurements ↑ 5-10% with inspiration
      - PA systolic velocity & RVOT gradient
      - TR velocity
      - Tricuspid inflow Doppler
    - Inability to detect small changes in RV status
Assessment of RV Function

RV $dP / dt$

- Rate of rise of RV systolic pressure ($dP / dt$)
  - Velocity curve transferred to pressure gradient curve via modified Bernoulli equation (mean $dP / dT$)
    - LV $> 1200$ mmHg / sec
    - RV $> 400$ mmHg / sec
Assessment of RV Function

RV dP / dt

• **Advantages**
  - Doppler-derived
  - Reproducible
  - Global function
  - Clinical outcome

• **Limitations**
  - Signal quality
  - Signal availability
  - Normal values
  - Load dependent

RV dP / dt = 640 mmHg / sec
Evaluation of RV Function
Visual RV Function

8 yo critical PS s/p RVOT reconstruction
Assessment of RV Function

RV Fractional Area & Volume Change

RV FAC = 42%
Assessment of RV Function

RV Diastolic Function

Forward flow with atrial systole
Assessment of RV Diastolic Function
Doppler Echocardiography

- Assessment of RV physiology - Challenges
  - RV is an “open” system in diastole
    - Restrictive RV → conduit
    - Antegrade diastolic forward flow into PA during atrial systole
Assessment of RV Function

Myocardial Performance Index

- **Doppler-derived index**
- Ratio of total time spent in isovolumic activity divided by the time spent in ventricular ejection
- **Increasing values** of the MPI indicate worsening global ventricular function
- MPI has high correlation with cath invasive measurements (+) dP/dT, (-) dP/dT, tau
- Correlation with outcome

\[
\text{MPI} = \frac{a-b}{b} = \frac{(\text{ICT} + \text{IRT})}{\text{ET}}
\]
Assessment of RV Function
Myocardial Performance Index (n=243)

- Clinical Outcome
  - LV dysfunction
    - DCM / HCM / ICM
    - AMI
  - Amyloidosis
  - Valvar diseases
  - Systemic diseases
  - OHT rejection
- RV dysfunction
  - Pulmonary hypertension
  - Pulmonary embolism
  - Systemic diseases

- Clinical Outcome
  - Congenital heart disease
    - Ebstein anomaly
    - ASD, PS
    - D-TGA, CC-TGA
    - TOF, VSD
  - Acquired heart disease
    - Anthracyclines
  - Fetal heart disease
    - CHF, ductal constriction
  - Functional class
  - Exercise performance
  - Response to medical & surgical therapy
Assessment of RV Function
Myocardial Performance Index

- **Normal LV Values**
  - Fetal: 0.36 +/- 0.06
  - Peds: 0.35 +/- 0.03
  - Adult: 0.39 +/- 0.05

- **Normal RV Values**
  - Fetal: 0.35 +/- 0.05
  - Peds: 0.32 +/- 0.03
  - Adult: 0.28 +/- 0.04
Assessment of RV Function
Myocardial Performance Index

- **Advantages**
  - Doppler-derived
  - Simple to perform
  - Reproducible
  - Non-geometric
  - Global function
  - Clinical outcome

- **Limitations**
  - Non-simultaneous acquisition
  - Rhythm
  - Load dependent
  - HR, age, BSA dependent
  - Non-specific
    - Systole vs diastole
    - Pseudo-normalization
Evaluation of Ventricular Function

New Modalities

Tissue Doppler

Strain & strain rate imaging
Tissue Doppler Imaging

Systole

Peak systole

IVC

IVRT

Diastole

E

A

20 cm/s

20 cm/s
Pulsed Wave Tissue Doppler
Longitudinal Velocities

Lateral mitral annulus

Septal annulus

Tricuspid annulus
Assessment of RV Function

Tissue Doppler (n = 9,491)

- Clinical Outcome
  - LV dysfunction
    - HCM / DCM / ICM / LVNC
    - Hypertension
    - Rhythm disorders
    - Amyloidosis
    - Valvar diseases
    - Systemic diseases
    - OHT rejection
    - Obesity
  - RV dysfunction
    - Pulmonary hypertension
    - ARVD
    - Pulmonary fibrosis
    - Sleep apnea
    - Systemic diseases

- Clinical Outcome
  - Congenital heart disease
    - ASD / VSD / PDA
    - Valvar diseases
    - D-TGA, CC-TGA
    - UVH
    - Post op CHD
    - Eisenmenger / ACHD
  - Fetal heart Disease
    - CHF
    - Hydrops / Extracardiac
  - Exercise Performance
  - Post-operative Outcome
  - Loading Conditions
    - Preload
    - Afterload
Assessment of RV Function

