Fetal Doppler Velocimetry

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Disclosures

Giancarlo Mari, MD, FACOG, FAIUM, MBA

No Relevant Financial Relationships

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Learning Objectives

- Doppler principle
- Umbilical Artery, Middle Cerebral Artery, Ductus Venosus
- Fetal Growth Restriction
- Fetal anemia
- Hydrops
- Twin to twin transfusion syndrome (TTTS)
- Twin anemia polycythemia sequence (TAPS)
- Ductal constriction
- Fetal lung maturity

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Doppler Formula

$$Fd = \frac{2(Fc \times V \times \cos \alpha)}{C}$$

Christian J. Doppler was an Austrian physicist who described the Doppler effect in 1842.

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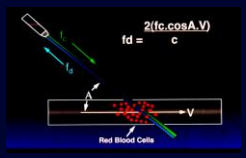
Doppler Effect: Application to Obstetrics



From a transducer, ultrasounds are emitted at a frequency Fc. When they hit a structure that moves (for example, blood flow) they are backscattered and return to the transducer at a different frequency. This different frequency is the Doppler shift (Fd). The Doppler shift increases as the velocity of the blood flow increases (V) and as the cosine of the angle (A) between the ultrasound beam and the direction of the blood flow increases. C is a constant (velocity of the ultrasound in water: 1540 m/sec).

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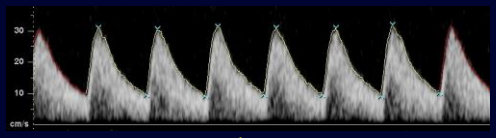
The Doppler shift arrives to the transducer. The information is analyzed, and it is presented as waveforms.



On the y-axis, there is the velocity value. Some of the old ultrasound equipment reported the Doppler shift on the y-axis.

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Doppler Modalities Used in Obstetrics

There are 4 types of Doppler ultrasound

- Spectral Doppler (Pulsed and Continuous)
- Color flow Doppler
- Power Doppler
- Tissue Doppler

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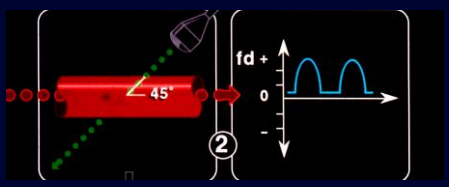
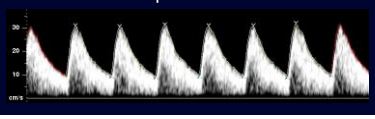
Direction of Blood Flow Toward the Transducer



The waveforms are represented above the baseline.



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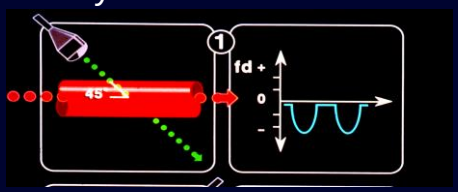
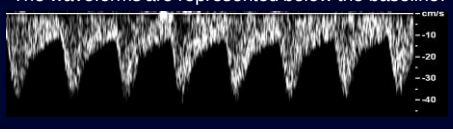
Direction of Blood Flow Away from the Transducer



The waveforms are represented below the baseline.



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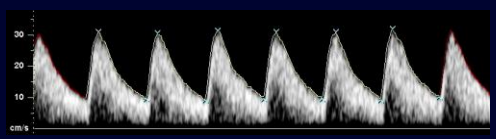
Does the velocity value reported on the y-axis of this set of waveforms reflect the real velocity of the blood flow?



Based on what we said about the angle and the velocity, the answer is: "We do not know." If the angle between the ultrasound beam and the direction of the blood flow was 0°, the answer is YES.
If the angle was not close to 0°, the answer is NO.

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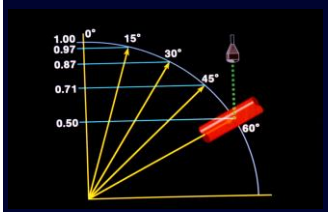
Angle Dependence



$$Fd = \frac{2(Fc \times V \times \cos \alpha)}{C}$$

This slide shows the cos α values (horizontal lines) at different angles. When the angle is 90°, the cos α = 0. Therefore, the value of the Doppler shift becomes 0. If this value is 0, there is no waveform generated, and no velocity can be measured.

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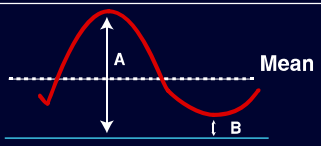
Angle-Independent Indices



$\frac{A}{B}$ = A/B ratio (Stuart et al, 1980)

$\frac{A - B}{B}$ = Resistance index (Pourcelot, 1974)

$\frac{A - B}{Mean}$ = Pulsatility index (Gosling and King, 1975)

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Angle-Independent Indices

These indices are independent of the angle. Therefore, the values do not change significantly when the angle changes.

