# Doppler Ultrasound

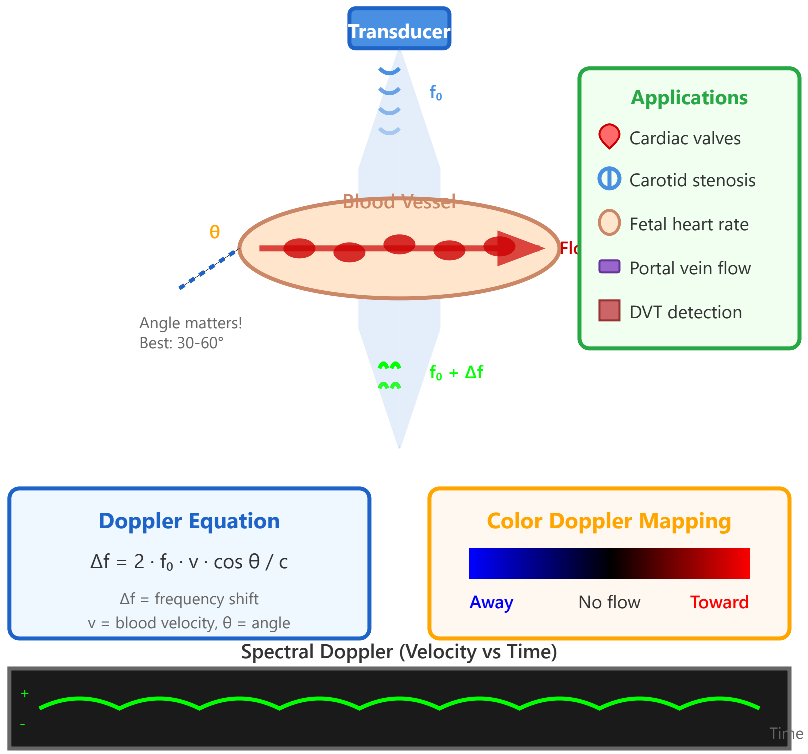
**Doppler shift principle**
Frequency change with moving blood

**Color flow mapping**
Direction and velocity visualization

**Power Doppler**
More sensitive to low flow

**Spectral analysis**
Velocity vs time waveforms

**Clinical applications**
Vascular, cardiac, obstetric imaging



# 1. Doppler Shift Principle

The Doppler effect is the change in frequency of a wave when there is relative motion between the source and the observer. In medical ultrasound, this principle is used to detect and measure blood flow by analyzing the frequency shift of ultrasound waves reflected from moving red blood cells.

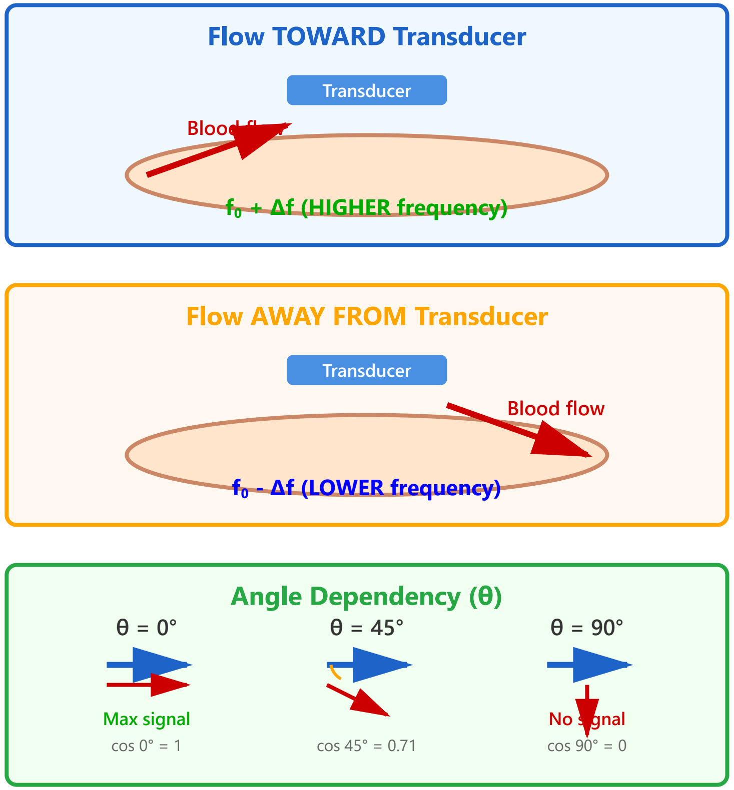
**Doppler Equation:**

$$\Delta f = (2 \cdot f_0 \cdot v \cdot \cos\theta) / c$$

### Variables Explained:

- **$\Delta f$** = Frequency shift (Doppler shift)
- **$f_0$** = Transmitted frequency (2-10 MHz)
- **$v$** = Velocity of blood flow
- **$\theta$** = Angle between ultrasound beam and flow direction
- **$c$** = Speed of sound in tissue (~1540 m/s)

