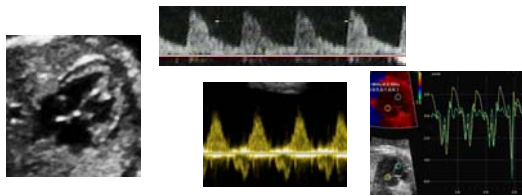


## Advanced Fetal Cardiac Doppler



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 Children's National Medical Center



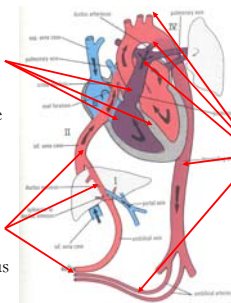
## Why Doppler?

- ♥ Physiologic and functional assessment
  - Assessment of blood flow
    - Across valves
      - » Stenosis
      - » Regurgitation
    - In vessels
      - » Direction of flow (backwards is never good)
      - » Velocity
      - » Vascular reactivity
    - In fetal shunt pathways- Predicts postnatal care
      - » Ductus arteriosus- Reversed flow: ductal dependent pulmonary flow
      - » Foramen ovale/aorta- Reversed flow: ductal dependent systemic flow
  - Assessment of cardiac rhythm
  - Assessment of heart function

## Fetal Doppler

### Cardiac Doppler

1. Inflows
2. Outflows
3. Doppler tissue imaging



### Arterial Doppler

1. Ductus Arteriosus
2. Pulm Arteries
3. Aorta/ Isthmus
4. Cerebral
5. Umbilical

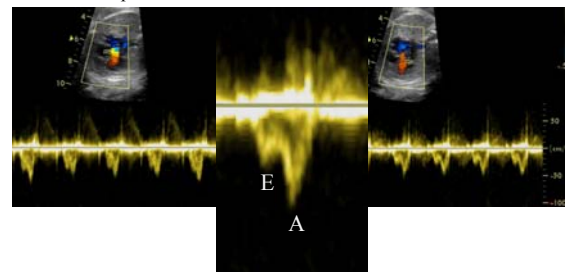
### Venous Doppler

1. Umbilical
2. Ductus Venosus
3. IVC
4. Hepatics

## Doppler Inflows

### Tricuspid Valve

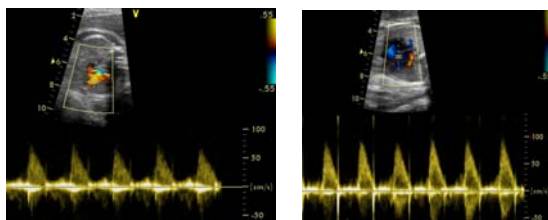
### Mitral Valve



## Doppler Outflows

### Pulmonary Valve

### Aortic Valve



## Diagnosis of Valve Disease

### ♥ Valve gradient

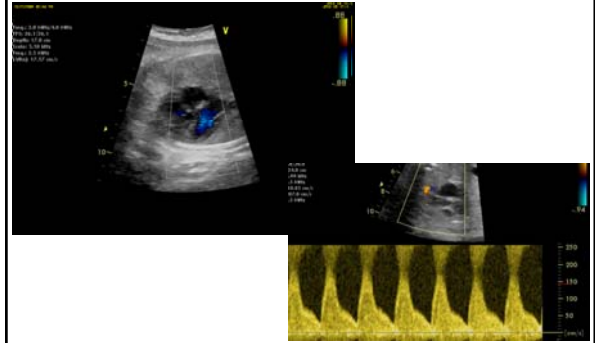
- $P = 4v^2$  (modified Bernoulli equation)



