

Ultrasound Physics Vocabulary Reference

Chapters 19–22 | Edelman, *Understanding Ultrasound Physics*, 4th Ed.

An In-Depth Review by Dr. Alice Matthews

amatthews@concorde.edu

Chapter 19: Doppler

Term	Definition	Analogy / Example
Aliasing	An artifact unique to pulsed wave Doppler in which high blood velocities exceed the system's sampling rate and are incorrectly displayed as flowing in the opposite direction. On a spectral display, aliasing appears as "wraparound" of the velocity signal to the other side of the baseline. Aliasing occurs when the Doppler shift exceeds the Nyquist limit.	Like a car wheel in a movie that appears to spin backwards when the car speeds up: the camera (sampling rate) cannot keep up with the true motion.
Autocorrelation	The digital technique used to analyze color flow Doppler signals. It is somewhat less accurate than FFT but substantially faster, which is necessary because of the enormous amount of data processed in two-dimensional color Doppler.	Like a quick estimate vs. a precise calculation: autocorrelation trades a little accuracy for the speed needed to fill an entire 2D color image in real time.
Color Flow Doppler	A form of two-dimensional Doppler that assigns colors to represent the direction and velocity of blood flow, superimposed on a grayscale anatomic image. Uses pulsed ultrasound, so it has range resolution but is subject to aliasing. Two common display modes: velocity mode (direction and speed) and variance mode (adds turbulence detection).	Like a weather radar map overlaid on a geographic map: blue and red show which way and how fast the "storm" (blood) is moving, all on top of a picture of the anatomy.
Continuous Wave (CW) Doppler	A Doppler technique using two crystals: one continuously transmits and the other continuously receives. Its greatest advantage is the ability to accurately measure very high velocities without aliasing. Its primary disadvantage is range ambiguity (it cannot determine the exact depth of the moving blood cells).	Like a highway speed camera that reads every car on the road but cannot tell which lane the speeding car is in.
Crosstalk	A special form of mirror image artifact unique to spectral Doppler. An identical spectrum appears both above and below the baseline, making unidirectional flow look bidirectional. Caused by excessive receiver gain or a Doppler angle near 90°.	Like hearing an echo of your own voice repeated back: the same signal appears as a "ghost copy" on the other side of the baseline.
Doppler Angle (θ / Angle of Insonation)	The angle between the direction of the sound beam and the direction of blood flow. At 0° (parallel), the full Doppler shift is detected. At 90° (perpendicular), no Doppler shift is detected ($\cos 90^\circ = 0$). Clinically, angles less than 60° are preferred for accuracy.	Trying to hear a train horn: standing on the tracks (0°) you hear the full pitch change; standing at a right angle to the tracks (90°) you hear almost no change.
Doppler Equation	Doppler shift = $(2 \times \text{blood velocity} \times \text{transducer frequency} \times \cos\theta) / \text{propagation speed}$. The "2" accounts for the double shift: once when sound hits the moving blood cells, and again when the reflection returns to the transducer.	The equation is like a recipe that combines four ingredients (velocity, frequency, angle, and tissue speed) to calculate how much the pitch changes.

