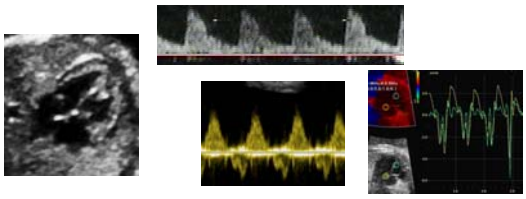
Advanced Fetal Cardiac Doppler



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Children's National Medical Center

Children's National HeartInstitute

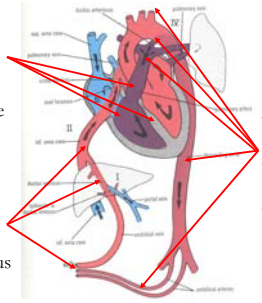
Why Doppler?

- 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

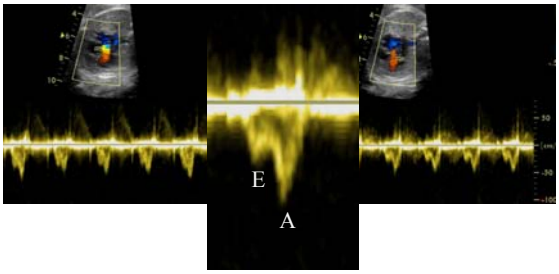
Venous Doppler
1. Umbilical
2. Ductus Venosus
3. IVC
4. Hepatics



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

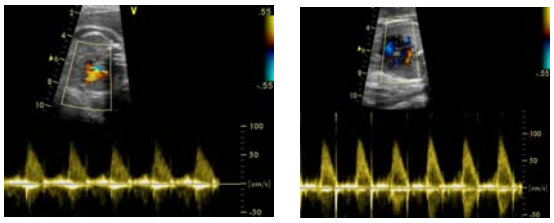
Doppler Inflows

Tricuspid Valve | Mitral Valve



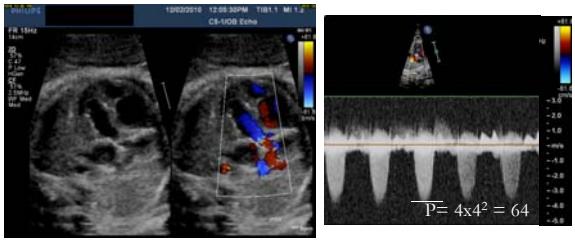
Doppler Outflows

Pulmonary Valve | Aortic Valve



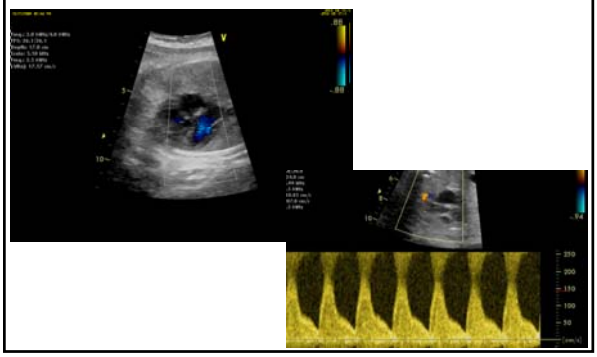
Diagnosis of Valve Disease

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

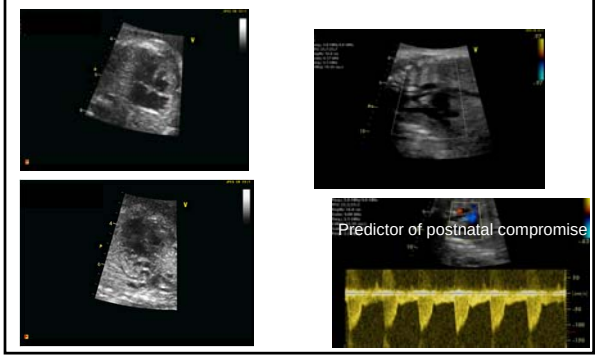


Ductus Arteriosus Doppler

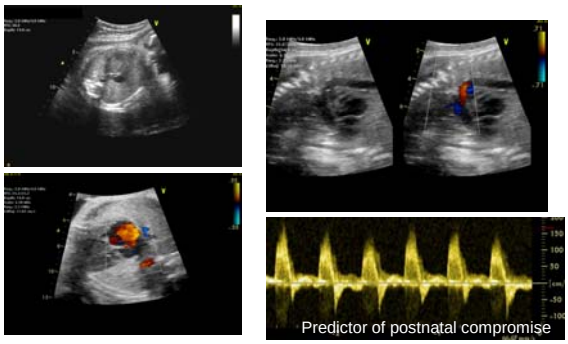
Ductal Restriction



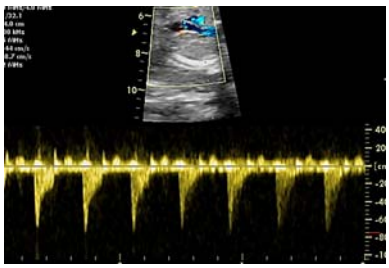
Ductus Arteriosus Doppler in Tetralogy of Fallot



