PRINCIPLES OF ULTRASOUND

Lecture One - Basic physics of ultrasound & artifacts

MK MEDICAL CENTER

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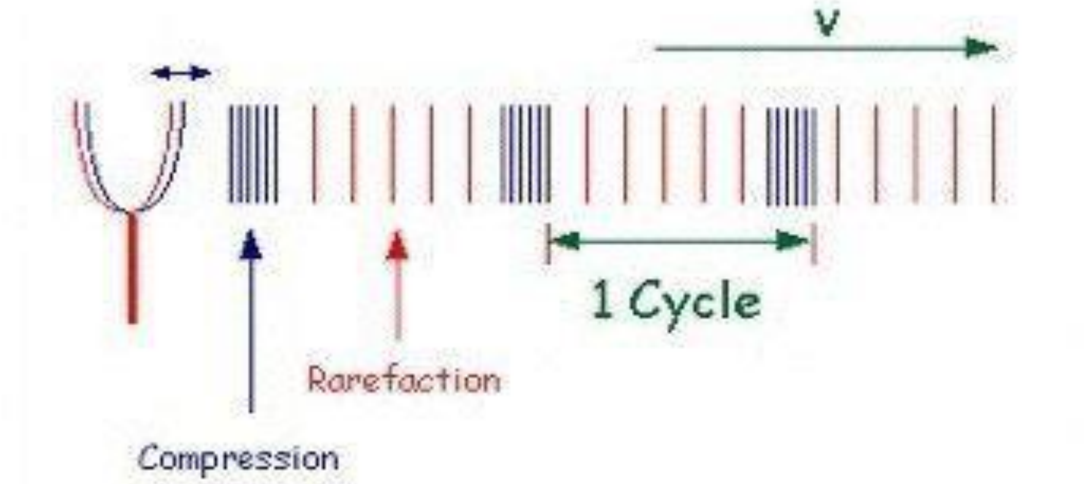
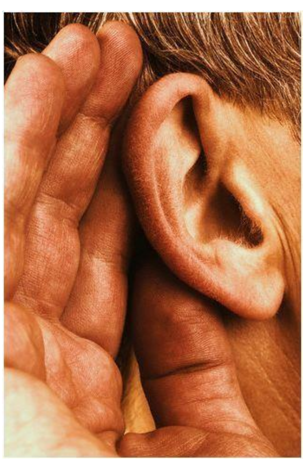
Basic Physics of Ultrasound

What is ultrasound?

- A longitudinal wave - particles move in the same direction as the wave.
- A succession of rarefactions and compressions transmitted due to elastic forces between adjacent particles.
- Audible sound has frequency 20 Hz to 20 kHz



- Most diagnostic ultrasound has frequencies in range 2-20 MHz



Wavelength

- Frequency of oscillations is inversely proportional to wavelength
- f = c/l (c ≈ 1540 m s-1 in soft tissue).

What is sound?

- Sound is a mechanical wave.
- Sound is a longitudinal wave.
- Sound is a type of pressure wave.
- Sound is a form of energy.
- Sound is able to converge and diverge. Sound is able to reflect. Sound is a form of radiant energy.
- Sound is NOT ionizing radiation. Sound is NOT a transverse wave. Sound is NOT an electromagnetic wave

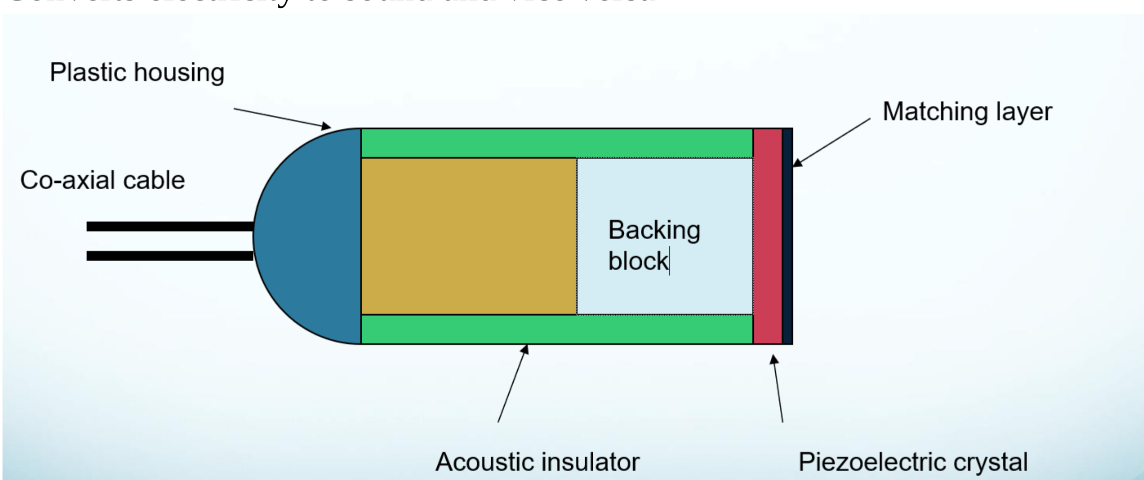
Generation of Ultrasound

- US generated by piezoelectric crystal
- Commonest material is lead zirconate titanate (PZT)
- When electric field applied, crystal rings like a bell at a resonant frequency determined mainly by its thickness