Term	Definition	Analogy / Example
Doppler Packet (Ensemble Length)	The group of multiple ultrasound pulses sent along each color Doppler scan line to accurately determine blood cell velocities. Larger packets improve velocity accuracy and sensitivity but reduce frame rate.	Like taking multiple photos of a runner to precisely measure their speed: more photos = more accurate measurement, but slower to process.
Doppler Shift (Doppler Frequency)	The change in frequency of sound that results from relative motion between the sound source and the receiver. A positive shift indicates flow toward the transducer; a negative shift indicates flow away. The Doppler shift is a low frequency that "rides" on top of the much higher transmitted frequency.	A motorcycle approaching you sounds higher pitched; as it passes and moves away, the pitch drops. That perceived frequency change is the Doppler shift.
Duplex Imaging	The simultaneous performance of anatomic (B-mode) imaging and Doppler (either PW or CW) using the same transducer. The grayscale image shows anatomy while the Doppler provides flow information.	Like watching a security camera (anatomy) while also listening to an audio feed (Doppler) from the same location at the same time.
Fast Fourier Transform (FFT)	The digital (computer-based) mathematical technique used to process pulsed and continuous wave Doppler signals into a spectral display. Extremely accurate and displays all individual velocity components, allowing distinction between laminar and turbulent flow.	Like a prism that splits white light into all its component colors: FFT splits a complex Doppler signal into all its individual velocity frequencies.
Nyquist Limit	The maximum Doppler frequency shift that a pulsed system can accurately measure without aliasing. $\text{Nyquist limit} = \text{PRF} / 2$. Velocities producing Doppler shifts above this limit will alias.	A speed limit sign for pulsed Doppler: any blood velocity that produces a shift above $\text{PRF} / 2$ will be misrepresented. Five techniques to avoid aliasing: maximize scale, lower frequency, shallower gate, use CW Doppler, or baseline shift.
Power Doppler (Energy Mode / Color Angio)	A Doppler display that only identifies the presence of a Doppler shift without evaluating speed or direction. It is nondirectional. Power Doppler displays the amplitude (strength) of the reflected signal rather than velocity. It is more sensitive to low-velocity flow and small blood volumes than conventional color Doppler.	Like an angiogram of blood vessels: all vessels light up the same color regardless of flow direction, making it ideal for detecting the presence of any flow at all.
Pulsatility Index (PI)	A quantitative Doppler-derived measurement similar to RI but using the mean velocity: $\text{PI} = (\text{peak systolic velocity} - \text{end diastolic velocity}) / \text{mean velocity}$. PI can exceed 1.0 and is useful when end-diastolic flow is absent or reversed.	Like RI but normalized to average flow rather than peak flow, making it useful even when the faucet completely shuts off between surges.
Pulsed Wave (PW) Doppler	A Doppler technique using a single crystal that alternates between transmitting and receiving. The sonographer places a sample volume (gate) at a specific depth to measure velocity at that location. Provides range resolution but is subject to aliasing at high velocities.	Like pointing a radar gun at one specific car in one specific lane: you know exactly where the measurement came from, but the gun has a speed limit it can read.
Resistivity Index (RI)	A quantitative Doppler-derived measurement of downstream vascular resistance. $\text{RI} = (\text{peak systolic velocity} - \text{end diastolic velocity}) / \text{peak systolic velocity}$. Values range from 0 to 1. Higher RI indicates greater downstream resistance.	Like grading how much a faucet restricts water flow: an RI of 0 means no restriction (continuous flow), while an RI of 1 means complete restriction (flow stops between pulses).

Term	Definition	Analogy / Example
Sample Volume (Gate)	The small region of interrogation in a pulsed wave Doppler exam. The sonographer positions the sample volume on a 2D image at the desired depth. Only Doppler shifts from blood cells within this region are measured.	Like placing a microphone at one specific seat in a concert hall: you only hear what happens at that exact location.
Spectral Broadening	An increase in the range of velocities displayed on a Doppler spectrum, resulting in "filling in" of the spectral window. Can be caused by turbulent flow (pathologic) or by a large sample volume, wide beam, or intrinsic broadening (technical).	In laminar flow, the spectrum shows a thin line because most cells move at similar speeds. In turbulent flow, the spectrum fills in because cells are moving at many different speeds, like a highway where cars are going 20 to 80 mph simultaneously.
Spectral Window	The clear (dark) area beneath the Doppler waveform on a spectral display, present during normal laminar flow when most blood cells travel at similar velocities. The window "fills in" with spectral broadening during turbulence or with technical artifacts.	Like the gap between the waveform and the baseline on a clean Doppler tracing. When it fills in, it suggests either disturbed flow or a technical problem.
Variance Mode (Color Map)	A color Doppler display that provides direction and speed information (like velocity mode) plus distinguishes laminar flow from turbulent flow. In addition to directional colors, a third color (typically green or yellow) is added to indicate turbulence.	Like velocity mode with a built-in turbulence detector: smooth flow shows clean red or blue, while chaotic flow shows green or yellow mixed in.
Velocity Mode (Color Map)	A color Doppler display where colors indicate flow direction and speed. One color represents flow toward the transducer; the other represents flow away. Faster velocities appear as brighter shades. Color changes are always vertical on the color bar (up/down), never side to side.	Red toward, blue away (or vice versa, depending on the map). Brighter red = faster toward; brighter blue = faster away.
Wall Filter (High-Pass Filter)	An electronic filter that eliminates low-frequency Doppler shifts caused by moving tissue (vessel walls, heart muscle) rather than blood flow. On a spectral display, these unwanted low-frequency signals are called clutter; on a color display, they are called ghosting.	Like noise-canceling headphones tuned to block the low rumble of an engine so you can hear the higher-pitched conversation (blood flow) clearly.