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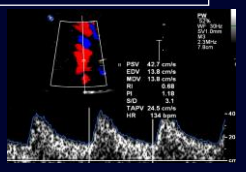
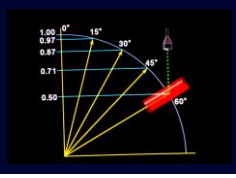
The following slides provide a few examples

Angle Dependence



Angle 45°

Angle close to 0°



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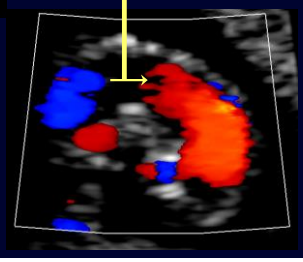
Angle Dependence

$$fd = \frac{2(fc.\cos A.V)}{c}$$

Flow is perpendicular to angle of incidence (cos 90º = 0)



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Common Pulsed Doppler Studies

- Umbilical artery
- Middle cerebral artery
- Ductus Venosus

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Umbilical Artery

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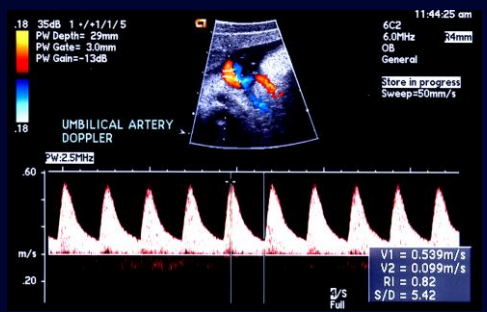
Umbilical Artery



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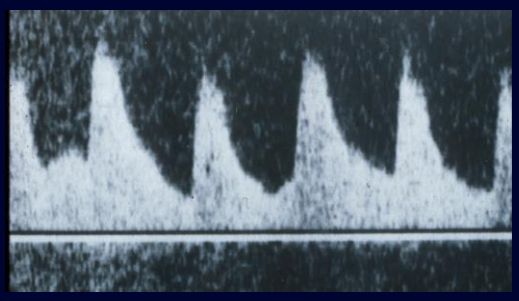
Fetal Breathing



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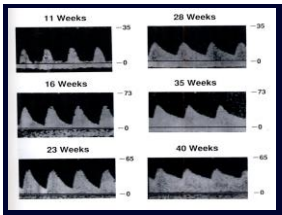
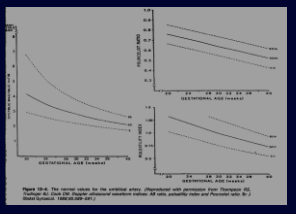


Umbilical Artery

Flow velocity waveforms of the umbilical artery in a normal fetus from 11 to 40 weeks. Note the diastole that increases with advancing gestation. This indicates that the placental vascular resistance decreases in the normal fetus with advancing gestation.

Reference ranges for the umbilical artery RI, A/B ratio, and PI.



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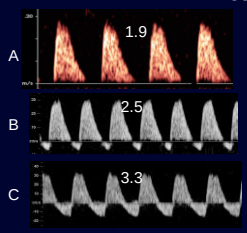
Angle-Independent Indices

The pulsatility index is the only index that quantifies the waveforms in all of the cases.



- The end-diastolic velocity (EDV) is equal to 0 in all 3 sets
- The A/B ratio is infinite (A/0) and, the RI is equal to 1 (A – 0/A) in all 3 cases
- The pulsatility index is different in the 3 cases (1,9, 2.5, 3.3), and it reflects the worsening of the condition

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Middle Cerebral Artery

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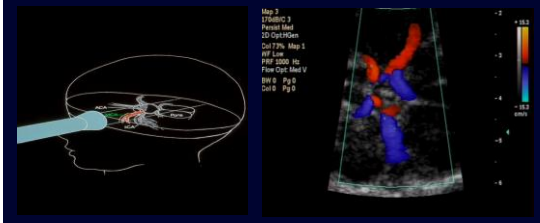
Circle of Willis



The most studied artery of the Circle of Willis is the middle cerebral artery (MCA).

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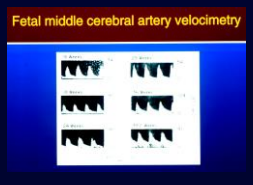

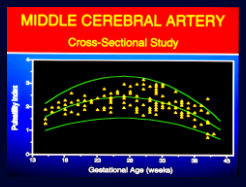

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Ductus Venosus

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Appropriate Technique for Ductus Venosus

- Sagittal section
- Axial section

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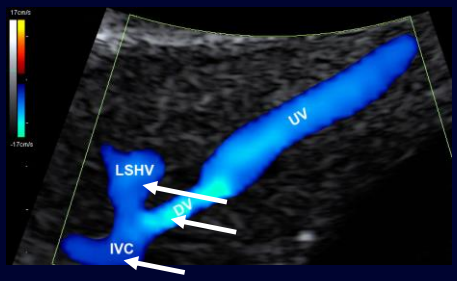

