

Ultrasound Physics & Terminology

Basic Ultrasound Physics Terms

Ultrasound:	An imaging modality that utilizes sound waves of very high frequency (2 MHz or greater, 20 MHz+ is referred to “micro-ultrasound” or “high-frequency ultrasound”). It is propagated via waves of compression and rarefaction, and requires a medium (tissue) for travel. The higher the frequency, the better the resolution however the depth of penetration is lower.
Resolution:	The parameter of an ultrasound imaging system that characterizes its ability to detect closely spaced interfaces and displays the echoes from those interfaces as distinct and separate objects. The better the resolution, the greater the clarity of an ultrasound image.
Axial Resolution:	The minimum reflector separation along the direction of propagation required to produce separate reflections. Good axial resolution is achieved with short spatial pulse lengths. Short spatial pulse lengths are a result of higher frequency and higher damped transducers . Therefore the higher the frequency, the better the resolution .
Lateral Resolution:	The minimum reflector separation perpendicular to the direction of propagation required to produce separate reflections. Good lateral resolution is achieved with narrow acoustic beams. A narrow acoustic beam is the result of a long near zone and a small angle of divergence in the far zone.
Transducers (or probe):	<p>A device which houses the element(s) for transmitting and receiving ultrasound waves. Also referred to as a probe or scanhead.</p> <p>Ultrasound transducers convert electric energy into ultrasound energy and vice versa. Transducers operate on piezoelectricity, meaning that some materials (ceramics, quartz) produce a voltage when deformed by an applied pressure, and reversely results in a production of pressure when these materials are loaded with an applied voltage.</p>
Linear-array transducer:	<p>Transducers with multiple elements arranged in a linear fashion. Each element is sequentially fired to produce parallel beams of ultrasound, creating a rectangular field of view.</p> <p>Note: This is the case of the Vevo 2100 and 3100; MS and</p>

	MX series transduces.
Attenuation:	A decrease in amplitude and intensity as sound travels through a medium. Attenuation occurs with absorption (conversion of sound to heat), reflection (portion of sound returned from the boundary of a medium, and scattering (diffusion or redirection of sound in several directions when encountering a particle suspension or a rough surface). These different forms of attenuation are responsible for artifacts that may be in your image . Some of these artifacts are useful and some are not. Some artifacts are produced by improper transducer location or machine settings .

Basic Principles of Ultrasound

Sound Waves

Audible sound waves lie within the frequency range of 20 to 20,000 Hz. Conventional ultrasound systems use transducers of between 2 and 17 MHz. The Vevo micro-ultrasound system uses frequencies of between 15 - 70 MHz..

Sound waves do not exist in a vacuum, and propagation in gases is poor because the molecules are too widely spaced. This is why lung does not image well with ultrasound.

A coupling gel is used between the skin of the subject and the transducer face to allow transmission across the otherwise air-filled gap.

The strength of the returning echo is directly related to the angle at which the beam strikes the acoustic interface. The more nearly perpendicular the beam is, the stronger the returning echo; smooth interfaces at right angles are known as specular reflectors. This is best seen in the walls of a large blood vessel such as the aorta or the carotid artery.

Commonly Used Ultrasound Terms

Frequency:	The number of complete cycles per second (Hertz)
Gain:	The amount of amplification of the returning echoes.
Coupling Gel:	A trans-sonic material which eliminates the air interface between the transducer and the animal's skin.
Homogenous:	Of uniform appearance and texture.
Anechoic:	A structure that does not produce any internal echoes.
Hypo-echoic:	A relative term used to describe an area that has decreased brightness of its echoes relative to an adjacent structure.
Hyper-echoic:	A relative term used to describe a structure which has increased brightness of its echoes relative to an adjacent structure.
Interface:	Strong echoes that delineate the boundary of organs, caused by the difference between the acoustic impedance of the two adjacent structures; an interface that is usually more pronounced when the transducer is perpendicular to it.
Noise:	An artifact that is usually due to the gain control being too high.
Velocity (of sound):	The speed at which a sound wave is traveling. In soft tissue (at 37 degrees C) sound travels at 1540 m/second.

