

Week 3: Ultrasound Physics & Instrumentation

CVSG2280 Cardiovascular Registry Review by Dr. Alice Matthews

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Registry weight this week. Physics is the engine room of every other module. **ARDMS RDCS** (Adult Echo V24.2): this week feeds **Instrumentation 9%** directly and underpins **Measurement/Views 25%** and **Clinical Care/Safety 11%** (bioeffects, ALARA). **CCI RCS**: maps to **Domain E (Physics of Ultrasound) 13%**. If you also sit the **ARDMS SPI** exam, the same content is weighted even more heavily there: **Doppler 34%** and **Image Optimization 26%** are the two largest SPI domains. Roughly one in nine RDCS items and one in eight RCS items is pure physics, and physics literacy quietly decides whether you read the Doppler and measurement questions correctly.

Note to students: This guide follows **Edelman, *Understanding Ultrasound Physics* (4th ed.)**, the [ARDMS SPI outline](#), and the safety / output-display recommendations summarized by the [AIUM official statements](#) on bioeffects and ALARA. Doppler velocity numbers match the [ASE guideline library](#) values used across these guides. **What Week 2 gives you:** the views and windows you learned last week are where you place every sample volume; this week explains why the machine behaves the way it does when you get there. Always defer to the protocol your clinical site follows.

At a Glance: this week in one box

Must-know numbers. Speed of sound in soft tissue **1,540 m/s** ($= 1.54 \text{ mm}/\mu\text{s}$). Attenuation **0.5 dB/cm/MHz** (the 0.5 rule). **13 μs** round-trip = 1 cm depth. Diagnostic frequencies **2 to 10 MHz** (cardiac 2.5 to 5 MHz). Keep the **cardiac Doppler angle** **< 20°** (ideally 0°); at 60° you lose 50% of velocity; at 90° the signal is zero. (**Vascular** duplex is different: it uses an angle-corrected **60°** ($\leq 60^\circ$) intercept because vessels run parallel to the skin.)

Formulas you will reuse. $\lambda = 1.54/f$; range equation $d = (1.54 \times t)/2$; $PRF = 77,000/d$; axial resolution $AR = SPL/2$; Doppler $\Delta F = 2F_0 V \cos \theta / c$; Nyquist $f_{Nyq} = PRF/2$.

Top 3 EOM traps. (1) Thinking you can turn a knob to improve **axial** resolution (you cannot; it is fixed by the transducer). (2) Reaching for **output power** when the image is dark (raise receiver gain first; ALARA). (3) Using **PW** Doppler on a high-velocity stenotic jet (it aliases; use CW, which never aliases).

The Sound Wave and Its Parameters

Diagnostic ultrasound is a **mechanical, longitudinal** pressure wave: it needs a medium to travel through and it pushes tissue along the direction of travel. Everything else in this module is built on a handful of wave parameters and which ones you, the sonographer, can actually change.

★ **Frequency and period** are reciprocals: $f = 1/T$. Frequency is the number of cycles per second (Hz); diagnostic ultrasound runs **2 to 10 MHz**. Frequency is fixed by the transducer, not by a knob. ★ **Wavelength** is the physical length of one cycle; in soft tissue $\lambda = 1.54/f$ (mm with f in MHz). Wavelength sets the resolution floor: you cannot resolve two structures closer together than roughly one wavelength.

★ **Propagation speed** in soft tissue is the single most important constant in the course: **1,540 m/s**, which the machine assumes for every depth calculation. Speed depends on the medium (its stiffness and density), *not* on frequency. **Amplitude, power, and intensity** describe the strength of the wave; intensity is proportional to amplitude squared ($I \propto A^2$), so doubling amplitude quadruples intensity. That square relationship is why output power is the bioeffects lever, not gain.

Memory hook: Speed of sound, slowest to fastest: **Air, Fat, Soft tissue, Blood, Muscle, Bone** (“**A Fast Saab Blew My Bumper**”). Pair each medium with its speed: air 500, fat 1,450, soft tissue 1,540, blood 1,560, muscle 1,600, bone 3,500 m/s (exact medium speeds vary slightly by source; some references list muscle near 1,580 m/s). The order, not the second decimal, is what the registry tests.