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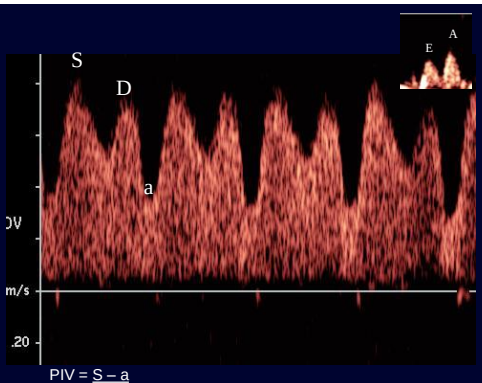

$$PIV = \frac{S - a}{Tmax}$$

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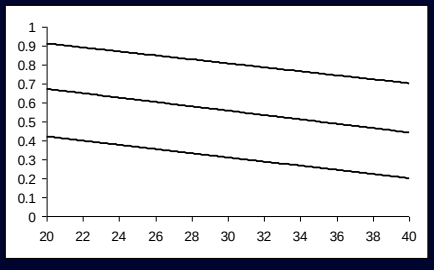
Ductus Venosus



Gestational age (weeks)

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IUGR

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IUGR

Definitions:

- EFW < 10th percentile (USA)
- EFW < 5th percentile (USA)
- EFW < 3rd percentile (USA)
- EFW < 15th percentile (USA)
- EFW > 2 SD below mean (Europe)
- AC (10th → 2.5th percentile) (Europe)

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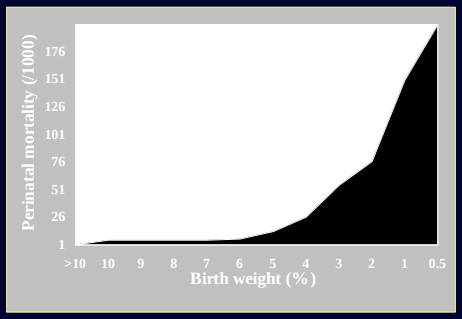
Perinatal Mortality



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EFW < 10th percentile

Normal — **80% ?**

Pathologic — **20% ?**

IUGR

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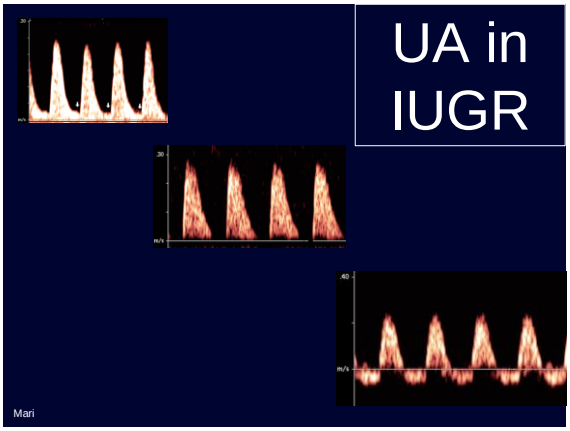
UA in IUGR



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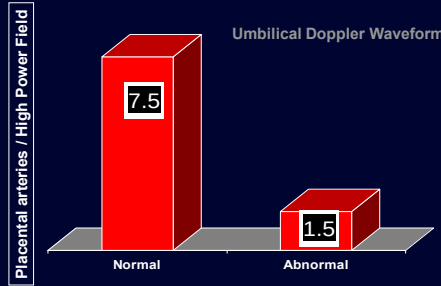
Umbilical Artery Doppler and Placental Vascular Histology



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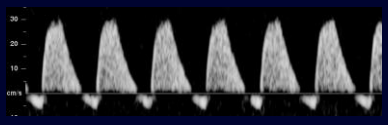
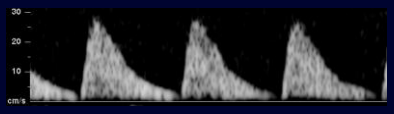
Umbilical Artery Transitional Phase

A



B



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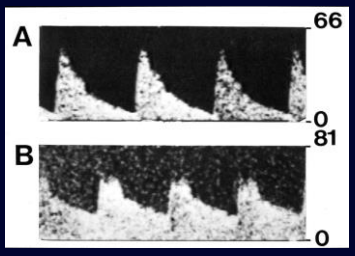
MCA Waveforms at 24 Weeks

A = Normal



B = "Brain sparing effect"

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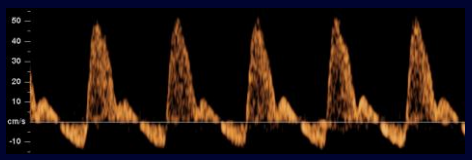
Middle Cerebral Artery



Reversed flow at the MCA often is not pathologic; rather, it is due to compression of the transducer on the fetal head.