### Doppler Shift Mechanism




### Key Concept: The Factor of 2

The factor "2" in the equation accounts for the double Doppler shift: once when the ultrasound hits the moving red blood cells, and again when the reflected waves return to the transducer.

**Clinical Significance:**

- Optimal Doppler angle: 30-60° (best compromise between signal strength and accuracy)
- At 0°: Maximum frequency shift but difficult to achieve in practice
- At 90°: No Doppler shift detected (perpendicular flow)
- Angle correction must be applied for accurate velocity measurements

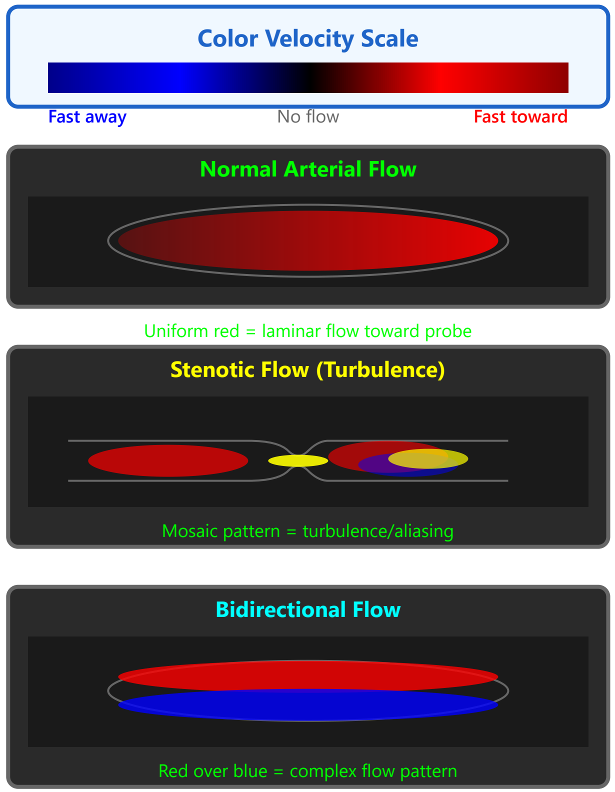
# 2. Color Flow Mapping (CFM)

Color Flow Mapping is a technique that displays blood flow information as colored pixels superimposed on a grayscale B-mode image. It provides real-time visualization of blood flow direction and velocity within vessels and cardiac chambers.

**Color Coding Convention:**

- **Red:** Flow toward the transducer
- **Blue:** Flow away from the transducer
- **Brightness:** Indicates flow velocity (brighter = faster)
- **Yellow/Green:** Turbulent or high-velocity flow (aliasing)

### Color Flow Display




## Technical Parameters

- **Color Gain:** Controls sensitivity to flow detection
- **PRF (Pulse Repetition Frequency):** Determines velocity range
- **Color Box Size:** Region of interest for flow detection
- **Wall Filter:** Eliminates low-velocity vessel wall motion

- **Baseline:** Can be shifted to display higher velocities in one direction

**Aliasing Artifact**

Occurs when blood velocity exceeds the Nyquist limit (PRF/2). The color wraps around, showing incorrect direction. Appears as mixture of red and blue colors (mosaic pattern).

**Clinical Applications:**

- Rapid detection of vascular stenosis or occlusion
- Evaluation of cardiac valvular regurgitation or stenosis
- Assessment of fetal circulation (umbilical cord, heart)
- Detection of arteriovenous malformations (AVMs)
- Guidance for spectral Doppler sample volume placement

# 3. Power Doppler Imaging

Power Doppler (also called color Doppler energy or amplitude Doppler) displays the amplitude (power) of the Doppler signal rather than the frequency shift. It shows the presence and intensity of blood flow without indicating direction or velocity.

