Tissue Doppler Imaging in Congenital Heart Disease

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“The potential advantage of ultrasound cardiography is to permit the study of the soft tissues without catheterization and the introduction of contrast media. With regard to cardiovascular diagnosis the method is still in the stage of research.”

from 1/2 page on ultrasonic cardiography in chapter-
“Phonocardiography and other graphic methods”

Friedberg, Diseases of the Heart, 1966
What is TDI?

Quantitative Tissue Doppler Imaging
What is the Principle of TDI?

- TDI is based on the difference between signals returned from blood and tissue.

- It filters out the high velocity, low amplitude signals, leaving the tissue motion information visible. (low velocity, high amplitude)

- The familiar color coding of color Doppler signals:
  - red-to-yellow scale: tissue movement towards the transducer
  - blue-to-green scale: movement away
  - red and blue --- low velocities
  - yellow and green --- high velocities
LV  Longitudinal Shortening

2D

Diastole

Systole
Why do TDI exam in Apical View?

70% of fibers are longitudinal!
Tissue Doppler Echocardiography

- Simple, non-invasive and reproducible method for assessing cardiac physiology.
- Provide a velocity value for every point in the myocardial wall.
- Assessing wall motion not only regionally, but also quantitatively.
- This may afford the opportunity to study regional systolic and diastolic function.
Where can TDI be used?

- Quantify myocardial velocities in multiple segments of the myocardium from different echocardiographic windows
- Accurate estimate of LV relaxation
  - Insensitive to the effects of preload compensation
- Potential to assess regional systolic and diastolic function in both LV and RV
- Diastolic regional change is an early marker of ischemia (regional isovolumic relaxation time obtained by DTI)
  --- before the development of regional systolic dysfunction
How is Tissue Doppler displayed?

**Color B-scan** : the best overall impression
provide good view of a heart chambers and walls
frame rate limitations:
maximum frame rate 30 –90 frames/s

**M-mode** : dramatically improves time resolution
sampling is only performed on a single line
such a line– positioned on a clinically significant position

**PW analysis** :
produces the maximum amount of information
highest temporal and velocity range resolution
Conventional Doppler vs TDI

Conventional Doppler
- velocity and direction of blood flow (RBC)

Tissue Doppler
- velocity and direction of myocardial tissue

Blood: Mitral Flow  Tissue: MV Ring Motion
Tissue Doppler in M-mode
Advantages of Color M-mode

- better temporal resolution of systolic diastolic velocity
  high frame rate obtained with M-mode

- represent in the same image
  both systolic diastolic velocities

- accurate quantitative information about myocardial motion
  during the cardiac cycle
- accurately assess in one scan plane the different phases
  of the cardiac cycle
What is the Limitation of TDI?

- The Angle dependency
- The agreement between pulsed and color Doppler derived velocities has not been systematically studied. ---- pulsed Doppler derived velocities are higher.
- Sometimes difficult to distinguish whether the lack of color due to akinesia or to uncontrolled technical factors
- The Tethering effect
The assessment of ventricular function

TDE has the potential to assess
- segmental systolic and diastolic function in both LV and RV

- transmural velocity gradient
- asynchronous ventricular contraction and relaxation visualized online
- global and regional systolic and diastolic time interval
The amount of color in an image can be increased by:
- increasing the Doppler tissue imaging or color Doppler gain
- modifying the depth gain to take away some of the underlying gray scale image
- increasing the gate size
- using lower filter settings
- decreasing the scale
- adjusting the ROI size
- changing the transducer position or orientation

* Gain settings must be carefully adjusted to obtain the most homogeneous non-saturated color filling.
Myocardial Tissue Velocity

Normal heart: endocardium moves faster than epicardium during myocardial contraction because of the change of wall thickness. Myocardial velocities are highest in the base of the heart and decrease toward the apex, with reversal in apical area.

The velocity gradient between the endo and epicardium is an indicator of the regional myocardial contraction. --- decrease in the velocity gradient should be expected in infarcted myocardium when compared to a normal one.

\[ G = \frac{(V_{endocardium} - V_{epicardium})}{W \cos \theta} \]
Myocardial Tissue Velocity
Myocardial Tissue Velocity
Parasternal long axis view
Myocardial Tissue Velocity
Tissue Doppler Velocity & Strain Rate

Tissue Velocity

Strain Rate

[v_1, v_2, v_1, v_2] [m/s]

[SR_1, SR_2, SR_1, SR_2] [1/s]

Expand

No deformation

Contract
Tissue Doppler Velocity

Longitudinal Velocity

Velocity

Time

Systole

Diastole

IVC

IVR

E

A
Tissue Tracking (Displacement)

Velocity Time Integral (VTI) = Systolic Displacement
Tissue Tracking = Color Coded Systolic Displacement
Strain Rate: Rate of Deformation (Spatial velocity gradient)

\[ \text{Strain Rate} = \frac{v_2 - v_1}{\Delta x} \]
Strain - Local Deformation

Strain Rate

Strain

Time

IVC

IVR

E

A
Color encoding based on tracked motion
Longitudinal Displacement and Strain during the Systolic phase

Displacement = 0 mm

Strain Rate

Deformation = 0 %
Longitudinal Displacement and Strain during the Systolic phase

Displacement = 6 mm

Deformation = 10 %

Systole

Diastole

Velocity

Strain Rate
Longitudinal Displacement and Strain during the Systolic phase

Displacement = 12 mm

Deformation = 20 %
TDI, TT, SRI, Strain imaging & Profile
TDI, Tissue tracking imaging
Displacement
TDI Curved Anatomical M-mode

Curved Anatomical M-Mode

Septum
Apex
Lateral Wall
NORMAL
CAMM: Apex Post systolic thickening
CAMM: Strain rate imaging