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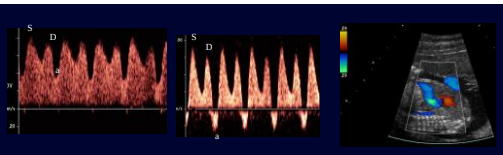

Ductus Venosus

Hemodynamically, these phases (S, D, a) reflect the rapid chronologic change in pressure gradients between the umbilical vein and the right atrium.

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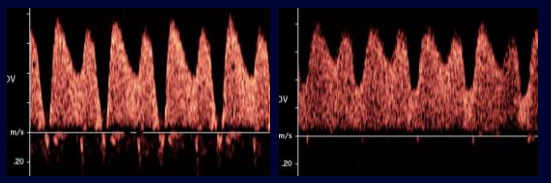
DV Transitional Phase



DV RF **1 hour later**

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Abnormal UA Doppler and Outcome

IUGR fetuses with abnormal UA end-diastolic velocity are at increased risk of adverse perinatal outcome.

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Abnormal UA Doppler in Early IUGR Fetuses

Early IUGR fetuses with UA AREDV are either delivered preterm or they will die in-utero.

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Do we need to use the UA Doppler as a screening test for IUGR?

- **Randomized and quasi-randomized studies (Doppler vs no Doppler in normal pregnancies)**
- **Five trials (14,624 women)**
- **There is no conclusive evidence that the use of routine UA Doppler, or combination of UA and uterine artery Doppler in low-risk or unselected populations benefits either mother or baby**

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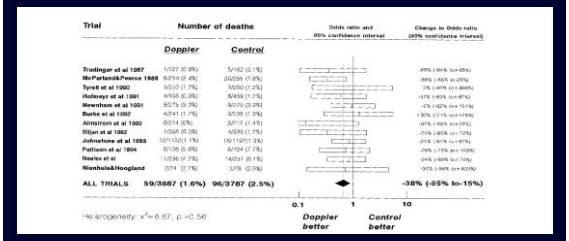
Alfirevic Z. et al. Cochrane Database Sys Rev. 2015

Do we need to use the UA Doppler in high risk pregnancies?



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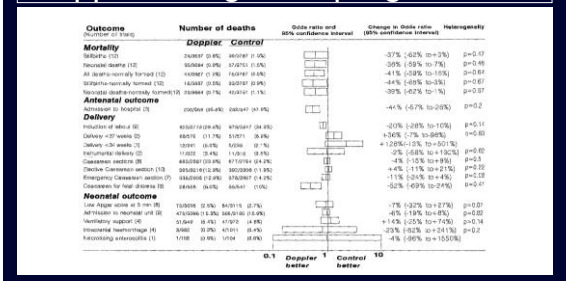
Alfirevic Z. and Neilson JP. Am K Obstet Gynecol 1995;172:1379

Do we need to use the UA Doppler in high risk pregnancies?



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Alfirevic Z. and Neilson JP. Am K Obstet Gynecol 1995;172:1379

Do we need to use the UA Doppler in high risk pregnancies?

- **Randomized and quasi-randomized studies (Doppler vs no Doppler in high risk pregnancies)**
- **Eighteen trials (over 10,000 women)**
- **Reduction in perinatal death (RR 0.71, 0.52-0.98)**
- **Fewer inductions of labor: (RR 0.89, 0.80-0.99)**
- **Fewer cesarean sections: (RR 0.90, 0.84-0.97)**
- **No difference in Apgar scores < 7 at 5 minutes**

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Do we need to use the MCA Doppler or the MCA/UA in IUGR?

- **It has not to be used as a screening test**
- **There is no data that shows that the MCA/UA ratio is better than the MCA PI in IUGR**
- **It can be used with the umbilical artery Doppler in fetuses suspected to be IUGR**

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Do we need to use the DV Doppler in IUGR?

- **It provides information on the severity of IUGR**
- **A randomized trial on the use of Doppler of the DV for timing IUGR delivery was not conclusive**
- **It has not to be used for timing the delivery of IUGR fetuses**

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Fetal Anemia

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Definition of Fetal Anemia

Hemoglobin value below the 5th percentile (2 SD; 95% CI) for gestational age

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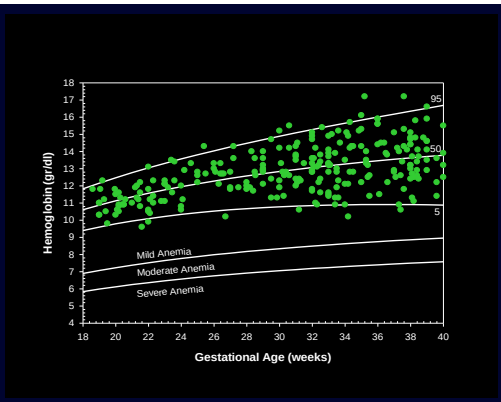