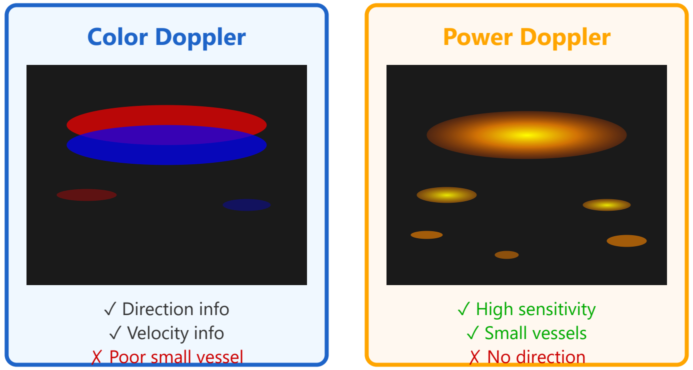
## Advantages of Power Doppler

- **Higher Sensitivity:** 3-5 times more sensitive to slow flow than color Doppler
- **No Aliasing:** Not subject to aliasing artifacts
- **Angle Independent:** Less affected by Doppler angle
- **Better SNR:** Superior signal-to-noise ratio
- **Small Vessel Detection:** Excellent for detecting perfusion in tiny vessels

## Limitations

- No directional information (cannot distinguish toward/away)
- No velocity information
- More susceptible to motion artifacts
- Flash artifacts from tissue motion

### Power Doppler vs Color Doppler




### Technical Comparison

| Parameter | Color | Power |
|---|---|---|
| Sensitivity to flow | Moderate | High |
| Direction info | Yes | No |
| Velocity info | Yes | No |
| Aliasing artifact | Yes | No |
| Angle dependency | High | Low |
| Frame rate | Fast | Slow |

**Ideal Power Doppler Applications:**
• Tumor vascularity • Testicular torsion • Synovitis
• Transplant perfusion • Small vessel disease

- Slower frame rates than color Doppler

**Color Scale**

Power Doppler typically uses a monochromatic scale (orange-yellow or red-yellow) where brightness indicates the amplitude of flow signal, not velocity. Darker = weaker signal, Brighter = stronger signal.

**When to Choose Power Doppler:**

- Evaluating tissue perfusion (tumors, inflammation, transplants)
- Detecting low-flow states (testicular torsion, ovarian torsion)
- Imaging small vessel architecture
- When directional information is not required
- In situations with suboptimal Doppler angles

# 4. Spectral Doppler Analysis

Spectral Doppler provides detailed quantitative information about blood flow by displaying velocity as a function of time. It analyzes the frequency distribution of reflected ultrasound signals and displays them as a waveform.

## Types of Spectral Doppler

### 1. Pulsed Wave (PW) Doppler

- Range-specific: samples flow at a specific depth (sample volume)
- Subject to aliasing at high velocities
- Nyquist limit: PRF/2
- Best for: low-to-moderate velocities, specific location sampling

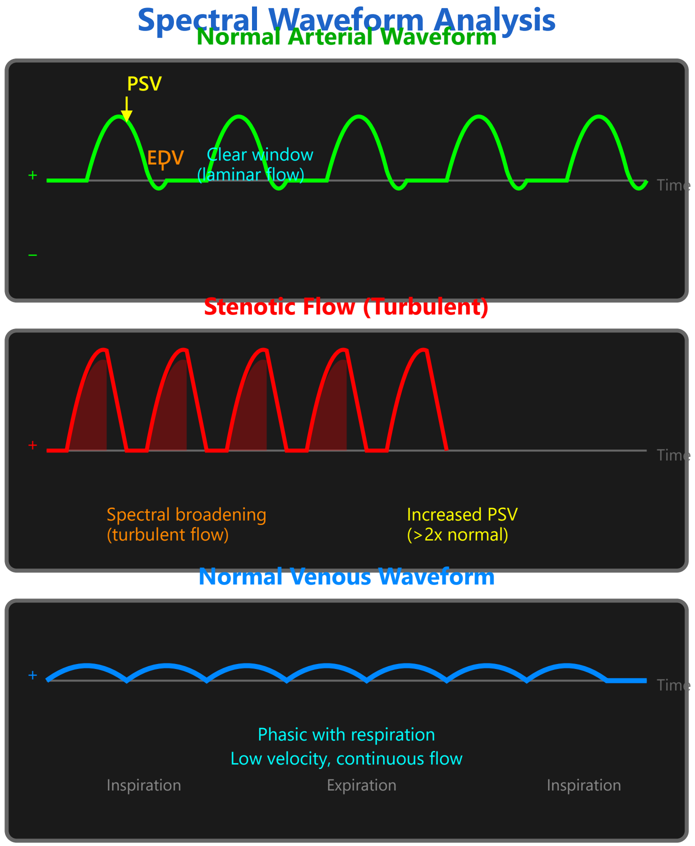
### 2. Continuous Wave (CW) Doppler

- No range resolution: samples all velocities along the beam
- No aliasing: can measure very high velocities