Chapter 20: Artifacts

Term	Definition	Analogy / Example
Anechoic	An extreme form of hypoechoic, meaning entirely without echoes (echo-free). Appears completely black on the image.	Simple fluid (urine in the bladder, bile in the gallbladder) appears anechoic because sound passes through without reflecting.
Artifact	Any error in imaging. An artifact is information on the display that does not accurately represent the anatomic structures being imaged. Artifacts may add, remove, or misplace structures. Ultrasound imaging relies on several assumptions, and when those assumptions are violated, artifacts result.	Like a fun-house mirror: the reflection exists, but it does not accurately represent reality.

Term	Definition	Analogy / Example
Comet Tail (Ring-Down)	A special form of reverberation where closely spaced reverberations merge into a solid, hyperechoic line directed downward from a small, highly reflective structure. Often seen with metallic objects or gas bubbles.	Like reverberation with the spaces squeezed out: instead of separate echoes, you see a bright, continuous streak trailing downward.
Edge Shadow	A special form of shadowing that appears as a hypoechoic region extending along the edge of a curved reflector. Caused by refraction at the curved surface, which bends and diverges the beam.	Like light bending around the edge of a glass sphere: sound refracts at the rounded edge of a cyst, creating thin shadow lines on either side.
Enhancement (Posterior Enhancement / Through-Transmission)	A hyperechoic (brighter than expected) region appearing beneath structures with abnormally low attenuation (such as fluid-filled cysts). The correct number of reflectors is displayed, but some appear overly bright.	Like sunlight passing through a clean window: the area behind the window (cyst) appears brighter because less energy was absorbed along the way.
Focal Enhancement (Focal Banding)	A special form of enhancement in which a horizontal band of the image appears brighter at the depth of the focal zone, where beam intensity is greatest. Has the same appearance as an incorrect TGC setting.	Like a horizontal bright stripe across the image at the depth of the focus, as if someone turned up the brightness for just that one depth.
Hyperechoic	Portions of an image that are brighter than surrounding tissues, or tissues that appear brighter than normal.	Bone and calcifications appear hyperechoic (bright white) because they strongly reflect sound.
Hypoechoic	Portions of an image that are not as bright as surrounding tissues, or tissues that appear less bright than normal.	Fat often appears hypoechoic (darker gray) relative to surrounding soft tissue.
Isoechoic	Describes structures that have the same brightness as surrounding tissues, making them difficult to distinguish from adjacent anatomy.	A liver lesion that is the same shade of gray as normal liver tissue is isoechoic and may be nearly invisible.
Mirror Image Artifact	Created when sound reflects off a strong reflector (the "mirror"), then redirects toward a second structure, causing a duplicate copy of that structure to incorrectly appear on the image on the opposite side of the mirror. Common near the diaphragm.	Like seeing a reflection of a lamp in a window: the lamp appears to exist both inside the room and outside. The diaphragm commonly acts as the mirror, creating a false copy of the liver above it.
Multipath Artifact	Created when a sound pulse takes an indirect path to or from a reflector, bouncing off an intervening structure. The transmit path length differs from the return path length, producing subtle, nonspecific image distortion that cannot be explicitly identified.	Like a billiard ball that banks off a rail before hitting its target: the ball arrives, but the path was not straight, so the system miscalculates the location.
Reverberation	An artifact appearing as multiple, equally spaced echoes caused by sound bouncing back and forth between two strong, parallel reflectors. Each successive echo is weaker and placed deeper on the image than the actual structure.	Like standing between two parallel mirrors: you see infinite copies of yourself stretching into the distance, each one fainter.
Shadowing	A hypoechoic or anechoic region extending downward from a structure with very high attenuation. Shadows prevent the display of true structures located deeper than the attenuating object.	Like a shadow cast by a rock blocking sunlight: nothing behind the rock is illuminated. Gallstones and bones commonly produce acoustic shadows.
Speed Error (Range Error / Range Ambiguity Artifact)	Created when sound propagates through a medium at a speed other than the assumed 1,540 m/s. Structures appear at incorrect depths: too shallow if the actual speed is faster than 1,540 m/s (shorter go-return time), too deep if slower.	Like a GPS that assumes you drive 60 mph: if you actually drive 70, the GPS calculates you have gone farther than you have, placing your pin at the wrong location.