Tissue or medium	Speed (m/s)	Speed (mm/ μ s)	Attenuation (dB/cm/MHz)
Air	500	0.5	very high
Fat	1,450	1.45	0.45
Soft tissue (reference)	1,540	1.54	0.5
Blood	1,560	1.56	0.18
Muscle	1,600	1.60	0.54
Bone	3,500	3.50	1.5+

Common Trap

A 10 MHz linear probe gives gorgeous detail on the carotid but is useless for an apical four-chamber on an adult. A student concludes the cardiac probe is "lower quality." What is the error?

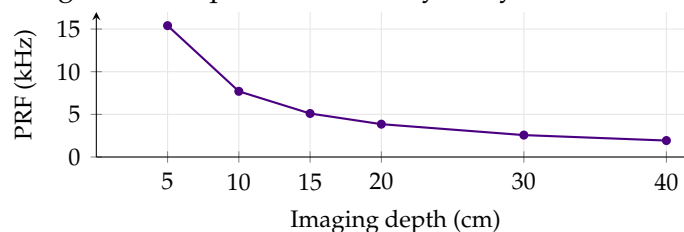
Higher frequency means shorter wavelength and better resolution, but attenuation rises with frequency (the 0.5 rule scales with MHz), so high-frequency beams cannot penetrate to cardiac depth. There is a permanent **resolution-versus-penetration trade-off**: cardiac uses 2.5 to 5 MHz to reach the heart, accepting coarser resolution. Neither probe is "better"; each is matched to its depth.

Pulsed Ultrasound and Timing

Imaging ultrasound is **pulsed**: transmit a short burst, then listen before the next. These timing terms are heavily tested because they cascade into frame rate and aliasing.

★ **Pulse duration (PD)** is the "on" time of one pulse ($PD = n \times T$, where n is the number of cycles). ★ **Spatial pulse length (SPL)** is its physical length ($SPL = n \times \lambda$); SPL is what sets axial resolution. ★ **Pulse repetition period (PRP)** is the time from the start of one pulse to the start of the next, and ★ **PRF** (pulse repetition frequency) is its reciprocal, $PRF = 1/PRP$. **Duty factor** is the fraction of time spent transmitting ($DF = PD/PRP \times 100\%$): imaging is far below 1%, while **CW Doppler is 100%** (always transmitting and listening).

★ The **13-microsecond rule**: sound takes about 13 μ s to travel 1 cm and return. From it comes the depth-to-PRF relationship $PRF = 77,000/d$ (d in cm). Deeper imaging needs a longer listening window, which lowers PRF, which lowers frame rate. This single chain explains most "why is my frame rate so low?" questions.



PRF falls as imaging depth rises ($PRF = 77,000/d$). Representative points: 5 cm $\rightarrow$ 15.4 kHz ($\sim$ 154 fps); 10 cm $\rightarrow$ 7.7 kHz ($\sim$ 77 fps); 20 cm $\rightarrow$ 3.85 kHz ($\sim$ 38 fps); 40 cm $\rightarrow$ 1.93 kHz ($\sim$ 19 fps). Deeper imaging is slower imaging.

Attenuation, Impedance, and Propagation

★ **Attenuation** is the weakening of sound as it travels (absorption, reflection, scatter). In soft tissue it follows the **0.5 rule: 0.5 dB per cm per MHz**. The **half-value layer** is the depth at which intensity drops by 50% (a 3 dB loss). **Watch the decibel trap: 3 dB is half the intensity**, but **6 dB is half the amplitude** (which is one quarter of the intensity, since $I \propto A^2$); the exam likes to swap these. ★ **Acoustic impedance** ($Z = \rho \times c$, density times speed) governs how much sound reflects at a boundary: the bigger the impedance mismatch, the stronger the reflection. Air-to-skin is a near-total mismatch, which is exactly why **coupling gel** is mandatory; it removes the air gap so almost all the sound enters the body.

★ **Speed-error artifact** comes from the 1,540 m/s assumption. Through **fat (1,450 m/s, slower)** the echo returns later than the machine expects, so structures are placed **too deep**; through a faster path the echo returns early, so structures are placed **too shallow**. **Snell's law** describes **refraction**: at an oblique boundary between two speeds, the beam bends, shifting structures laterally from their true position.