Commonly used Imaging Modes and Tools

B-MODE (brightness mode):

- Standard two-dimensional display of ultrasound. Ultrasound signals are electronically converted into dots and displayed at the correct depth from the transducer.
- The display of echos returning to the transducer are represented by shades of gray.
- Typically the brighter gray shades represent echoes with greater intensity levels. **This is the main mode that allows real-time scanning.**

Time Gain Compensation (TGC):

- Sound attenuates as it travels deeper into tissue and TGC compensates for this attenuation.
- TGC Equalizes differences in received reflection amplitudes because of the reflector depth. Reflectors with equal reflector coefficients will not result in equal amplitude reflections arriving at the transducer if their travel distances are different.
- TGC allow you to adjust the amplitude to compensate for the path length differences. The longer the path length, the higher the amplitude

M-MODE (motion mode):

- Displays moving structures along a single ultrasound line across time, at a high sampling rate (1000 fps).
- **This mode allows you to trace motion (i.e. heart wall motion, vessel wall motion).**

Color Doppler:

- Doppler echoes are displayed with colors corresponding to the direction of flow.
- Positive or negative Doppler shifts represent toward or away from the transducer, respectively.
- The brightness of the color represents the intensity of the echoes, and sometimes other colors are added to indicate the extent of spectral broadening.

Power Doppler:

- Depicts the amplitude (or power) of Doppler signals rather than the frequency shift. This allows detection of a larger range of Doppler shifts and therefore better visualization of the smaller vessels, at the expense of directional and velocity information.

PW MODE (Pulsed-Wave Doppler mode):

- With the use of a sample gate or volume, Pulsed-Wave Doppler provides a graphical display of all the velocities within the area sampled. The amplitude of the signal is proportional to the number of blood cells and is indicated as a shade of gray.
- If the blood is moving away from the transducer, a negative shift is detected and the spectrum appears **below** the baseline. If the blood is moving toward the transducer, a positive shift is detected and the spectral displays **above** the baseline.

Sample Volume:

- The gate length which chooses the Doppler shifts that will be used to produce audible sounds or spectral display.
- **The larger the sample volume, the more Doppler frequencies that are detected.**

Doppler Principles

Doppler ultrasound imaging is used to detect and evaluate blood flow; it presents information on the presence, direction, speed and character of blood flow. More specifically, the Doppler Effect is used to measure the differences of movement.

In Doppler Modes, the ultrasound scanner transmits a series of pulses to detect motion. Returning pulses from tissue are mostly the same from pulse to pulse, in other words there is little difference in time of these returning pulses. However, pulses returning from moving scatter, such as blood, produce measurable changes in time. This is often referred to as a phase or Doppler shift. These phase shift measurements can be further processed and presented graphically on a PW Doppler spectral display, or a Color Doppler display, or even a Power Doppler display.

The Doppler shift is dependent on the insonating frequency (transducer frequency), the velocity of the moving red blood cells, the angle of the sound beam, and direction of the moving red blood cells. The following is the Doppler equation:

$$Df = \frac{2f v \cos q}{c}$$

Df = Doppler shift frequency (difference between transmitted and received)

f = Transmitted frequency

v = Velocity of the blood

c = Speed of sound

q = Angle of the sound beam and direction of moving blood cells

The equation can be rearranged to detect the velocity of the blood flow with the following equation:

$$v = \frac{Df \ c}{2 f \cos q}$$

Two important facts can be observed from this equation:

- 1) The cosine of 90 degrees is zero; if the ultrasound beam is almost perpendicular to the direction of the blood flow, a very poor Doppler signal will be detected.
- 2) The cosine function is steeper above 60 degrees and therefore errors are magnified with insonating angles above this. Therefore, careful consideration should be taken to obtain an angle of less than 60 degrees to the direction of the blood flow to obtain reliable and accurate results in quantifying the velocity in a certain blood vessel.

Commonly used Doppler terms:

Aliasing:

- The production of false Doppler shift and blood velocity information when the Doppler shift exceeds a threshold.
- Aliasing appears as if the spectral display is cut off and wraps around and reappears in the opposite region of the display.

Spectral Broadening:

- The widening of the Doppler shift spectrum (i.e. the increase of the range of Doppler shift frequencies present, owing to a broader range of flow speeds encountered by the sound beam).

Terms for Labeling and Scan Orientation

Coronal:	The long axis of a scan performed from the subject's side where the slice divides the anterior from the posterior or the dorsal from the ventral in the long axis
Transverse:	A cross-sectional view
Sagittal (Longitudinal):	The long axis plane
Superior, Cranial, Cephalad, Rostral:	Interchangeable terms indicating the direction towards the head
Inferior or Caudal:	Indicating the direction towards the feet
Anterior or Ventral:	A structure lying towards the front of the subject
Posterior or Dorsal:	A structure lying towards the back of the subject
Medial:	Towards the midline
Lateral:	Away from the midline
Proximal:	Towards the origin
Distal:	Away from the origin

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