Basics on sound and ultrasound physics 2018-08-22 Large Animal Medicine Patrick Hemming DVM

An ultrasound machine in “brightness mode” (B mode) is the basis for veterinary ultrasonography. Ultrasonography in B Mode, or real-time imaging mode, will produce as a video on a monitor that represents a cross sectional image of the body and organs that have been scanned. That video (20-60 video frames per second) can be used in evaluating soft tissue and liquid structures in the body; such as muscle, tendons, ligament, ovaries, the uterus and pregnancy, testicles in males, and the organs of any other soft tissue body system.

Imaging skeletal component of the body is not very useful with ultrasound since bone surfaces are nearly 100% reflective, and nothing beyond the boney surface can be imaged.

The ultrasound machine consists of a "transducer" which is the probe that contains the ultrasound generating and recieving apparatus and the chassis which generates the electrical pulses sent to the transducer and which recieve electrical pulse signals from the transducer. The chassis also contains an amplifyer for the electric signals and a Central Processing Unit (CPU) that convert the electric signals into a 2 dimensional video image on the monitor.

The most popular transducers contain a linear array of ceramic (piezo-electric) crystals. These crystals will vibrate for a short period of time when they receive an electrical charge. That vibration will produce sound with frequencies of 3.5 million to 15 million hertz (cycles per second) or 3 to 15 megahertz (MHz) depending on the size and thickness of the crystal. The ultrasound frequency is referred to in a unit called a megahertz. 1 MHz is 1 million cycles per second. The transducer array will emit a “thin sheet” of rapidly repeating ultrasound pulses. The pulse frequency is typically 20 to 60 pulses per second. These short sound pulses will penetrates the tissues that is to be imaged, distal to the probe. Some of the sound will be echoed back to transducer's crystal array, during the relatively long period between the emitted pulses. The transducer’s electrically charged piezo electric crystals will receive these echoes and convert that sound back into an electrical signal. That signal, from the reflected sound, will then be interpreted by the machine's CPU, and is used to produce a video image that represents a two dimension cross sectional, image of the tissues distal to the probe.

Gaschen, L, Diagnostic Imaging, In: Bassert J, McCurnin’s Clinical Textbook for Veterinary Technicians, 2014, pp 551-556

Sound is a form of energy that is imparted by mechanical force on gasses, on liquids or on solid materials. Gas includes air, other gaseous mixtures of freely moveable molecules in space. Liquids are a loose lattice of freely moveable molecules such as water. A solid material is a lattice of fixed molecules in a solid lattice. Body tissues are a mixture of all three types of materials.

Sound travels in a non-linear pattern in gasses. A portion of the mechanical energy of a moving molecule is transferred to the next molecule, similarly to how a pool ball transfers a portion of its energy to any other balls that it strikes. The proportion of energy transferred depends on the angle of impact and can be anything nearly 0% to 100% for a direct hit. The energy imparts movement on impacted ball or molecule at an angle from 0 to nearly 90 degrees away from the point of impact. Sound movement involves the actual movement of large groups of energized particles in a compression wave. The molecular movement can be very short (angstrom dimensions) when the particles are constrained within a solid or liquid lattice; or very long in gasses (meters).

Sound is a rhythmic form of energy. Sound travels as a compression wave through air, water or solids. A surface wave in water is similar but different than a sound wave. In a surface wave the entire water mass is moved by wind or seismic energy. A surface wave is a very slow, low pressure, low frequency compression wave. Sound wave travelling through water is a high frequency short wavelength compression wave that move at about 3,440 miles per hour. Sound in air travels at about 760 miles per hour. Like any wave, in addition to the speed of the wave, sound has a wave length and sound has a frequency. The E-2 guitar string creates a sound wave that has a frequency of about 82 cycles per second. One cycle per second is called one Hertz (Hz). The string vibrating at 82 cycles per second creates sound of that frequency by alternately compressing through impaction and then rarefication as the string moves in the alternating directions.