Common Trap

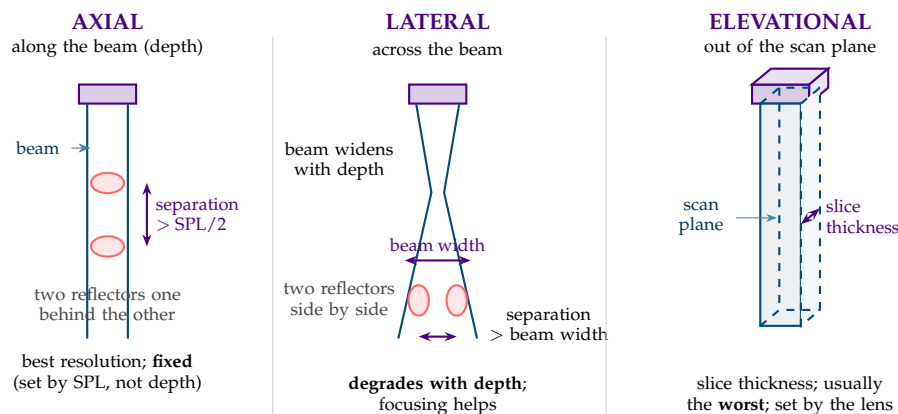
A measurement of a structure imaged through a thick subcutaneous fat layer reads a few millimeters deeper than the same structure measured from a leaner window. A student assumes the deeper number is "more accurate" because the window looked cleaner. What is the error?

Fat propagates sound at about 1,450 m/s, slower than the assumed 1,540 m/s. The slower path makes echoes arrive later, and the machine, still assuming 1,540, plots the structure **too deep**. This is speed-error artifact, not a truer measurement. Confirm depth from an alternate window with less intervening fat.

The Range Equation and Depth

★ Every depth on the screen comes from the **range equation**: $d = (1.54 \times t)/2$ (the machine times the round trip and halves it for the return leg). Depth is the master control: setting deeper imaging lengthens the listening window, which lowers PRF and frame rate, while choosing a higher-frequency probe sharpens resolution but costs penetration through attenuation.

Image Quality and Resolution



The three spatial resolutions. **Axial** (along the beam) resolves two reflectors stacked in depth when their separation exceeds half the spatial pulse length; it is the best resolution and is fixed by the transducer. **Lateral** (across the beam) resolves two side-by-side reflectors when their separation exceeds the beam width; because the beam widens with depth, lateral resolution degrades in the far field and improves with focusing. **Elevational** is the slice thickness perpendicular to the scan plane; it is usually the worst and is set by the lens.

There are three spatial resolutions plus a temporal one; the registry loves asking which a sonographer can and cannot change.

★ **Axial resolution** (along the beam) equals $SPL/2$. It is the **best** of the spatial resolutions (0.1 to 1.0 mm) and is **fixed by the transducer** (frequency, damping, cycles per pulse); you **cannot** improve it with a knob. ★ **Lateral resolution** (across the beam) equals the beam width, so it is best at the focus and worsens in the far field; **focusing and higher frequency can improve it**. **Elevational resolution** (slice thickness, out of the imaging plane) is usually the **worst** and causes slice-thickness artifact. **Temporal resolution** is frame rate; it improves with shallower depth, fewer focal zones, and a narrower sector.

Memory hook: Axial synonyms (**LARRD**): Longitudinal, Axial, Range, Radial, Depth. Lateral synonyms (**LATA**): Lateral, Angular, Transverse, Azimuthal. If the word is on the LARRD list, it is fixed; if it is on the LATA list, focusing helps.

