Fetal Doppler Velocimetry

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Disclosures

No Relevant Financial Relationships
Learning Objectives

- Doppler principle
- Umbilical Artery, Middle Cerebral Artery, Ductus Venosus
- Fetal anemia
- Hydrops
- Twin to twin transfusion syndrome (TTTS)
- Twin anemia polycythemia sequence (TAPS)
- Ductal constriction
- Fetal lung maturity
Christian J. Doppler was an Austrian physicist who described the Doppler effect in 1842.

Doppler Formula

\[ F_d = \frac{2(F_c \times V \times \cos \alpha)}{C} \]
From a transducer, ultrasounds are emitted at a frequency $F_c$. 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 ($F_d$). 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).
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.
Doppler Modalities Used in Obstetrics

There are 4 types of Doppler ultrasound

- **Spectral Doppler** (Pulsed and Continuous)
- Color flow Doppler
- Power Doppler
- Tissue Doppler
Direction of Blood Flow Toward the Transducer

The waveforms are represented above the baseline.
Direction of Blood Flow
Away from the Transducer

The waveforms are represented below the baseline.
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.
This slide shows the \( \cos \alpha \) values (horizontal lines) at different angles. When the angle is \( 90^\circ \), the \( \cos \alpha = 0 \). 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.

\[
F_d = \frac{2(F_c \times V \times \cos \alpha)}{C}
\]
Angle-Independent Indices

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

\[
\frac{A - B}{B} = \text{Resistance index (Pourcelot, 1974)}
\]

\[
\frac{A - B}{\text{Mean}} = \text{Pulsatility index (Gosling and King, 1975)}
\]
These indices are independent of the angle. Therefore, the values do not change significantly when the angle changes.
Angle Dependence

Angle 45°

Angle close to 0°
Angle Dependence

\[ \text{Flow is perpendicular to angle of incidence (cos } 90^\circ = 0) \]

\[ f_d = \frac{2(fc \cdot \cos A \cdot V)}{c} \]
Common Pulsed Doppler Studies

- Umbilical artery
- Middle cerebral artery
- Ductus Venosus
Umbilical Artery
Umbilical Artery

UMBILICAL ARTERY DOPPLER

PW: 2.5 MHz

V1 = 0.539 m/s
V2 = 0.099 m/s
RI = 0.82
S/D = 5.42
Fetal Breathing
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.
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
Middle Cerebral Artery
Circle of Willis

The most studied artery of the Circle of Willis is the middle cerebral artery (MCA).
Normal Range of Middle Cerebral Artery Pulsatility Index as a Function of Gestational Age Constructed from a Study of 128 Normal Fetuses

Ductus Venosus
Appropriate Technique for Ductus Venosus

- Sagittal section
- Axial section
PIV = \frac{S - a}{T_{\text{max}}}

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Ductus Venosus

Gestational age (weeks)
Fetal Anemia
Definition of Fetal Anemia

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

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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
Rh Hemolytic Disease
United States

Rhogam (1968)

~ 4000 cases per year
“Irregular” red blood cell antigens

<table>
<thead>
<tr>
<th>Blood group system</th>
<th>Antigen</th>
</tr>
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<tbody>
<tr>
<td>Rh</td>
<td>C, c, e, E</td>
</tr>
<tr>
<td>Kell</td>
<td>K, k, Ko, Kp(^a), Kp(^b), Js(^a), Js(^b)</td>
</tr>
<tr>
<td>Duffy</td>
<td>Fy(^a), Fy(^b), Fy(^3)</td>
</tr>
<tr>
<td>Kidd</td>
<td>Jk(^a), Jk(^b), Jk(^3)</td>
</tr>
<tr>
<td>MNSs</td>
<td>M, N, S, s, U, Mi(^a), Mt(^a), Vw, Mur, Hil, Hut</td>
</tr>
<tr>
<td>Lutheran</td>
<td>Lua, Lub</td>
</tr>
<tr>
<td>Diego</td>
<td>Dia, Dib</td>
</tr>
<tr>
<td>Xg</td>
<td>Xga</td>
</tr>
<tr>
<td>P</td>
<td>PP(_1p^k(Tj^a))</td>
</tr>
<tr>
<td>Public antigens</td>
<td>Yt(^a), Yt(^b), Lan, En(^a), Ge, Jr(^a), Co(^a), Co(^a-b)</td>
</tr>
<tr>
<td>Private antigens</td>
<td>Batty, Becker, Berrens, Biles, Evans, Gonzales, Good, Heibel, Hunt, Jobbins, Radin, Rm, Ven, Wright(^a), Wright(^b), Zd</td>
</tr>
</tbody>
</table>
Blood Velocity in Anemia