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Causes of Fetal Anemia

- **Red blood cell alloimmunization**
- **Infections**
- **Fetomaternal hemorrhage**
- **Twin-twin-transfusion syndrome**
- **TAPS**
- **Thalassemia**
- **Enzymopathies**
- **Fanconi anemia**
- **Diamond-Blackfan anemia**

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Rh Hemolytic Disease United States

Rhogam (1968)

~ 4000 cases per year

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"Irregular" red blood cell antigens

Blood group system	Antigen
Rh	C, c, e, E
Kell	K, k, Ko, Kp^a, Kp^b, Js^a, Js^b
Duffy	Fy^a, Fy^b, Fy^3
Kidd	Jk^a, Jk^b, Jk^3
MNSs	M, N, S, s, U, Mi^a, Mt^a, Vw, Mur, Hil, Hut
Lutheran	Lua, Lub
Diego	Dia, Dib
Xg	Xga
P	$PP_1p^k(Tj^a)$
Public antigens	Yt^a, Yt^b, Lan, En^a, Ge, Jr^a, Co^a, Co^{a-b-}
Private antigens	Batty, Becker, Berrens, Biles, Evans, Gonzales, Good, Heibel, Hunt, Jobbins, Radin, Rm, Ven, $Wright^a$, $Wright^b$, Zd

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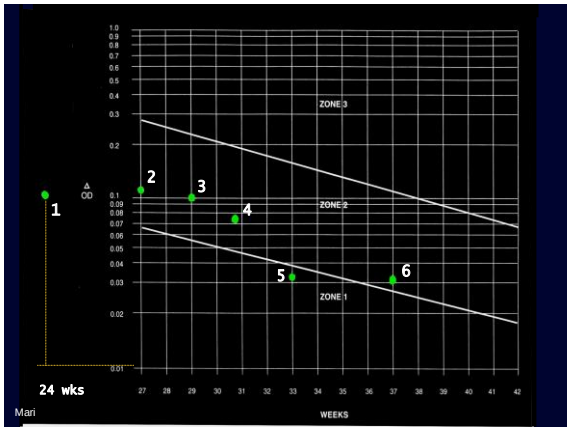

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Blood Velocity in Anemia

↓ **Viscosity** ↑ **CO**

↑ **Velocity**

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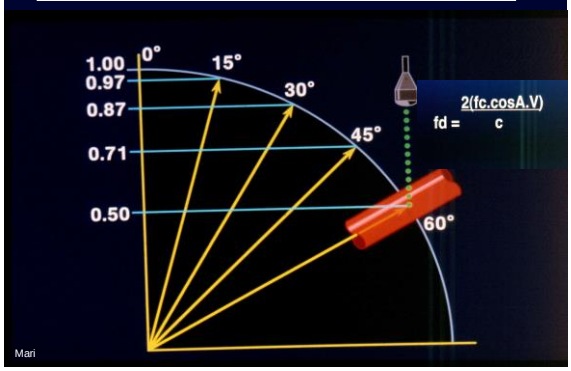
Angle Dependence



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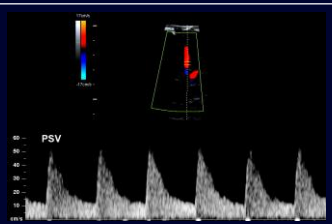
Middle Cerebral Artery Peak Systolic Velocity



The middle cerebral artery can be easily sampled with an angle of 0°, and the true velocity of the blood flow can be obtained. The peak systolic velocity (PSV) is the highest point of the waveform. Therefore, for the MCA, we can easily obtain the PI (angle independent) and the PSV (an angle close to 0° is needed).

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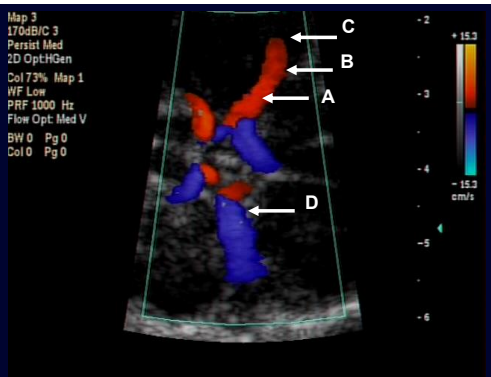

Where to sample the MCA?

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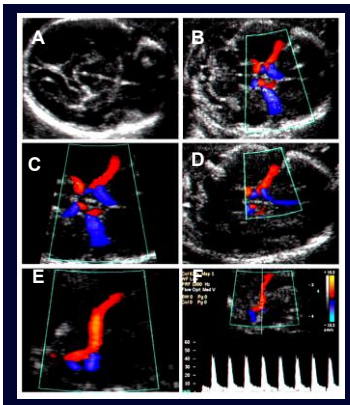

It is easy to sample the MCA with an angle of zero degrees, which allows for the real velocity of the blood flow to be determined.