Resolution	Direction	Typical range	Determined by	Sonographer can change?
Axial	Along beam	0.1 to 1.0 mm	$SPL/2$ (frequency, damping, cycles)	No
Lateral	Across beam	1 to 8 mm (worse with depth)	Beam width, focusing, frequency	Partly (focus)
Elevational	Slice thickness	2 to 8 mm	Elevation focus, lens	Limited

Resolution	Direction	Typical range	Determined by	Sonographer can change?
Temporal	Frame to frame	frame rate (fps)	PRF, depth, line density	Yes

Common Trap

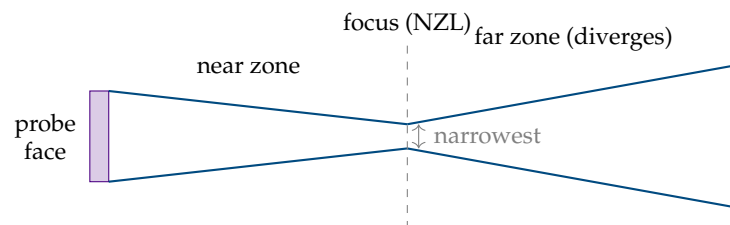
An echo of a small apical thrombus looks blurry. A student turns up the gain and adds focal zones to "sharpen the axial resolution." What is the error?

Axial resolution is **not adjustable**; it is set by the spatial pulse length built into the transducer ($AR = SPL/2$). Gain only brightens; focal zones improve **lateral** resolution near the focus (and lower frame rate). To genuinely improve axial detail you must select a **higher-frequency probe**, accepting reduced penetration.

Transducers and Beam Shape

★ The **piezoelectric (PZT) crystal** converts voltage to sound on transmit and sound to voltage on receive. ★ Crystal **frequency is set by its thickness**: $f = c_{PZT} / (2 \times \text{thickness})$, thinner means higher frequency. **Damping** material shortens the pulse (fewer cycles), which sharpens axial resolution at the cost of penetration. The **quality factor** $Q = f / BW$: imaging probes are **low Q** (short pulse, wide bandwidth), while CW probes are **high Q** (long pulse, narrow bandwidth).

The beam narrows to its tightest point at the **near-zone length**, $NZL = D^2 f / 61.6$ (a larger or higher-frequency element focuses deeper), then diverges in the far field, which is why lateral resolution degrades with depth. **Side lobes** and **grating lobes** are off-axis energy that paint faint copies of strong reflectors in the wrong place.



Beam shape: the beam converges through the near zone to its narrowest point at the near-zone length (focus), then diverges in the far zone. Lateral resolution is best at the focus and worsens with depth.

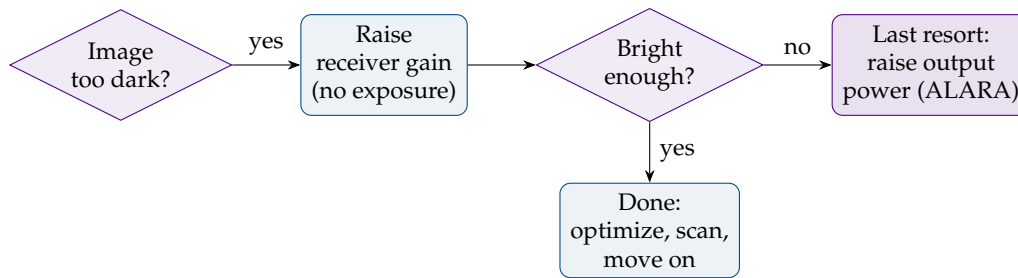
The Receiver Chain and ALARA

★ Returning echoes pass through a fixed pipeline whose order is worth memorizing, because exam questions ask which step does what.

Memory hook: Receiver chain order (All Cats Claw Dusty Rugs): Amplification → Compensation (TGC) → Compression → Demodulation → Reject.

Amplification is master volume on the returning signal. ★ **Time-gain compensation (TGC)** preferentially boosts deep echoes to undo attenuation, so a uniform medium looks uniformly bright. **Compression** squeezes the enormous returning dynamic range (about 120 dB) into the 20 to 30 dB a monitor can show. **Demodulation** rectifies and smooths the signal. **Reject** discards the weakest signals, cleaning up noise.

★ **ALARA** (As Low As Reasonably Achievable) drives the most testable instrumentation rule in echo: **if the image is too dark, raise receiver gain first**; gain costs the patient nothing because it only amplifies returning echoes. **Output power is the last resort** because it raises the transmitted energy and therefore thermal and mechanical bioeffects.



ALARA decision: gain first, output power last. Output power increases patient exposure; receiver gain does not.