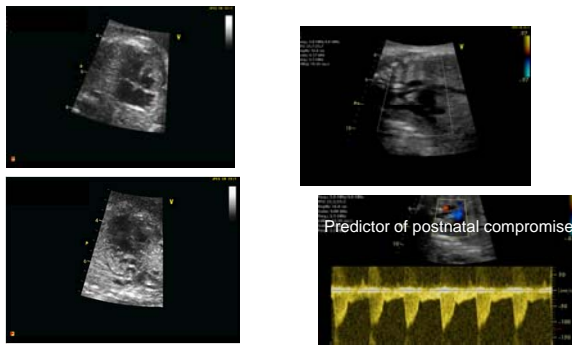
## Ductus Arteriosus Doppler



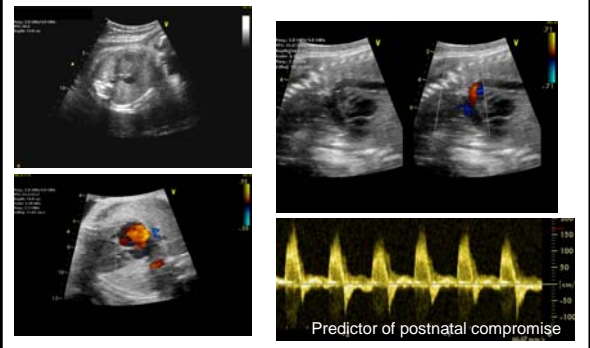
## Ductal Restriction



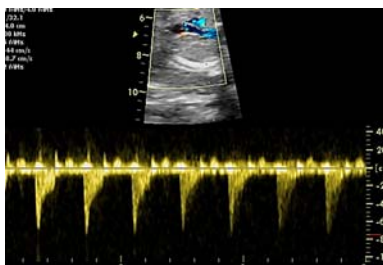
## Ductus Arteriosus Doppler in Tetralogy of Fallot



## Ductus Arteriosus Doppler in Transposition of the Great Arteries



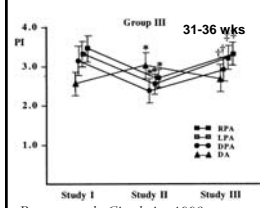
## Branch PA Doppler



## Pulmonary Reactivity

### ♥ Pulmonary Circulation In-Utero

- High PVR limits pulmonary blood flow (10-20% CCO to lungs)
- PVR very sensitive to oxygen in the 3rd trimester



Rasanen et al. Circulation 1998

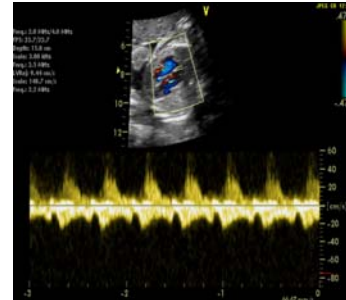
### ♥ Pulmonary Reactivity Test

- Maternal delivery of 60% humidified O<sub>2</sub> via facemask (hyperoxia)
- 20-26 weeks: no change
- 31-36 weeks:
  - MPA, RPA, LPA resistance decreased
  - DA resistance increased
  - Q<sub>p</sub> increased

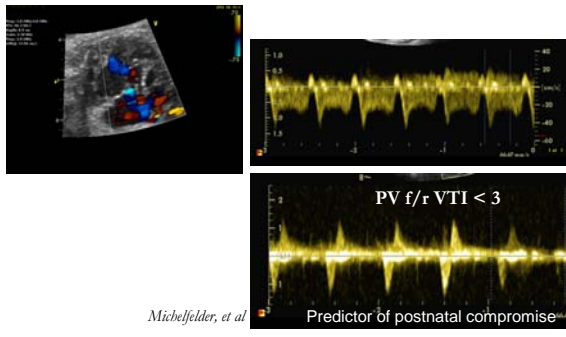
## Pulmonary Reactivity Testing in High Risk Fetuses

- ♥ Study of fetuses at risk for lung hypoplasia *Broth, 2002*
  - CDH                    - Skeletal dysplasia
  - Renal disease       - Twin-twin
  - CCAM                - Pleural effusion
- Results:
  - 52% reactive
    - » only 1 death
  - 48% non-reactive
    - » 79% with a non-reactive test died
- Prediction of neonatal death- sensitivity 92%, specificity 82%
- ♥ Study of fetuses with HLHS *Szyvas, 2009*
  - HLHS with open atrial septum vs. restrictive or intact atrial septum
- Prediction of intervention- sensitivity 100%, specificity 94%