Tissue Doppler

**Advantages**
- Doppler-derived
- Quantitative
  - Systolic
  - Diastolic
- Myocardial
- Less load dependent
- Longitudinal & radial function
- Early identification of RV dysfunction
- Clinical outcome

**Limitations**
- Angle dependent
- Load dependent
- Cardiac tethering
- Cardiac translation
Strain Rate Imaging

Velocities

Natural Strain Rate

Natural Strain

\[ \Delta r \]

\[ v_1 \]

\[ v_2 \]

Calculate spatial gradient

Integrate temporally

Strain (rate) estimation = velocity estimation + post processing
Strain Rate Imaging
Longitudinal Function

- Shortening
- Lengthening

Peak systolic strain rate

Peak systolic strain

Strain rate (sec\(^{-1}\))

Strain (%)

SYS
DIAST
Strain Rate Imaging
Postoperative Tetralogy of Fallot

- Variable degree of pulmonary regurgitation
- Can lead to RV dilatation and dysfunction
- Pulmonary valve replacement ??
Tetralogy of Fallot

RV Longitudinal Function

Velocity (cm/s)

Strain rate (s⁻¹)

Strain (%)

Normals

TOF

*P<0.001

Weidemann F: AJC, 2002
Effect of PR on Strain & SR

Strain RV base (%)

PR fraction (%)  0  20  40  60  80

Strain rate RV base/sec

PR fraction (%)  0  20  40  60  80

Eyskens B et al: AEPC, 2004

$r=-0.53$  $P<0.001$

$r=-0.35$  $P<0.01$
Assessment of RV Function
Strain & Strain Rate Imaging

• Advantages
  • Doppler-derived
  • Quantitative
    • Systolic
    • Diastolic
  • Myocardial
  • Less load dependent
  • Longitudinal & radial function
  • Early identification of RV dysfunction
  • Clinical outcome

• Limitations
  • Angle dependent
  • Load dependent
  • Aliasing
  • High frame rates
  • Data analysis
Evaluation of Ventricular Function

Speckle Tracking
Evaluation of Systemic RV Function
Pressure - Volume Relationship

RV Pressure - Volume Loop
LV Pressure - Volume Loop

Redington A, Cardiol Clin 2002
Evaluation of Systemic RV Function
Strain & Strain Rate

- Systemic RV
  - Circumferential > longitudinal RV strain
  - Similar to normal LV strain pattern

Petterson E, JACC 2007
Evaluation of Systemic RV Function
Ventricular Rotation & Torsion in D-TGA

- **Normal LV & RV**
  - Clockwise rotation of base
  - Counterclockwise rotation of apex

- **Systemic RV**
  - Absence of rotation
  - Absence of torsion

- **Sub-pulmonary LV**
  - ↓ rotation
  - ↓ torsion

Petterson E, JACC 2007
Evaluation of Systemic RV Function
Ventricular Rotation & Torsion in D-TGA

- **Systemic RV Function**
  - **Adaptive changes in systemic RV**
    - Shift from longitudinal $\rightarrow$ circumferential shortening (not RV “dysfunction”)
    - $s_{RV} \rightarrow L V$ deformation pattern
  - **Myocardial dysfunction in systemic RV**
    - $\downarrow$ strain rate
    - Absence of twist & torsion
    - $\downarrow$ compensatory RV - LV interaction

Petterson E, JACC 2007
Assessment of RV Function
Cardiac MRI

Gold Standard
Assessment of RV Function

Cardiac MRI

Post-operative Tetralogy of Fallot
Assessment of RV Function
Cardiac MRI

- **Advantages**
  - Non-geometric
  - Quantitative global function
    - RV EF %
    - Gold standard
  - Reproducible
  - Clinical outcome
  - Emerging capabilities
    - Regional function
    - Shunt calculation
    - Regurgitant volume

- **Limitations**
  - Availability
  - Cost
  - Patient issues
    - Metallic devices
  - Access / portability
# Assessment of RV Function

## Summary

<table>
<thead>
<tr>
<th>Method</th>
<th>Available</th>
<th>Ease of Use</th>
<th>Reliability</th>
<th>Outcome</th>
<th>Regional Function</th>
<th>Loading Condition</th>
<th>Overall</th>
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<tbody>
<tr>
<td>2D FAC</td>
<td>+++</td>
<td>+</td>
<td>+</td>
<td>++</td>
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Assessment of Right Ventricular Function
Segmental Approach

**RV systolic function**
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- 3-D Echo
- RV dP / dt

**RV diastolic function**
- Tricuspid inflow Doppler
- Hepatic venous Doppler
- RVOT Doppler

**RV global function**
- Myocardial performance index

**RV longitudinal function**
- Tissue Doppler

**RV regional function**
- Strain and strain rate
- Twist & Torsion

Serial Evaluation