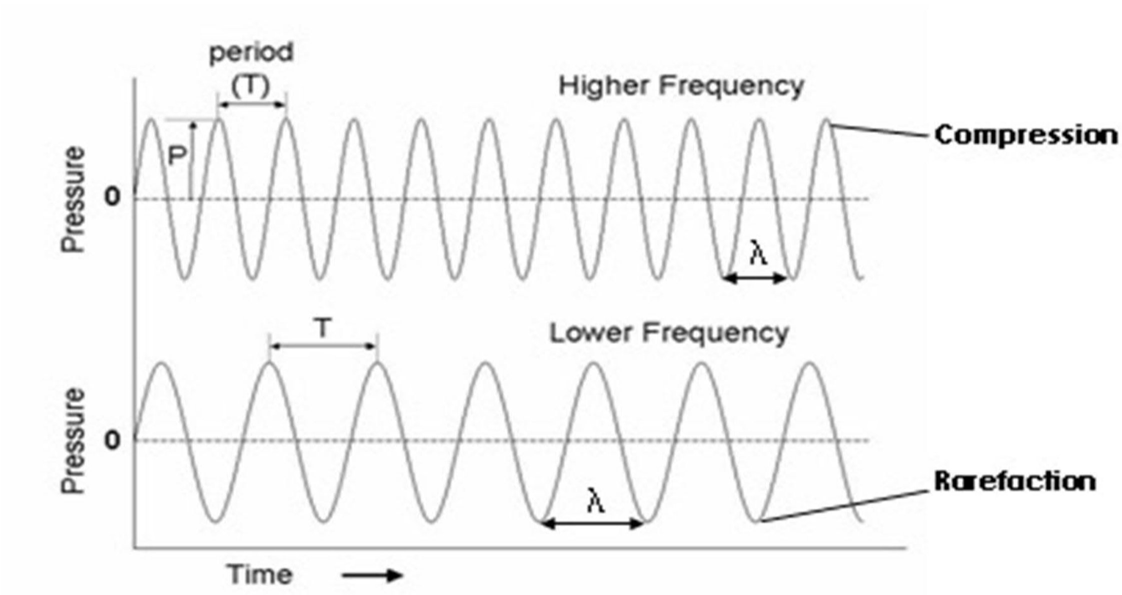

Image from :Neil, McGhi, https://paws.augusta.edu/pub/anesthesia/rotations/chronicpain/Documents/Ultrasound/BASIC CHARACTERISTICS OF ULTRASOUND.doc

The amount of energy imparted on the molecules in space is referred to as the amplitude. The amplitude could also be referred to as volume. It is a measure of the kinetic energy of the sound wave. High energy sound can noticeably vibrate a still object. Sound can also increase the thermal energy (heat) in an object that is exposed to sound waves. Heat is rapid movement of molecules.