These are the steps for the correct sampling of the middle cerebral artery peak systolic velocity.
The use of an angle corrector increases the intra- and inter-observer variability; therefore, its use is not recommended.

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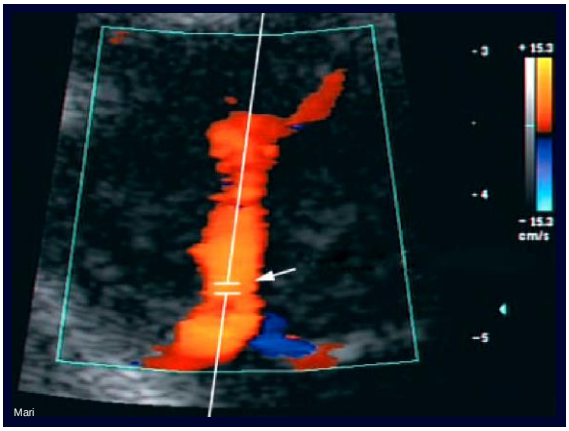

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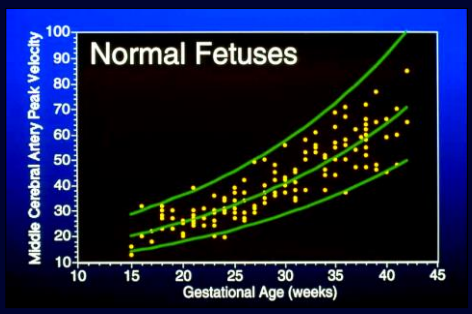

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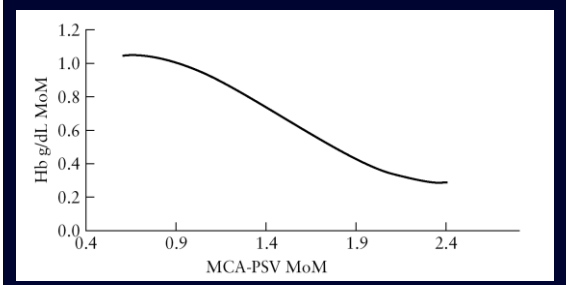

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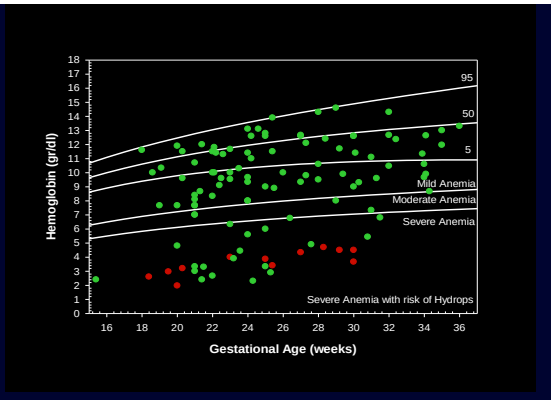

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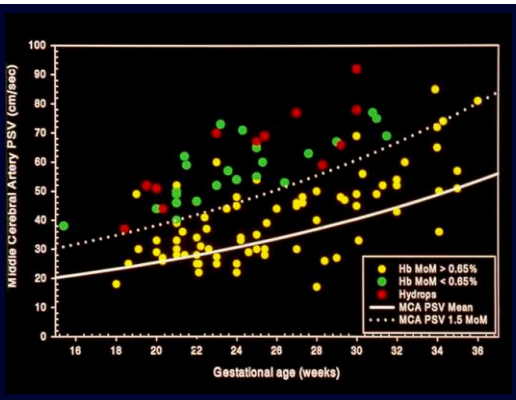

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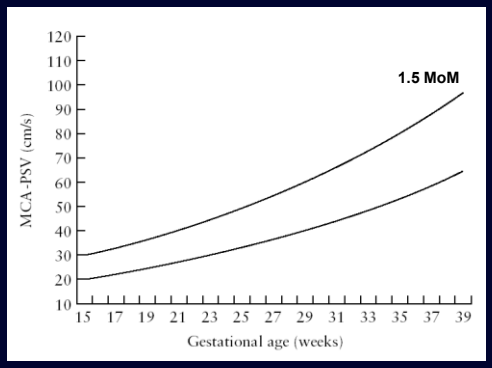
Mari G, et al. N Engl J Med. 2000;342(1):9-14



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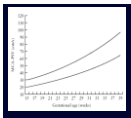
Mari G, et al N Engl J Med 2000; 342:9

Prospective Study on an Intention to Treat

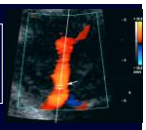
- **Multicenter study in 5 tertiary referral centers**
- **125 fetuses at risk for anemia**
- **MCA-PSV used for timing a cordocentesis**