Common Trap

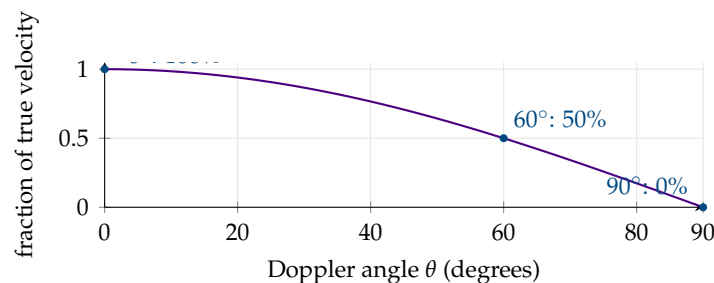
A faint apical four-chamber will not brighten. A student immediately raises **output power** to the maximum to "get a better picture." What is the error?

This violates ALARA. Receiver gain, reject, transmit focus, frequency, and Doppler angle should all be optimized **before** touching output power, because gain amplifies only returning echoes and adds no patient exposure, whereas output power raises thermal (TI) and mechanical (MI) bioeffects. Output power is the **last** lever, not the first.

The Doppler Effect and Doppler Modes

★ The **Doppler effect** is the frequency shift when sound reflects off moving blood: flow toward the transducer raises the returning frequency, flow away lowers it. ★ The **Doppler equation**, $\Delta F = 2F_0 V \cos \theta / c$, carries a factor of 2 (shifted on the way in and out) and a $\cos \theta$ term that is the source of nearly every Doppler error.

★ **The angle problem**: the machine reports $V_{\text{measured}} = V_{\text{true}} \times \cos \theta$. At 0° you capture the true velocity; **at 60° you measure only 50%** ($\cos 60^\circ = 0.5$); **at 90° the shift is zero** and you see no flow. Keep the Doppler angle $< 20^\circ$ in cardiac work. Note that color flow can look absent simply because the beam crossed flow at 90° , not because flow stopped.



The cosine curve: measured velocity is true velocity times $\cos \theta$. Keep the angle below 20° ; the loss is small there but accelerates past 60° .

★ **PW (pulsed-wave)** Doppler samples one depth (the sample volume), so it tells you exactly *where* flow is, but it is limited by the **Nyquist limit** and aliases on fast flow. ★ **CW (continuous-wave)** Doppler uses two crystals listening continuously: it has no depth selectivity but **never aliases**, so it is the tool for high-velocity jets. **Color flow** is PW-based and therefore also Nyquist-limited; it maps direction and velocity in 2D. **Tissue Doppler imaging (TDI)** applies Doppler to slow, high-amplitude myocardial motion to measure the annular e' velocity for diastolic function.

Memory hook: Mode picker: PW for Place (low velocity, exact location); CW for Crank (high velocity, no aliasing); **Color** for the cartoon map.

Feature	PW	CW	Color flow
Range selectivity	yes (sample volume)	no (whole beam)	yes (2D map)
Velocity limit	Nyquist ($\text{PRF}/2$)	unlimited (never aliases)	Nyquist ($\text{PRF}/2$)
Best for	low velocity, exact site	high-velocity jets	direction, extent, PISA
Crystals	1 (time-shared)	2 (simultaneous)	1 array

Nyquist Limit and Aliasing

★ The **Nyquist limit** is the maximum velocity PW Doppler can display unambiguously: $f_{Nyquist} = PRF/2$. ★ **Aliasing** occurs when the true velocity exceeds Nyquist; the signal wraps to the opposite direction on the display.

Memory hook: watch a car **wheel** in a video; spin it fast enough and it appears to rotate backward. The camera samples too slowly to keep up, just as PW samples flow too slowly past Nyquist.

Memory hook: Five fixes for aliasing (only the first four are real physics; the fifth is cosmetic): (1) raise PRF (raise scale); (2) use a lower-frequency transducer (smaller shift for the same velocity); (3) move the sample volume shallower (allows higher PRF); (4) switch to **CW**, which never aliases; (5) shift the baseline (looks better, fixes nothing).