Sound Waves

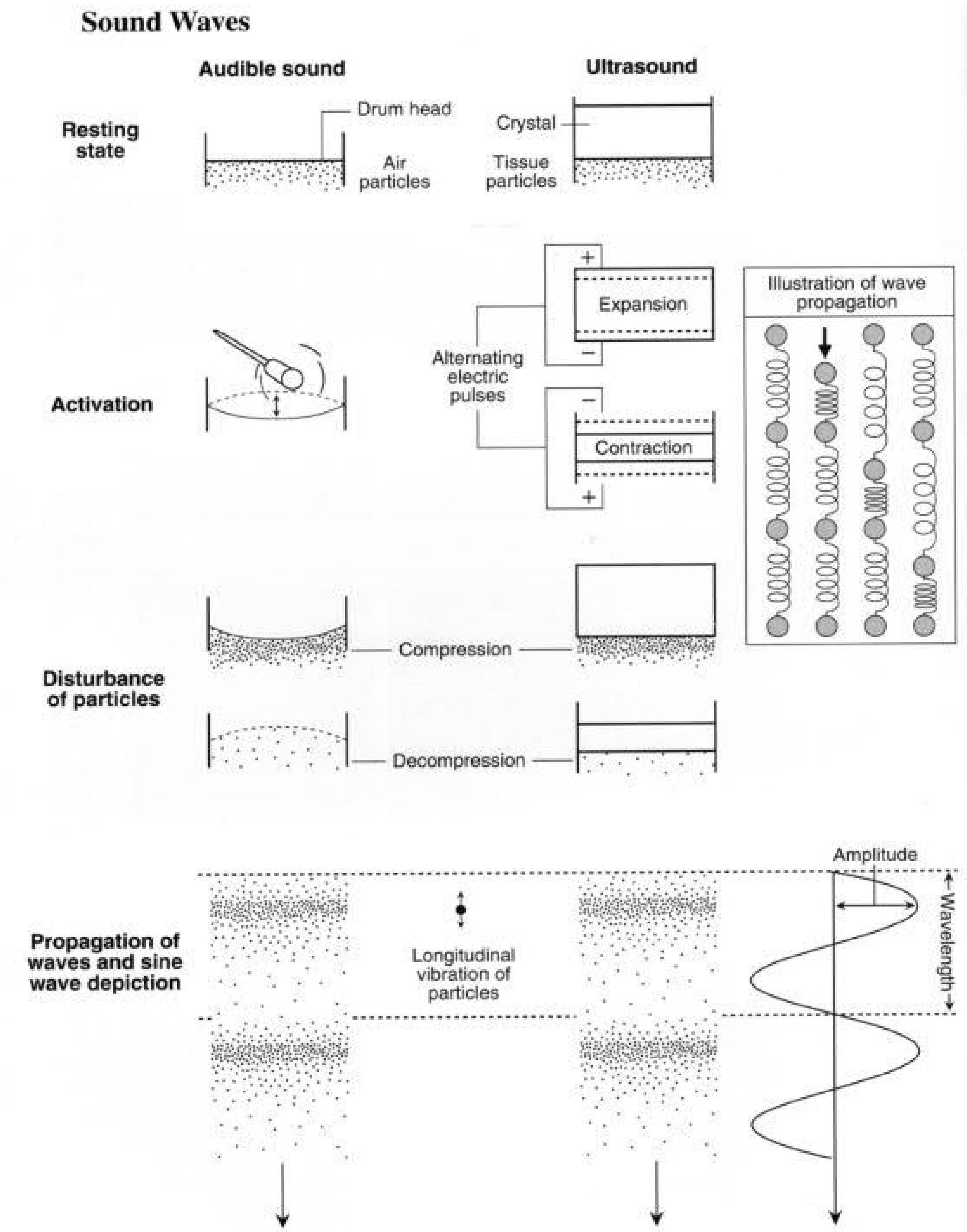

Image from :Ginther O.J., Ultrasonic Imaging and Animal Reproduction: Fundamentals, Book 1, Ch. 2 p. 28, Equiservice Publishing, 1995

The Speed of Sound

The speed of sound varies dramatically in different materials. Other things that have varying degrees of effect on the speed of sound are the density of the material, the temperature of the material, and the elasticity of the material. In any single material the speed of sound is constant regardless of the frequency of the sound wave.

In a vacuum the speed of sound is 0 meters per second (m/s).

In dry air at 20°C (68 °F), the speed of sound is 343.2 m/s (1,126 ft/s). This is 1,234 kilometers per hour or 767 mph.

In sea water at 25°C, the speed of sound is 1,535 m/s (5,036 ft/s).

This is 5,526 kilometers per hour or 3,434 mph. This is ~4.5 times faster than the speed of sound in air. This is also the near the speed of sound in body tissues.

Attenuation of sound

Sound is rapidly attenuated in any medium by several factors. The main factors that cause attenuation are reflection, refraction, scattering, and absorption.

Reflection occurs any interface between two mediums different acoustic properties. Reflections can vary in the percentage of the energy that is reflected and the percentage of the energy that is transmitted through the interface.

Refraction is bending of the direction of the sound that is transmitted through an angled interface between two mediums with different acoustic properties.

Scattering or diffusion is the spreading out of the sound wave front caused by impaction of molecules at any angle other than a direct 0 degree impact. Scattering is also caused by refraction of transmitted sound through uneven or wavy media interfaces. Scattering is immediate and complete in a gaseous media.

Absorption is the conversion of mechanical sound energy into heat energy within the molecules of the media the sound is passing through.

Thankfully at MHz frequencies there is very little absorption of sound by body tissues and unmeasurable increase in tissue temperatures with judicious use of ultrasound equipment. Regardless, there is plenty of attenuation of ultrasound as it passes through the body tissues. Attenuation limits the depth that can be examined using ultrasound.

Important relationships between ultrasound frequency & other parameters:

1. Sound Frequency - Wavelength Relationship:
The frequency is inversely proportional to the wavelength.
The wavelength of 10MHz sound in tissue is 0.15 mm.
The wavelength of 3.5 MHz sound in tissue is 0.44 mm.

2. Sound Wavelength - Image Resolution Relationship:
It can be said that **the ultrasound frequency is directly proportional to the resolving power of an ultrasound machine.**
It may be better to consider that the ultrasound wavelength is directly proportional to the size of the smallest structures that can be resolved.
An ultrasound machine using 10.0 MHz sound, with a 0.15 mm wavelength, will resolve structures as small as 0.3 mm (~ 2 wavelengths).
An ultrasound machine using 3.5 MHz sound with 0.44 mm wavelength will only resolve structures that are near 1.0 mm (also ~ 2 wavelengths).