Ductus Arteriosus Doppler in Transposition of the Great Arteries

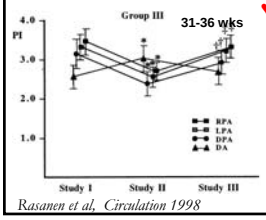


Branch PA Doppler



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



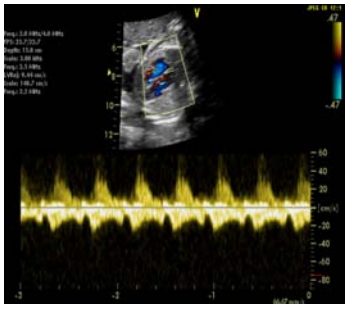
Rasanen et al, Circulation 1998

- Pulmonary Reactivity Test
  - Maternal delivery of 60% humidified O2 via facemask (hyperoxia)
  - 20-26 weeks: no change
  - 31-36 weeks:
    - MPA, RPA, LPA resistance decreased
    - DA resistance increased
    - Qp increased

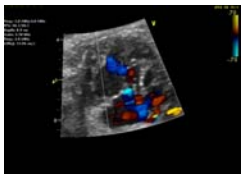
Pulmonary Reactivity Testing in High Risk Fetuses

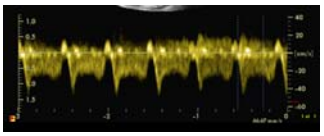
- Study of fetuses at risk for lung hypoplasia *Broth, 2002*
  - CDH
  - Renal disease
  - CCAM
  - Skeletal dysplasia
  - Twin-twin
  - Pleural effusion
  - Results:
    - 52% reactive
      - » only 1 death
    - 48% non-reactive
      - » 79% with a non-reactive test died
  - Prediction of neonatal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

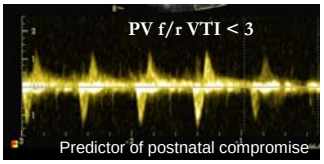
Pulmonary Vein Doppler



Pulmonary Vein Doppler in HLHS

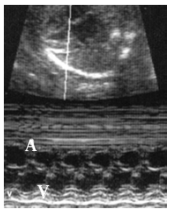




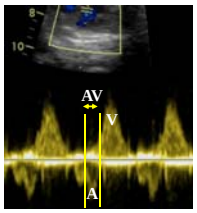


Michelfelder, et al

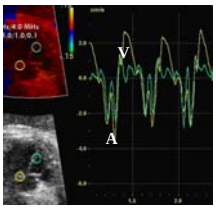
Doppler Assessment of Rhythm



M Mode



Doppler



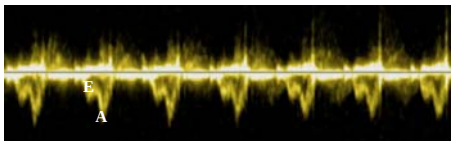
Tissue Doppler

Doppler Assessment of Heart Function

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

Doppler Inflows

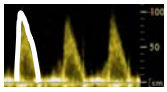
- Tricuspid and Mitral Valves
  - Assessment of diastolic function
    - E- passive filling, A- active filling
    - A>E wave through gestation
    - E/A~ 0.6 mid gestation; 0.8 late gestation

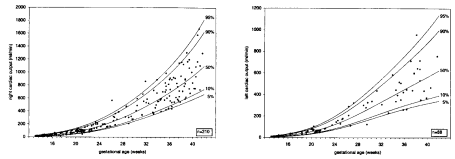


Reed, et al

Doppler Outflow

- Pulmonary and Aortic Valves
  - Stroke Volume/ Cardiac Output
  - CO = HR x VTI x CSA (CSA=πr^2)
    - » Right and left CO increase exponentially throughout gestation
    - » Right CO> Left CO through gestation

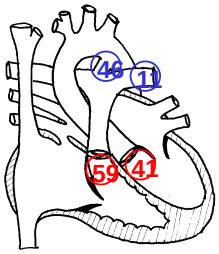




Mielke et al, Circulation 2001

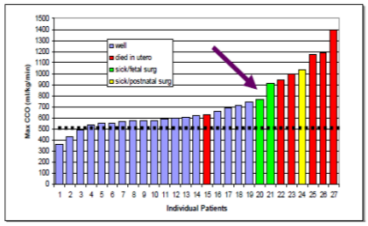
Doppler Outflow: Cardiac Output Calculation