Term	Definition	Analogy / Example
Subdicing	The process of dividing each PZT array element into smaller pieces to reduce grating lobe artifacts. Grating lobes can be further reduced by applying special electrical voltages to inactive (non-firing) elements.	Like cutting a picket fence's wide slats into thinner strips: the narrower gaps reduce the unwanted light beams (grating lobes) that pass through.

Chapter 21: Quality Assurance

Term	Definition	Analogy / Example
AIUM 100 mm Test Object	An older quality assurance device: a fluid-filled tank with strategically located stainless steel pins or plastic strings. The speed of sound matches soft tissue (1,540 m/s), but it lacks attenuation properties, so grayscale cannot be evaluated. Originally designed for A-mode and static scanners.	Like an older, simpler version of the tissue phantom: it tests distances and positions accurately but cannot check brightness or gray-scale performance.
Dead Zone	The region closest to the transducer where images are inaccurate and diagnostically unreliable. Caused by transducer ringing and the time required for the system to switch from transmit to receive mode. Extends from the transducer face to the shallowest depth from which meaningful reflections appear.	Like the blind spot right in front of your car bumper: you cannot see anything in that zone, no matter how good your mirrors are.
Quality Assurance (QA)	The routine evaluation of an ultrasound system and its transducers to validate the consistency of images and the accuracy of measurements. A medical and legal necessity for every laboratory. Includes system assessment, repairs, preventive maintenance, and record keeping.	Like taking your car in for regular inspections: you check the brakes, tires, and engine to make sure everything still works properly before problems arise.
Range Accuracy (Vertical Depth Calibration)	The system's accuracy in placing reflectors at correct depths along the direction parallel to the sound beam. Errors may indicate a problem with the system's assumed propagation speed. Sometimes called the "caliper check."	Like verifying that a ruler's markings are spaced correctly: if the ruler says 5 cm, there should actually be 5 cm between two pins in the phantom.
Registration Accuracy	The ability of the system to place reflections in their proper positions while imaging from different orientations. Tested by scanning a phantom from multiple angles and verifying that pin positions remain consistent.	Like checking that a map is accurate from every direction: whether you enter a city from the north or south, the landmarks should appear in the same locations.
Sensitivity	The ability of a system to detect and display weak (low-level) echoes. Evaluated at minimum, normal, and maximum settings. Minimum sensitivity assesses the weakest echo the system can accurately display, typically in the far field.	Like the sensitivity of a microphone: a highly sensitive mic picks up whispers, while a less sensitive one only catches shouts.
Tissue-Equivalent Phantom	A test device that mimics the acoustic properties of soft tissue (propagation speed of 1,540 m/s, attenuation, scattering, and echogenicity). Contains targets such as pin groups, cyst-like structures, and solid masses for evaluating system performance. Preferred over the older AIUM 100 mm test object because it allows grayscale evaluation.	Like a crash-test dummy for ultrasound: it simulates real tissue so you can test the machine without needing a patient.
Uniformity	The system's ability to display similar reflectors in the phantom with echoes of equal brightness, regardless of depth. Proper TGC settings should make identical reflectors appear the same on the monitor.	Like checking that all the bulbs in a string of lights are the same brightness: identical structures at different depths should look the same.