3. Sound Frequency - Tissue Penetration Relationship:
The ultrasound frequency is inversely proportional to the depth of the resulting image. Just as the frequency is inversely proportional to the wavelength, the same can be said regarding the depth of the sound penetration into body tissues. A lower frequency ultrasound can image structures deeper in the body than a higher frequency can. In other words sound penetration is directly proportional to the wavelength. The longer the wavelength the deeper the sound can penetrate into the tissues.
A 3.5 MHz transducer will penetrate tissue up to 18.0 cm. deep.
A 10.0 MHz transducer will penetrate structures up to 6.0 cm. without much degradation of image quality.

4. Sound Frequency - Transducer Length (and the Width of the Image) relationship:
The ultrasound frequency is inversely proportional to the size of the piezoelectric crystals that produce the sound. The thickness and width of crystals are larger for lower frequency transducers; and the crystals are smaller for higher frequency transducers. As a result it takes a longer linear array probe to accommodate 64 3.5 MHz crystals than it takes to house 64 10 MHz crystals.
A 64 crystal 10.0 MHz transducer will have an acoustic length of approximately 6.0 cm.
A 64 crystal 3.5 MHz transducer will have an acoustic length of approximately 18.0 cm.

Due to the relationships above; the overall size of the image produced by a 10 MHz ultrasound transducer will be much smaller (6cm x 6cm), but will have much better resolving power than the much larger image produced by a 3.5 MHz transducer (18cm x 18cm). The maximum width of the image is physically fixed by the size and shape of the transducer head. In reality though; the depth of the image can be increased beyond those mentioned above in relationship #3. This is done through the use of "focusing" or "dynamic focusing" of the sound beam onto deeper tissues. Regardless of focusing the highest resolution is constrained by the depths noted in #3 above.

It is important that you know the definition of these terms:

Echogenicity: This is the relative ability of different tissues, solid structures, liquids, suspensions and interfaces between these tissues, solids and liquids to echo or reflect sound. The greater the echogenicity the more sound will be reflected back to the transducer and the brighter the ultrasound image will be of that tissue.

Echogenic: Simply means that the surface of a tissue interface will reflect sound.

Echoic: (means the same as echogenic)

Greyscale: A Black to White Gradient in 64, or other number, of steps is used to represent the relative echogenicity of a tissue, liquid or solid structures when the image is drawn on the monitor.

Hyperechogenic or Hyperechoic: These are terms used to compare the echogenicity of two adjacent tissues. When one of the tissues appears brighter on the monitor, or echoes a larger volume of sound than the adjacent tissue it is said to be hyperechogenic.

Hypoechogenic: Similarly, Hypoechogenic or Hypoechoic are terms used to describe a tissue that appears darker on the monitor or echoes a lower volume of sound than the adjacent tissue.

Isoechogenic: This term is used to describe two tissues that have very similar brightness on the monitor or echo similar volumes of sound.

Nonechogenic or Non-echoic: These are terms that are used to describe a completely homogenous substance; usually an aqueous solution that contains no (or few) particles that will echo sound. Urine is non-echoic unless there are calculi suspended in the urine. Therefore urine creates a totally black image on the ultrasound monitor.

Pulse Rate: The ultrasound machine does not create continuous sound. Sound is created in very short millisecond pulses. Each pulse travels away from the piezoelectric crystal in a single direction into the tissues of the body. The sound is reflected back to the piezo electric an

Frame Rate: Images produced per second in the ultrasound video.

Standoff: A nonechogenic pliable material that will conform to body surface irregularity and produce a tighter couple between the transducer and the curved body surface.

Coupling Gel: A nonechogenic gel that will allow easy penetration of sound between the transducer and the body.

Doppler Effect: Look It Up!

Modes of ultrasound

A-Mode - Amplitude Mode, is a graph recording of the amplitudes of reflected sound from a single or small group of piezoelectric crystals. This records the depth of reflective interfaces inside of the examined subject. A mode is useful but rarely used in medicine.

B-Mode - Brightness Mode - is the primary mode that is used in veterinary ultrasonography. B-mode image are 2 dimensional or cross sectional images that are updated on a "real time" basis. B-mode creates a moving video image of the tissues distal to the acoustic surface of the transducer.

M-Mode - Movement Mode - collects the data from a single piezoelectric crystal and plots the movement in the tissues interfaces vs time.

Doppler Mode - creates a colorized B-mode image. The colorization reflects the measurement of the Doppler effect on the sound frequency of sound reflected from a moving tissue or fluid containing reflective materials, such as RBCs in blood. Measurement of the Doppler effect on the reflected sound allows actual calculation of the speed of movement of the area of interest. This allows for actual measurement of blood flow rates in vessels, identification of turbulence in a vessel, prediction of ovulation in mares, assist in viability evaluation of fetuses during early pregnancy diagnosis, etc.