- % Combined CO calculations



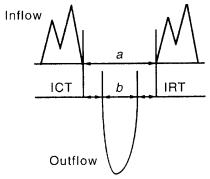
Cardiac Output in Volume Loaded States

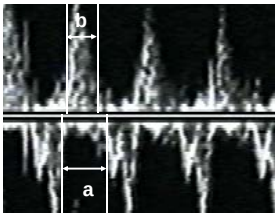
- Fetuses with volume load evaluated
  - SCT
  - Vascularized neck mass
  - Cerebral AVM
  - Teratoma



Rychik, Prog in Ped Cardiol 2006

Tei Index/ MPI



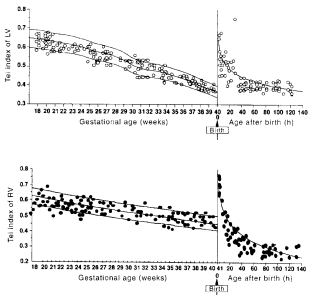


- Assessment of global heart function
- Increased Tei index represents worse function
- Normal: LV- 0.36 ± 0.06 / RV- 0.35 ± 0.05 (No change with GA)

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

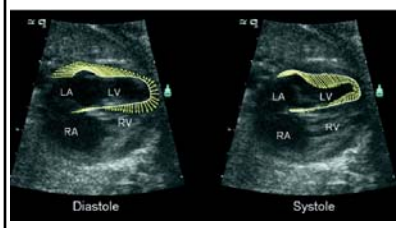


Tsutsumi et al, Ped Int 1999

Tei Index

- Tei in fetuses exposed to indomethecin *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, gastroschesis, 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



Strain

ℓ_0 ℓ

$$\varepsilon = \frac{\ell - \ell_0}{\ell_0} = \frac{\Delta \ell}{\ell_0}$$

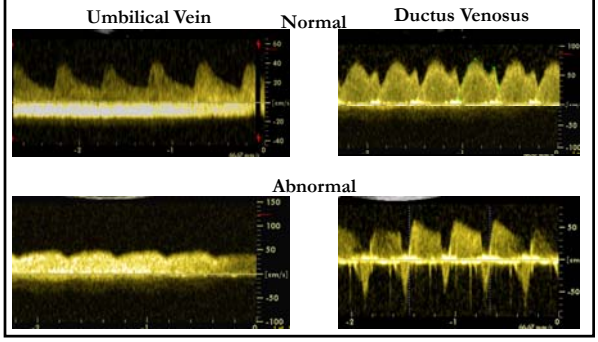
Younosani et al, JASE 2008

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



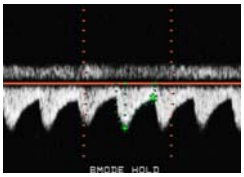
Venous Doppler in CHD

- 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 *Pagatto/Huhta, 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

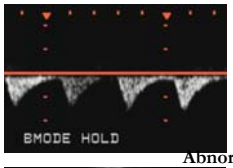
Arterial Doppler

- 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_{MCA}/ Increase RI_{UA}
      - » Hypoxemia: Decreased RI_{MCA}/ NL RI_{UA}
  - Ratios more predictive of compromise than using indices alone

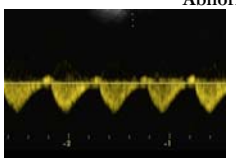
Umbilical Artery



Normal

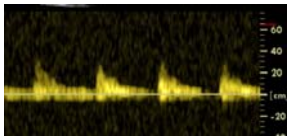


Abnormal

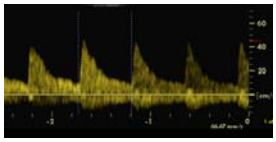


Middle Cerebral Arteries

Normal



Abnormal



Cardiovascular Profile Score

CARDIOVASCULAR PROFILE SCORE 10 POINTS=NORMAL

	NORMAL	-1 POINT	-2 POINTS
Hydrops	None (2 pts)	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)	≤ 0.35 (2 pts)	0.35 - 0.50	> 0.50 <0.20
Cardiac Function	Normal TV & MV RV/LV S.F. > 0.28 Biphasic filling (2 pts)	Holosystolic TR or RV/LV S.F. < 0.28	Holosystolic MR or TR dP/dt < 400 or Monophasic filling
Arterial Doppler (Umbilical artery)	UA (2 pts)	UA (AEDV)	UA (REDV)

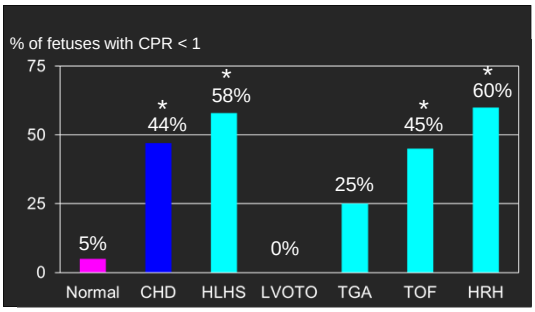
Huhta, Clin Obstet Gyn 2010

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



Donofrio, 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