Cardiac flow	Typical velocity	Mode to use	Aliases?
Mitral E wave	60 to 100 cm/s	PW at MV tips	no at usual scale
Normal TR	1.5 to 2.8 m/s	PW or CW	borderline on PW; prefer CW
Aortic stenosis	3 to 6 m/s	CW	never (CW)
Mitral regurgitation	4 to 6 m/s	CW	never (CW)
Severe TR / PASP	3 to 4+ m/s	CW	never (CW)

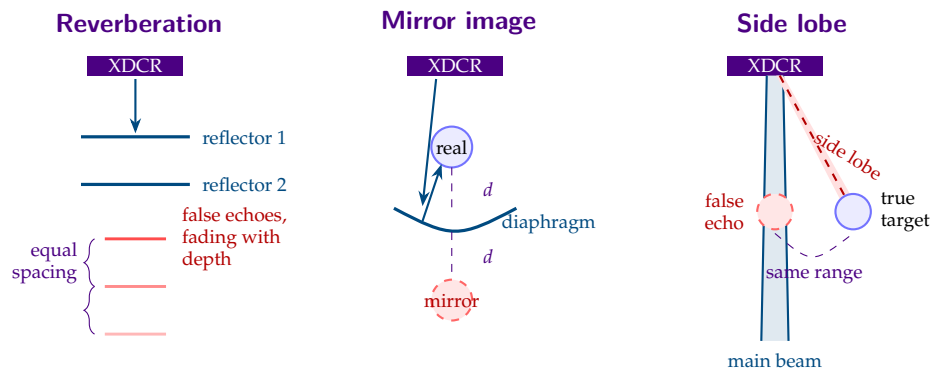
★ A normal TR Vmax is **up to about 2.8 m/s**; values above that prompt the pulmonary-hypertension screen you will use in Week 7 (TR Vmax > 2.8 m/s suggests elevated pulmonary pressure). Always capture the TR jet with **CW** so a high peak is not lost to PW aliasing.

Common Trap

A PW tracing of an aortic-stenosis jet wraps around the baseline and looks chaotic. A student shifts the PW baseline down to "uncover" the true peak velocity and reads a number off it. What is the error?

Baseline shift is cosmetic; it cannot recover a velocity beyond Nyquist, so the read-off peak is wrong. A 3 to 6 m/s stenotic jet far exceeds any PW Nyquist limit. Switch to **CW**, which has no PRF limit and never aliases, and measure the true peak. (For a borderline case, raising PRF, lowering frequency, or moving shallower can help PW; for stenosis, go straight to CW.)

Artifacts



Three classic ultrasound artifacts. Reverberation: two strong parallel reflectors generate equally spaced repeating echoes that fade with depth. Mirror image: a strong reflector (the diaphragm) duplicates a real structure deep to it at equal distance d . Side lobe: off-axis energy places an echo from a target outside the main beam onto the main-beam axis at the same range.

Artifacts arise when the machine's assumptions (straight-line travel at 1,540 m/s, out and directly back, main beam only, thin plane) are violated. Recognize each on sight.

Artifact	Violated assumption	Appearance	Fix or recognition
Reverberation	direct single path	equally spaced parallel lines distal to two reflectors	change angle; increase depth
Side lobe	main beam only	faint copy lateral to a strong echo, same depth	lower gain; reposition
Mirror	single reflection	duplicate beyond a strong specular reflector	change angle; move probe
Refraction	straight-line travel	structure shifted from true position	correlate with other views
Range ambiguity	one echo per pulse	echo at wrong (often half) depth from slow PRF	increase depth; adjust PRF
Acoustic shadowing	even attenuation	dark band distal to bone, calcium, prosthesis, gas	new window; TEE if needed
Enhancement	even attenuation	bright echoes distal to a cyst or chamber	recognize as normal, not disease
Speed error	1,540 m/s constant	depth misplacement (fat too deep; faster path too shallow)	recognize tissue; multiple windows
Slice thickness	thin imaging plane	out-of-plane echoes appear inside a cyst or chamber	confirm in orthogonal view
Dropout	adequate signal	segment of a structure vanishes	raise gain; change angle or frequency

★ **Normal right-atrial variants are not artifacts but are frequently mistaken for masses:** the **Chiari network**, **crista terminalis**, **Eustachian valve**, and **Thebesian valve** are all normal and benign. Knowing them prevents false alarms (a historically low-scoring exam topic).