Mari

Zimmermann R, et al. J Obstet Gynaecol. 2002;109:746-752



False Positive Rate



- MCA PSV single value: False positive rate: 12%
- MCA PSV trend: False positive rate: <5%

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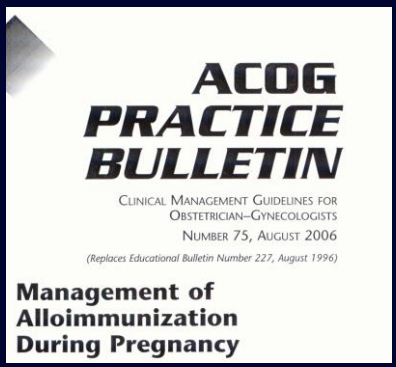
Mari G, et al N Engl J Med 2000; 342:9
Zimmermann R, et al. Br J Obstet Gynaecol 2002;109:746



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MCA-PSV predicts those fetuses that will become anemic.

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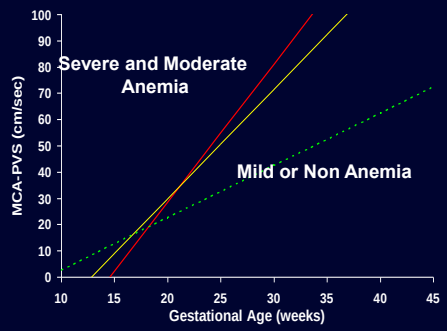

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HYDROPS

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Hydrops

- Immune
- Non-immune hydrops

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Prevalence of NIHF

- Non-immune hydrops now represents > 80% of all reported hydrops fetalis cases
- Routine immunization of Rhesus (Rh) negative mothers and detection of anemia before the development of hydrops have decreased hydrops fetalis cases from immune causes (e.g., erythroblastosis from Rh alloimmunization)

Mari

Fetal Blood Testing

- Recommendations:
  - Fetal karyotype
  - Fetal complete blood count
  - Hemoglobin electrophoresis
  - TORCH
  - Fetal albumin
  - Inborn errors of metabolism
- May instead be accomplished with:
  - Ultrasound
  - MCA-PSV
  - Amniocentesis
  - Maternal testing

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Twin-Twin Transfusion Syndrome

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International Registry on TTTS Treated by Serial Amnioreduction at < 28 Weeks' Gestation

Perinatal survival and morbidity

Mari

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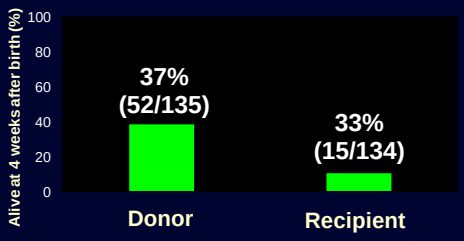
Survival Rate with Absent Umbilical Artery EDV



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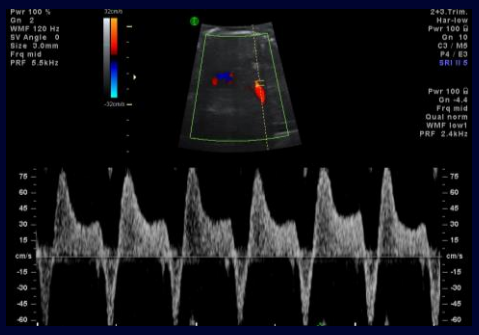

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TAPS

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Twin Anemia-Polycythemia Sequence

- Etiology lies in placental anastamosis
- Definition
  - Large intertwin hemoglobin differences
  - Absence of oligohydramnios/polyhydramnios findings
  - Can occur spontaneously (3-5% MC)
  - Post laser treatment for TTTS (2-13% of cases)

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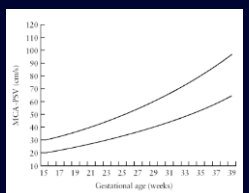
Criteria and Classification

Antenatal stage	Findings at Doppler ultrasound examination
Stage 1	MCA-PSV donor >1.5 MoM *and* MCA-PSV recipient <1.0 MoM, without other signs of fetal compromise
Stage 2	MCA-PSV donor >1.7 MoM *and* MCA-PSV recipient <0.8 MoM, without other signs of fetal compromise
Stage 3	as stage 1 or 2, with cardiac compromise of donor, defined as critically abnormal flow*
Stage 4	hydrops of donor
Stage 5	intrauterine demise of one or both fetuses preceded by TAPS

* Critically abnormal Doppler is defined as absent or reversed end-diastolic flow in umbilical artery, pulsatile flow in the umbilical vein, increased pulsatility index or reversed flow in ductus venosus.