Normal

Apical akinesia

Apical dyskinesia

Tissue Synchronization Imaging
Using Tissue Doppler to Map Synchrony

TSI does this calculation for every piece of myocardium and displays time-to-peak
**Parametric Imaging**

- **TVI** - Tissue Velocity Imaging
  Measures Myocardial Long. Velocity [m/sec]

- **TTI** - Tissue Tracking Imaging
  Measures Myocardial Longitudinal Displacement [mm]

- **TSI** - Tissue Synchronization Imaging
  Measures Timing; Time-to-Peak Systolic Velocity [msec]

- **SI** - Strain Imaging
  Measures Myocardial Longitudinal Deformation [%]

**Advance Applications**

TVI, TTI, TSI, Strain…
Clinical Application

Functional assessment in Congenital Heart disease

- s/p ASD device closure
- Aortic Stenosis
- RV function in TOF
- Diastolic dysfunction
- Ventricular function in Fontan physiology
- Etc.
Strain Rate vs Strain - longitudinal

\[ SR = \frac{V_1 - V_2}{L} \]

\[ \varepsilon_s = \int_{t_0}^{t} SR \, dt \]

Peak systolic SR

Systolic strain
Longitudinal motion and deformation in RV with TOF
Strain Rate vs Strain - radial
Peri-patch regional myocardial function in VSD repair

Eun, AHA 2002
Peri-patch regional myocardial function in VSD repair

Eun, AHA 2002
<table>
<thead>
<tr>
<th></th>
<th>Peripatch</th>
<th>Remote region</th>
<th>p-value</th>
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<td><strong>Longitudinal</strong></td>
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<tr>
<td>$SR_{ES}$</td>
<td>-3.79±3.19</td>
<td>-5.33±4.17</td>
<td>&lt;0.05</td>
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<tr>
<td>$SR_{ED}$</td>
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<td>$\varepsilon$</td>
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<td>$SR_{LD}$</td>
<td>-3.63±3.36</td>
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<td>$\varepsilon$</td>
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<td>$\varepsilon$ peak</td>
<td>19.02±16.36</td>
<td>37.27±28.37</td>
<td>&lt;0.0001</td>
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</table>

*Eun et al. AHA 2002*
### Table 2. Time to Strain parameters in VSD patients

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<td>$\varepsilon$ peak</td>
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_Eun et al. AHA 2002_
Tissue velocity in Normal vs RV dysplasia
Tissue velocity in Normal vs RV dysplasia

Conventional and TDI velocity

\[ \frac{E}{E_a} : \text{strong relation to invasively measured PCWP} \]

## Tissue Velocities in normal children by age group

<table>
<thead>
<tr>
<th>Age group</th>
<th>N</th>
<th>E'-wave velocity</th>
<th>A'-wave velocity</th>
<th>S'-wave velocity</th>
<th>ICT</th>
<th>IRT</th>
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<td>9.7 ± 3.3</td>
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<td>77.4 ± 18.4</td>
<td>57.0 ± 14.8</td>
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<td>(8.8-10.5)</td>
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<td>1-5 y</td>
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<td>15.1 ± 3.4†</td>
<td>6.5 ± 1.9</td>
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<td>76.9 ± 15.9</td>
<td>62.1 ± 13.2</td>
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<td>(14.3-15.4)</td>
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<td>6-9 y</td>
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### Tissue Velocities in normal children by age group

**Table 2** Pulse wave Doppler tissue velocities and time intervals in healthy children by age group

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<th>N</th>
<th>E'-wave velocity</th>
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<td>17.1 ± 4.0†</td>
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<td>(12.6–13.4)</td>
<td>(85.6–90.8)</td>
<td>(57.0–60.9)</td>
<td>(3.6–4.0)</td>
<td></td>
</tr>
</tbody>
</table>

*A*, Late diastolic velocity; *A’*, late diastolic annular velocity; *ICT*, isovolumic contraction time; *E*, early diastolic inflow Doppler velocity; *E’*, early diastolic annular velocity; *IRT*, isovolumic relaxation time; *S*, systolic velocity; *S’*, systolic annular velocity.

*P < .05; †P < .01 compared with preceding age group.

Data expressed as mean ± SD (95% confidence interval). Doppler tissue imaging velocities are expressed in cm/s. Time intervals are expressed in milliseconds.

**Eidem et al, J Am Soc Echocardiogr. 2004, Vol 17 (3) 212 – 221.**
TDI in Normal children

Eun, ACC 2004
TDI in Heart Transplant patient

Eun, ACC 2004
TDI in Heart Transplant patient

Grade 2b Rejection

Eun, ACC 2004
TDI in Heart Transplant patient

Eun, ACC 2004
TDI in Heart Transplant patient

Grade 2b Rejection

Eun, ACC 2004
TDI in Heart Transplant patient

Eun, ACC 2004
The myocardial performance index (Tei index) by TDI

--- > Tei can also be obtained by TDI.

• Simple and noninvasive measurement for assessing global right ventricular (RV) function

• Sensitive indicator of RV function promising new means - global RV function with PR

Myocardial Acceleration during Isovolumic Contraction (IVA)

AT : Acceleration time of myocardial velocity during isovolumic contraction
IVV : peak myocardial velocity during isovolumic contraction
Myocardial Acceleration during isovolumic contraction (IVA)
Myocardial Acceleration during isovolumic contraction (IVA)

a new index of right ventricular contractile function

--- unaffected by ventricular shape or loading conditions

--- assess RV contractile function for patients with repaired TOF and various degrees of PR

Clinical Application

Congenital Heart disease
- pre-operative assessment
- post-operative assessment

Acquired Heart disease
- Myocarditis
- Other infection
- Kawasaki disease
- Diastolic dysfunction
- Systolic dysfunction
- Heart failure