Harmonic Imaging

Harmonic imaging receives at an integer multiple of the transmitted frequency (the **second harmonic**: transmit near 3.5 MHz, receive near 7 MHz), formed by **nonlinear propagation**. ★ **Advantages**: better lateral resolution and far less side-lobe and near-field clutter, which rescues difficult windows; **disadvantages**: lower penetration and higher output power. **THI** uses native tissue harmonics; **CHI** uses resonating microbubbles for LV opacification.

Bioeffects and Safety

★ The **thermal index (TI)** estimates tissue heating and comes in three flavors: **TIS** (soft tissue, the default), **TIB** (bone at the focus, the fetal-bone concern), and **TIC** (cranial bone near the transducer, for transcranial Doppler). ★ The **mechanical index (MI)**, $MI = P_{neg} / \sqrt{f}$, estimates cavitation risk. Keeping **TI and MI below 1** is the general comfort zone; ALARA means using the lowest output that yields a diagnostic image and minimizing scan time, especially with spectral and color Doppler, which deposit the most energy.

Memory hook: Three thermal indices (Soft, Bone, Cranial): "**Sonographers Behave Carefully.**" Default to TIS; switch your concern to TIB in obstetrics and TIC in transcranial work.

Instrumentation and Machine Controls

Depth sets PRF, frame rate, and penetration at once. **Receiver gain** amplifies returning echoes with no patient exposure (raise first); **output power** raises exposure (raise last). **Frequency** trades penetration against resolution; more **focal zones**, higher **line density**, or a wider **sector** all lower the frame rate. **Reject** filters noise, **compression** maps dynamic range, the **TGC** curve balances brightness with depth, and the **color scale** adjusts color PRF (a baseline shift is cosmetic only). The cheat sheet below collects the "what do I turn, and in what order" answers.

Goal	Turn this UP	Cost / trade-off	First move vs. last resort
Brighter image	Receiver gain	amplifies noise too	first (no exposure)
Brighter image (gain maxed)	Output power	raises TI / MI bioeffects	last resort (ALARA)
Better axial resolution	Probe frequency	less penetration	only lever; not a knob
Better lateral resolution	Transmit focus at region of interest	lower frame rate	adjustable
Higher frame rate	Shallower depth, narrow sector, fewer foci	less coverage	adjustable
Less PW aliasing	PRF / scale	range ambiguity at extremes	first; else switch to CW
Reach a deep structure	Lower frequency, more depth	coarser resolution, slower frame	adjustable
Cleaner near field	Harmonic imaging	less penetration, more output power	adjustable

Essential Formulas

Period and frequency: $T = \frac{1}{f}, f = \frac{1}{T}$ Reciprocals. Frequency is fixed by the transducer; change it by choosing a different probe, not a knob.

Wavelength in soft tissue: $\lambda = \frac{1.54}{f}$ (λ mm, f MHz). Higher frequency means shorter wave; wavelength sets the resolution floor.

Propagation speed: $c_{\text{soft tissue}} = 1540 \text{ m/s} = 1.54 \text{ mm}/\mu\text{s}$ The assumed speed; when tissue differs (fat, bone), you get speed-error depth artifacts.

Intensity and amplitude: $I \propto A^2$ Intensity rises with amplitude squared, so small output-power increases raise exposure steeply (the basis of ALARA).

Pulse duration and spatial pulse length: $PD = n \times T, SPL = n \times \lambda$ (n = cycles). SPL sets axial resolution, so damping (fewer cycles) sharpens the image.

PRP and PRF: $PRP = \frac{1}{PRF}$ Reciprocals. Deeper imaging lengthens PRP, lowers PRF, and slows the frame rate.

Duty factor: $DF = \frac{PD}{PRP} \times 100\%$ Fraction of time transmitting. Imaging is well under 1%; CW is 100%, so CW deposits the most energy.

Attenuation (the 0.5 rule): $\text{Atten. (dB)} = \alpha \times d, \alpha = \frac{f}{2}$ About 0.5 dB/cm/MHz; why high frequencies cannot reach deep and why TGC boosts deep echoes.

Acoustic impedance: $Z = \rho \times c$ Density times speed. Large mismatches (air-skin) reflect almost all sound, which is why gel is required.