- Best for: high-velocity jets (stenosis, regurgitation)
- Trade-off: cannot specify exact location of flow

## Waveform Analysis Components

- **Peak Systolic Velocity (PSV):** Maximum velocity during systole
- **End Diastolic Velocity (EDV):** Minimum velocity at end of diastole
- **Mean Velocity:** Average velocity over cardiac cycle
- **Spectral Broadening:** Width of waveform (indicates flow disturbance)
- **Spectral Window:** Clear area under systolic peak (laminar flow)




**Important Indices:**

- **Resistive Index (RI):** (PSV - EDV) / PSV (normal: 0.5-0.7 in renal arteries)
- **Pulsatility Index (PI):** (PSV - EDV) / Mean velocity
- **Velocity Ratio:** PSV at stenosis / PSV proximal (>2.0 suggests ≥50% stenosis)
- These indices help assess vascular resistance and stenosis severity

# 5. Clinical Applications

Doppler ultrasound has revolutionized non-invasive vascular and cardiac assessment. Its applications span multiple medical specialties, providing real-time functional information that complements anatomical imaging.

## Vascular Applications

### Carotid Artery Assessment

- **Stenosis grading:** Velocity measurements classify disease severity
- Normal ICA PSV: <125 cm/s
- 50-69% stenosis: PSV 125-230 cm/s
- ≥70% stenosis: PSV >230 cm/s
- Used for stroke risk stratification and surgical planning

### Deep Vein Thrombosis (DVT)

- Absence of flow in compressible vein suggests acute thrombosis
- Augmentation testing: manual compression increases flow in patent veins
- Color filling defects indicate thrombus
- Chronic DVT shows recanalization patterns

### Peripheral Arterial Disease

- Monophasic waveforms indicate distal stenosis/occlusion

- Ankle-brachial index (ABI) calculation support
- Post-stenotic turbulence detection
- Bypass graft surveillance

## Cardiac Applications

### Valvular Assessment

- **Stenosis:** Peak velocity through valve indicates severity
- Aortic stenosis: Velocity >4 m/s = severe
- **Regurgitation:** Retrograde flow and jet characteristics
- Pressure gradient calculations using Bernoulli equation: $\Delta P = 4V^2$

### Cardiac Output Measurement

- Stroke volume = VTI × CSA (velocity time integral × cross-sectional area)
- Cardiac output = Stroke volume × Heart rate
- Diastolic function assessment (E/A ratio, E/e' ratio)

## Obstetric Applications

### Fetal Assessment

- **Umbilical artery:** Placental resistance monitoring
- Absent or reversed end-diastolic flow = severe fetal compromise
- **Middle cerebral artery (MCA):** Fetal anemia detection

- Increased PSV in MCA suggests fetal anemia
- **Ductus venosus:** Cardiac function indicator

## Abdominal Applications

| Application | Key Findings | Clinical Significance |
| --- | --- | --- |
| **Portal vein** | Hepatopetal vs hepatofugal flow | Portal hypertension diagnosis |
| **Hepatic veins** | Triphasic waveform | Right heart function assessment |
| **Renal arteries** | PSV >180 cm/s, RI <0.5-0.7 | Renal artery stenosis screening |
| **Transplant kidney** | RI >0.8, absent diastolic flow | Rejection or vascular complication |
| **Testicular torsion** | Absent intratesticular flow | Surgical emergency confirmation |

## Emerging Applications

- **Contrast-enhanced ultrasound:** Microbubble agents enhance Doppler signals for tumor characterization
- **Elastography guidance:** Doppler helps differentiate vessels from solid lesions
- **Interventional guidance:** Real-time vascular access monitoring
- **Musculoskeletal:** Inflammatory arthritis assessment via synovial hyperemia

### Clinical Pearls

- Always optimize Doppler angle (30-60°) for accurate velocity measurements
- Use appropriate PRF to avoid aliasing in spectral Doppler
- Color Doppler for rapid screening, spectral for quantification

- Power Doppler for slow flow and tissue perfusion assessment
- Consider patient factors: cardiac output, blood pressure, medications