Chapter 22: Bioeffects & Safety

Term	Definition	Analogy / Example
ALARA Principle	"As Low As Reasonably Achievable." The guiding safety policy that ultrasound exposure should be kept to the minimum level necessary to obtain diagnostic information. The benefits to the patient must always outweigh the risks of the exam.	Like the rule "use the least amount of seasoning needed to make the dish taste good": use the lowest power and shortest scan time that still gives a diagnostic image.
Bioeffects	The effects of ultrasound on the biological tissue through which it passes. The two primary mechanisms are thermal (heat-related) and mechanical (cavitation-related). No confirmed bioeffects on patients or sonographers have been reported at diagnostic intensity levels.	Like asking, "Does shining this flashlight cause any changes to what it illuminates?" At diagnostic levels, no harmful changes have been confirmed.
Cavitation	A mechanical bioeffect involving the interaction of ultrasound with microscopic gas bubbles (gaseous nuclei) in tissue. Has two forms: stable cavitation (bubbles oscillate but do not burst, at lower MI levels) and transient cavitation (bubbles violently collapse/burst, at higher MI levels). Transient cavitation is also called inertial cavitation.	Stable cavitation is like a balloon gently inflating and deflating with each sound pulse. Transient cavitation is like that balloon popping: the violent collapse can damage nearby tissue.
Epidemiology	A branch of medicine that uses population studies (clinical surveys) to investigate whether ultrasound exposure is associated with adverse outcomes. Epidemiologic data indicate that diagnostic ultrasound exposure is not associated with adverse fetal outcome.	Like surveying thousands of travelers to determine if a new highway is safer: you look at large populations over time to detect any patterns of harm.
Hydrophone (Microprobe)	A device used to measure acoustic pressure in a sound field. Consists of a tiny piece of piezoelectric material (like a small hypodermic needle) that can be moved to various locations to map the beam's shape and determine output parameters like period, PRF, and pulse duration.	Like a tiny underwater microphone that you move around in the sound beam to measure how loud (how much pressure) the beam is at each point.
In Vivo vs. In Vitro	In vivo studies examine bioeffects in living organisms (animals or humans). In vitro studies examine bioeffects on cells, tissues, or organisms outside the body (in a laboratory setting). In vitro findings that claim direct clinical significance without in vivo validation should be viewed with caution.	In vivo is like testing a new seatbelt in an actual car crash. In vitro is like testing the seatbelt material in a laboratory stretching machine. Both are useful, but lab results do not always predict real-world outcomes.
Mechanical Index (MI)	A calculated, unitless number displayed on the ultrasound screen that indicates the likelihood of harmful bioeffects from cavitation. MI is the best indicator of mechanical bioeffects. Higher MI values correlate with greater likelihood of cavitation. MI increases with higher peak negative pressure and lower frequency.	Like a "danger level" gauge for cavitation: as MI climbs, the risk of bubble-related tissue damage increases.
Output Display Standard (ODS)	The requirement that real-time values of the Thermal Index (TI) and Mechanical Index (MI) be displayed on the ultrasound screen during scanning. This allows the sonographer to monitor potential bioeffect risks and apply the ALARA principle.	Like a car dashboard showing speed and engine temperature: TI and MI are always visible so the sonographer can keep exposure within safe limits.

Term	Definition	Analogy / Example
Thermal Bioeffect	The mechanism by which ultrasound causes tissue temperature elevation as sound energy is absorbed and converted to heat. Maximal heating is related to the beam's SPTA (spatial peak, temporal average) intensity. No confirmed bioeffects for temperature elevations up to 2°C above normal for exposures less than 50 hours. Fetal tissue is less tolerant of heating than adult tissue.	Like a heating pad: the energy warms the tissue. At low power (diagnostic levels), the warming is negligible; at extreme levels, it could cause damage.
Thermal Index (TI)	A calculated, unitless number displayed on the ultrasound screen that estimates the potential for tissue temperature rise. Higher TI values indicate greater potential for heating. Three subtypes exist: TIS (soft tissue), TIB (bone at or near the focus), and TIC (cranial bone at the surface).	Like a thermometer warning label on the screen: a TI of 1.0 suggests the tissue could warm by approximately 1°C under worst-case conditions.

Dr. Alice Matthews · amatthews@concorde.edu · alice@deepneuro.ai · Concorde Career College Portland