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Slaghekke, F. et al. Fetal diagnosis and therapy 2010;27:181-90
Mari G, et al. N England J Med, 2000;342:9-14

Preterm Labor: Indomethacin

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Indomethacin

- Ductal constriction and tricuspid regurgitation
- Oligohydramnios

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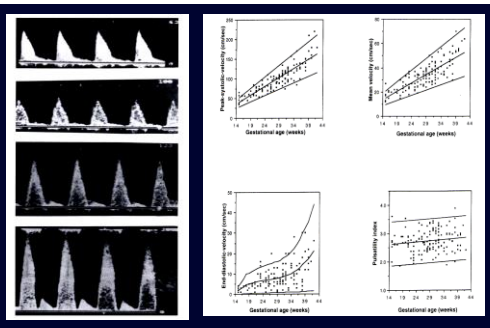

Ductus Arteriosus

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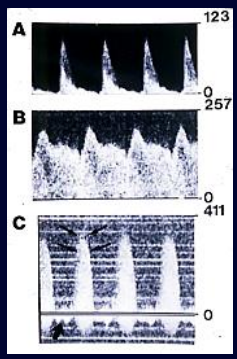
Mari G, et al. J Clin Ultrasound 1996; 24:185-96



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Mari G, et al. J Clin Ultrasound 1996; 24:185-96

Ductus Arteriosus Constriction

- It occurs in 50% of patients treated with indomethacin
- In 10% of the cases, the effect is severe
- The ductal constriction is reversible

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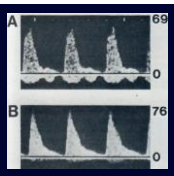
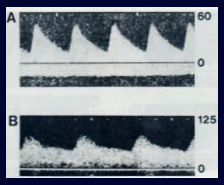
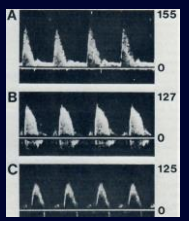
Mari G, et al. J Clin Ultrasound 1996; 24:185-196



Doppler and Nifedipine





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Doppler and Fetal Lung Maturity

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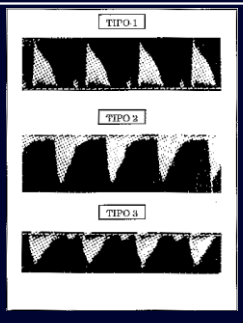
Pulmonary Artery Doppler Wave Morphology and GA



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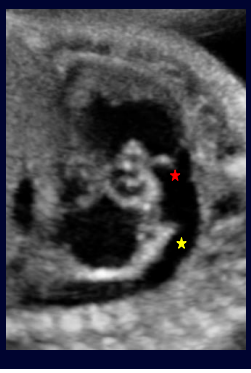

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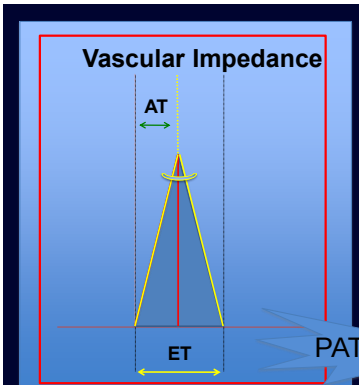
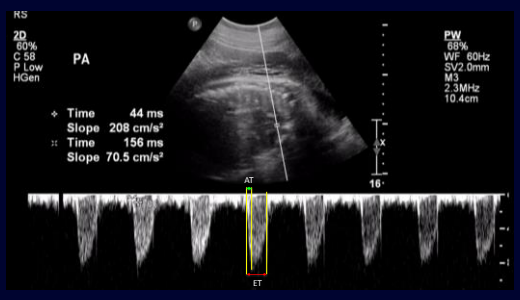
P A T E T



Mari

Schenone MH, et al. Fetal Diagn Ther. 2014;36(3):208-14

Immature TDx-FLM II



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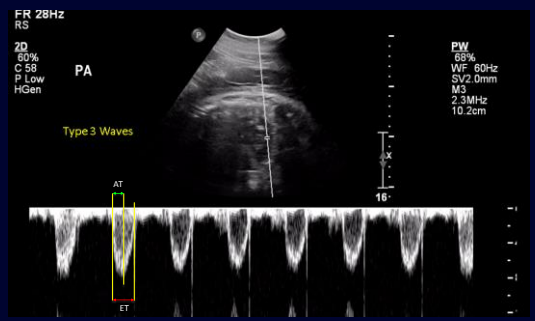
Schenone MH, et al. Fetal Diagn Ther. 2014;36(3):208-14

Mature TDx-FLM II



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Schenone MH, et al. Fetal Diagn Ther. 2014;36(3):208-14

PATET and Lung Maturity

- ROC cut off → 0.31.5
- Sensitivity 73% (95% CI 48-89%)
- Specificity 93% (95% CI 77-98%)
- PPV 85% (95% CI 58-96%)
- NPV 87% (95% CI 70-95%)
- R=0.80; p<0.01

Mari

Conclusion

Doppler ultrasonography has several applications in obstetrics

The most important are represented by

- Diagnosis of fetal anemia
- Diagnosis of IUGR

Mari

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