Range equation: $d = \frac{1.54 \times t}{2}$ Speed times round-trip time, halved for the return leg. This computes every pixel depth on the screen.

13-microsecond rule and PRF from depth: $13 \mu\text{s} = 1 \text{ cm}, PRF = \frac{77,000}{d}$ (d cm). Each cm of depth costs 13 μs , capping PRF and frame rate.

Axial resolution: $AR = \frac{SPL}{2}$ Half the spatial pulse length. Fixed by the transducer, always better than lateral; improve only via a higher-frequency probe.

Near-zone length: $NZL = \frac{D^2 \times f}{61.6}$ (D cm, f MHz). Bigger or higher-frequency elements focus deeper; the beam is narrowest (best lateral resolution) there.

Doppler equation: $\Delta F = \frac{2 \times F_0 \times V \times \cos \theta}{c}$ Shift depends on velocity and the cosine of the angle, so beam alignment matters for every velocity.

Angle correction: $V_{\text{measured}} = V_{\text{true}} \times \cos \theta$ Off-axis underestimates: 60° loses half, 90° measures nothing. In cardiac work keep the angle under 20° (ideally 0°); **vascular** duplex instead uses an angle-corrected 60° ($\leq 60^\circ$) intercept.

Nyquist limit: $f_{\text{Nyquist}} = \frac{\text{PRF}}{2}$ PW shows velocities up to half the PRF; above it PW aliases, so high-velocity jets need CW.

Glossary

- **Frequency** — cycles per second (Hz); diagnostic 2 to 10 MHz; fixed by the transducer
- **Wavelength** — length of one cycle; $\lambda = 1.54/f$ in soft tissue; sets the resolution floor
- **Propagation speed** — speed of sound in a medium; soft tissue 1,540 m/s
- **Intensity** — power per unit area (W/cm^2); $I \propto A^2$
- **Spatial pulse length (SPL)** — physical pulse length; $n \times \lambda$; sets axial resolution
- **PRF / PRP** — pulses per second ($77,000/d$) and the start-to-start interval ($1/\text{PRF}$); fall with depth
- **Duty factor** — percent time transmitting; imaging $\ll 1\%$, CW 100%
- **Attenuation** — weakening of sound; 0.5 dB/cm/MHz in soft tissue
- **Acoustic impedance (Z)** — $\rho \times c$; governs boundary reflection
- **Acoustic shadowing** — dark band distal to bone, calcium, or prosthesis
- **Axial resolution** — detail along the beam; $\text{SPL}/2$; fixed by the transducer
- **Lateral resolution** — detail across the beam; equals beam width; focusing helps
- **Elevational resolution** — slice thickness out of plane; usually worst
- **Frame rate** — images per second; falls with depth
- **Nyquist limit** — max unambiguous PW velocity; $\text{PRF}/2$
- **Aliasing** — velocity wrapping above the Nyquist limit
- **Piezoelectric effect** — PZT converts voltage to sound and back; thickness sets frequency
- **Damping** — shortens the pulse to improve axial resolution
- **TGC** — time-gain compensation; boosts deep echoes to offset attenuation
- **ALARA** — As Low As Reasonably Achievable; gain first, output power last
- **TI / MI** — thermal index (heating) and mechanical index (cavitation) safety gauges
- **Harmonic imaging** — receive at a multiple of transmit; better near field, less penetration

Registry Connection

Where this week lands. ARDMS RDCS Instrumentation (9%), plus spillover into Measurement/Views (25%) and Clinical Care/Safety (11%); CCI RCS Domain E (13%); and on the ARDMS SPI exam the dominant Doppler (34%) and Image Optimization (26%) domains. **Item formats:** formula recall (wavelength, range equation, PRF from depth, Nyquist, $\text{AR} = \text{SPL}/2$); image-based artifact recognition; "which control, in what order" optimization and ALARA questions; and PW vs CW vs color mode selection with angle and aliasing reasoning. **Carry forward into Week 4:** every valvular measurement you will grade (peak velocity, mean gradient, PISA, pressure half-time, TR-jet RVSP) rides on the Doppler, Nyquist, and angle physics locked in here.

Study smart. Scan with confidence.

[Dr. Alice Matthews](https://deepneuro.ai/alice) · deepneuro.ai/alice

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