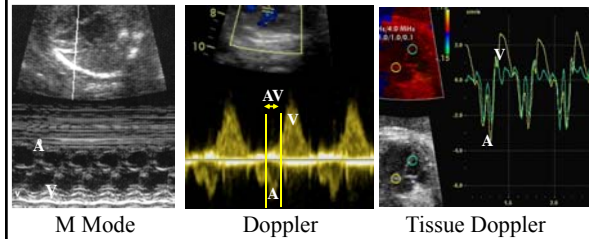
## Pulmonary Vein Doppler



## Pulmonary Vein Doppler in HLHS



## Doppler Assessment of Rhythm

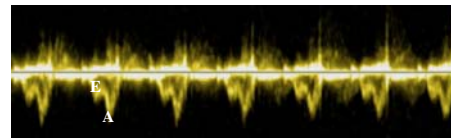


## Doppler Assessment of Heart Function

- ♥ Inflow
- ♥ Outflow
- ♥ Tei or MPI index
- ♥ CVP score
  - Venous Doppler
  - Arterial Doppler

## Doppler Inflows

- ♥ Tricuspid and Mitral Valves
  - Assessment of diastolic function
    - E- passive filling, A- active filling
    - A>E wave through gestation
    - E/A~ 0.6 mid gestation; 0.8 late gestation



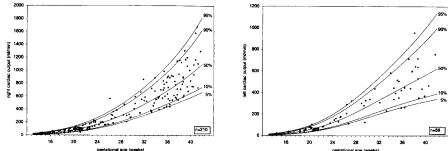
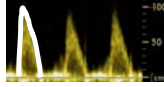
*Reed, et al*

## Doppler Outflow

### ♥ Pulmonary and Aortic Valves

- Stroke Volume/ Cardiac Output
- $CO = HR \times VTI \times CSA$  ( $CSA = \pi r^2$ )

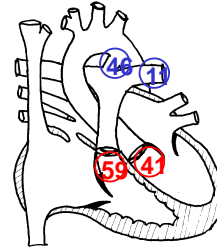
- » Right and left CO increase exponentially throughout gestation
- » Right CO > Left CO through gestation



Mielke et al, Circulation 2001

## Doppler Outflow: Cardiac Output Calculation

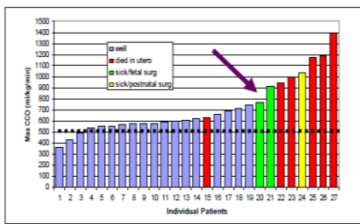
### ♥ % Combined CO calculations



## Cardiac Output in Volume Loaded States

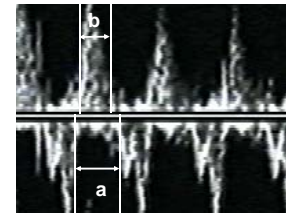
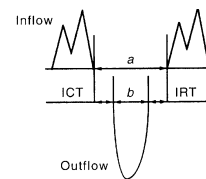
### ♥ Fetuses with volume load evaluated

- SCT
- Cerebral AVM
- Vascularized neck mass
- Teratoma



Rychik, Prog in Ped Cardiol 2006

## Tei Index/ MPI



- Assessment of global heart function
- Increased Tei index represents worse function
- Normal: LV-  $0.36 \pm 0.06$  / RV-  $0.35 \pm 0.05$  (No change with GA)

Eidem et al

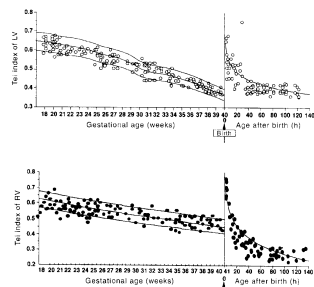
## Tei Index

### ♥ 50 normal fetuses 35 IUGR/30 of DM

#### ♥ Normal:

- No difference between LV and RV
- Gradual decrease from 18 wks to term
- Immediate increase at birth, then a gradual decrease