\[ \downarrow \text{Viscosity} \quad \uparrow \text{CO} \]

\[ \uparrow \text{Velocity} \]
Angle Dependence

$2(f_c \cos A \cdot V)$

$fd = c$
The middle cerebral artery can be easily sampled with an angle of $0^\circ$, 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 $0^\circ$ is needed).
Where to sample the MCA?
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.
Gestational Age (weeks)

Hemoglobin (gr/dl)

0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17

Moderate Anemia

Severe Anemia

Severe Anemia with risk of Hydrops

Mild Anemia

1.5 MoM

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

False Positive Rate

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

CLINICAL MANAGEMENT GUIDELINES FOR OBSTETRICIAN–GYNECOLOGISTS

NUMBER 75, AUGUST 2006

(Replaces Educational Bulletin Number 227, August 1996)

Management of Alloimmunization During Pregnancy
SMFM Clinical Guideline

Society for Maternal-Fetal Medicine (SMFM) Clinical Guideline #8: The fetus at risk for anemia—diagnosis and management

Society for Maternal-Fetal Medicine (SMFM); Giancarlo Mari, MD; Mary E. Norton, MD; Joanne Stone, MD; Vincenzo Berghella, MD; Anthony C. Sciscione, DO; Danielle Tate, MD; Mauro H. Schenone, MD
MCA-PSV predicts those fetuses that will become anemic.
HYDROPS
Hydrops

• Immune

• Non-immune hydrops
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)
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
Twin-Twin Transfusion Syndrome
International Registry on TTTS Treated by Serial Amnioreduction at < 28 Weeks’ Gestation

Perinatal survival and morbidity

Survival Rate with Absent Umbilical Artery EDV

- Donor: 37% (52/135)
- Recipient: 33% (15/134)
Twin Anemia-Polycythemia Sequence

- Etiology lies in placental anastomosis
- 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)
Criteria and Classification

<table>
<thead>
<tr>
<th>Antenatal stage</th>
<th>Findings at Doppler ultrasound examination</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stage 1</td>
<td>MCA-PSV donor &gt;1.5 MoM and MCA-PSV recipient &lt;1.0 MoM, without other signs of fetal compromise</td>
</tr>
<tr>
<td>Stage 2</td>
<td>MCA-PSV donor &gt;1.7 MoM and MCA-PSV recipient &lt;0.8 MoM, without other signs of fetal compromise</td>
</tr>
</tbody>
</table>
| 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.


Preterm Labor: Indomethacin
Indomethacin

- Ductal constriction and tricuspid regurgitation
- Oligohydramnios

Ductus Arteriosus

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

Doppler and Nifedipine
Doppler and Fetal Lung Maturity
Vascular Impedance

\[ PATET = \frac{AT}{ET} \]

Immature TDx-FLM II

Mari

Mature TDx-FLM II

Type 3 Waves

PATET and Lung Maturity

- ROC cut off $\rightarrow$ 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%)
- $R=0.80; \ p<0.01$
Doppler ultrasonography has several applications in obstetrics.

The most important are represented by:
- Diagnosis of fetal anemia
- Diagnosis of IUGR