#### ♥ Abnormal in IUGR and fetuses of DM



Tsutsumi et al, Ped Int 1999

## Tei Index

### ♥ Tei in fetuses exposed to indomethacin Mori

- Abnormal RV Tei in fetuses with ductal restriction
- Improved RV Tei with discontinuation of indomethacin

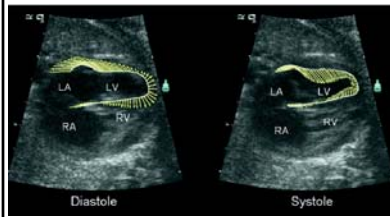
### ♥ Tei in fetuses with heart disease Faulkensammer

- Cardiomyopathy, aortic stenosis, heterotaxy, TTTS, gastroschisis, cystic hygroma (with and without hydrops)
- Abnormal Tei noted in those with hydrops

### ♥ LV Tei in fetuses with TV dysplasia or Ebstein's Inamura

- LV Tei abnormal
  - » IVRT prolonged (diastolic dysfunction)
  - » ET short (possibly due to decreased preload)

## Velocity Vector Imaging



Yonkosani et al. JASE 2008

Strain

$$\epsilon = \frac{l - l_0}{l_0} = \frac{\Delta l}{l_0}$$

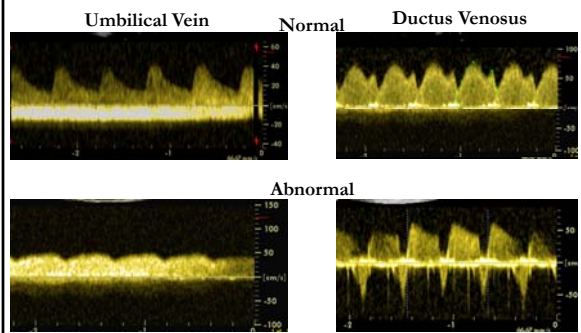
In normal fetuses:

- Systolic/diastolic velocities increased with GA
- Strain does not correlate with GA
- Results suggest increased velocity due to myocardial growth and not improved contractility

## Venous Doppler

- ♥ Veins
  - Umbilical vein
  - Ductus venosus
  - IVC and hepatic veins
- ♥ Representative of RA and RV diastolic pressure
- ♥ Venous Index
  - Peak Velocity Index = Systolic-Atrial/Diastolic Velocity
- ♥ In obstetrics- UV or DV Doppler pattern with cessation of flow or reversed flow during atrial systole is suggestive of fetal cardiac decompensation

## UV and DV Doppler



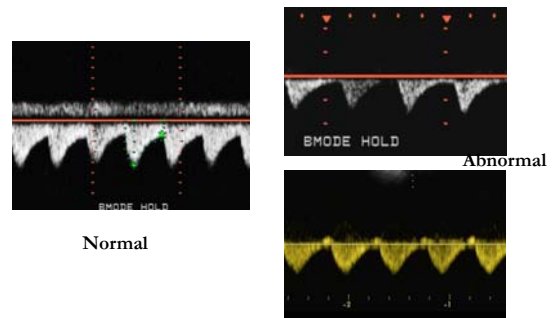
## Venous Doppler in CHD

- ♥ IVC Doppler in CHD *Gembruch et al*
  - Diagnoses: TA/HRHS, HLHS, VSD, other CHD
    - Abnormal venous Doppler
      - » Tricuspid Atresia/HRHS
      - » In other CHD, only with abnormal heart function or rhythm
- ♥ DV/IVC Doppler in CHD *Pagotto/Habita, et al*
  - Fetuses with isolated CHD had normal venous PVI
    - » 7 with abnormal PVI
      - Pulm stenosis, Tricuspid Atresia (2) (both with small FO)
      - TOF
      - HLHS (2), coarctation (with decreased or reversed FO flow)
  - Fetuses with other anomalies had abnormal venous PVI
    - » Hydrops, genetic abnormality or IUGR

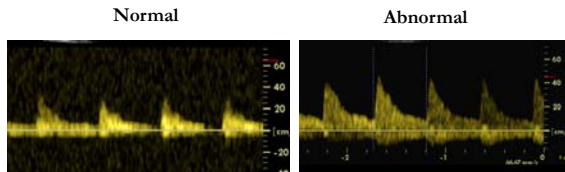
## Arterial Doppler

- ♥ Indices- Representative of vascular resistance
  - S/D ratio
  - Resistance Index (RI) = Systolic-Diastolic/Systolic Velocity
  - Pulsatility Index (PI) = Systolic-Diastolic/Mean Velocity
- ♥ RI ratios- Represent flow redistribution between vasc beds
  - Cerebral RI / Placental RI (CPR)
    - CPR > 1 is normal
    - CPR < 1 suggests a flow redistribution (Brain sparing)
      - » Placental disease: NL RI<sub>MCA</sub>/ Increase RI<sub>UA</sub>
      - » Hypoxemia: Decreased RI<sub>MCA</sub>/ NL RI<sub>UA</sub>
  - Ratios more predictive of compromise than using indices alone

## Umbilical Artery



## Middle Cerebral Arteries



## Cardiovascular Profile Score

	CARDIOVASCULAR PROFILE SCORE - 10 POINTS=NORMAL		
	NORMAL	-1 POINT	-2 POINTS
Hydrops (2 pts)	None	Ascites or Pleural effusion or Pericardial effusion	Skin edema
Venous Doppler (Umbilical vein) (Ductus venosus)	UV DV (2 pts)	UV DV	UV pulsations
Heart Size (Heart Area /Chest Area) (2 pts)	< 0.35	0.35 - 0.50	> 0.50
Cardiac Function	Normal TV & MV RV/LV S.F. > 0.28 Biphasic filling (2 pts)	Holysystolic TR or RV/LV S.F. < 0.28	Holysystolic MR or TR diast. < 400 gr Monophasic filling
Arterial Doppler (Umbilical artery)	UA (2 pts)	UA (AEDV)	UA (REDV)

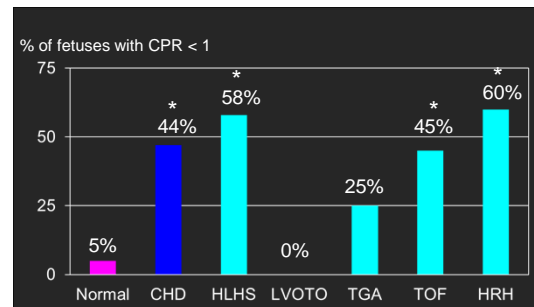
Huhta, Clin Obstet Gyn 2010

## CVP Score

- ♥ CVP in fetuses with hydrops
- ♥ Results:
  - CVP = 6 (range 5-6) in those with perinatal mortality
  - CVP = 7 (range 4-8) in survivors
  - Serial Evaluation
    - CVP decreased a median of 1.5 pts in those who died
    - CVP increased a median of 1.0 pts in those who lived
  - Best predictor for an adverse outcome- UV and DV Doppler

Hofstader, et al

## Cerebral Resistance in CHD



Domjrin, 2003

## MCA Doppler in CHD

- ♥ Cerebral resistance is altered in CHD
  - Hypoxia plays a role
    - Lesions with TGA or intra-cardiac mixing are affected
  - Cardiac output plays a role
    - Single ventricle fetuses more affected
    - HLHS most affected
- ♥ Cerebral resistance varies with gestational age
  - Periods of critical brain development
- ♥ Alterations in cerebral resistance may have neurologic effects
  - Relationship between CPR and head circumference
  - Relationship between CPR and brain lactate

## Fetal Doppler: Summary

- ♥ Doppler is a useful tool in fetal cardiology
  - Essential
    - Diagnosis of CHD
      - » Severity of valve disease
      - » Ductal dependence
    - Assessment of rhythm abnormalities
  - Useful
    - Physiologic assessment of disease severity
      - » TGA, HLHS
    - Cardiovascular function
      - » CO
      - » PVR
  - May be beneficial
    - Advanced function assessment
      - » Tei
      - » Regional wall motion, strain