Same or similar crystal used as receiver to produce electrical signal when struck by the returning ultrasound wave

Ultrasound Transducer

Converts electricity to sound and vice versa

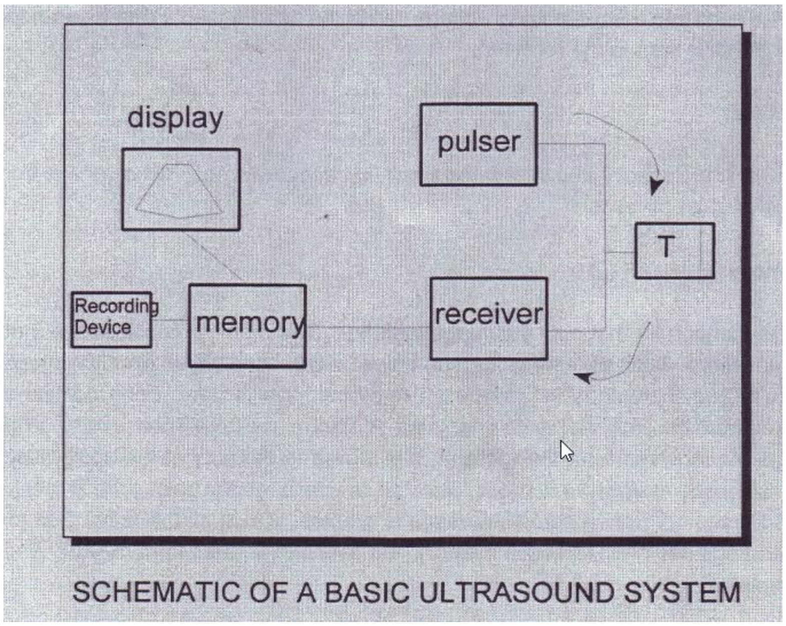


Speed of ultrasound in tissue

- Stiffer material e.g., solid transmits ultrasound faster
- Speed of US in tissue depends on stiffness and density

Medium	Speed of sound (ms-1)
Air	331
Muscle	1,585
Fat	1,450
Soft Tissue (average)	1,540

- In clinical practice, speed of US in tissue is almost constant at 1540 ms-1
- Ultrasound which enters tissue may be transmitted, attenuated or reflected.
- Ultrasound needs to be transmitted far enough into the tissues in order to image them but must be reflected to be received by the probe.
- Attenuation is a problem which needs to be addressed by the machine



The choice of transducer frequency:

The choice of transducer frequency used in diagnostic ultrasound is limited by two factors:

The first is tissue penetration (imaging depth).

The second is spatial resolution.

High frequencies have better spatial resolution, but do not penetrate as well as low frequencies. Selecting a transducer is always a compromise between penetration and resolution. The best images are produced using the highest frequency that will penetrate to the region of interest.

Rule of thumb: "use the highest frequency that will penetrate to the depth of interest." Typical SCANNING FREQUENCY RANGE (MHz):

General abdomen	2-5 MHz
Gallbladder	3-7.5 MHz
Obs/ Gyne	3 -7.5 MHz
Adult heart	2-3 MHz
Pediatric heart	3-5 MHz
Neck, breast, scrotum	5-15 MHz
Eyes	7-15 MHz

PERIOD

Period is the time it takes for a sound wave to complete one cycle. Period is the reciprocal of frequency. lt is determined by dividing the frequency into 1.

Period= 1 / frequency

The unit of period is the second (s) or any subunit of a second such as millisecond (ms) or microsecond.

Period is inversely related to frequency. An inverse relationship means that if one quantity increases, the other decreases. An increase in frequency means a decrease in period

Attenuation/ Absorption of ultrasound

Absorption of ultrasound means that lower tissues return less ultrasound (some absorbed as heat, some reflected/refracted out of field of probe).

Amplification

Each echo that returns to the transducer generates a weak electrical voltage called an Rf signal. So, the first step in processing each echo signal is to amplify the Rf signal. The operator controls this amplification with the OVERALL GAIN control.

Overall gain amplifies all received Rf signals by the same amount. For example, if the operator increases the overall gain by a factor of 2, the amplitude of all echo signals is increased by a factor of 2. This would then increase the brightness of all echoes in the image by a factor of 2.

For this reason, overall gain can also be described as linear amplification. (Overall Gain is nonselective Amplification).

***Note:** that an increase in output power can also be used to make the image brighter. However, an increase in gain should be the operator's first choice. Gain does not affect patient exposure since it is performed on reception, not on transmission.

Compensation

One of our imaging goals is to display all similar reflectors with the same brightness, regardless of their location in the anatomy. For example, we would like to display the entire normal liver with uniform brightness. However, attenuation reduces the strength of both the transmitted pulse and the returning echoes. Consequently, the longer the path length that the sound travels, the weaker the echo becomes. Because of this attenuation, echoes from deep interfaces will be weaker than echoes from superficial ones and would be displayed with decreased echo brightness unless attenuation compensation is applied. Without compensation echoes from deep in the liver would always be darker than echoes from more superficial liver tissue, even though the reflecting tissue is the same

TGC/ Selective Amplification

- The TGC (Time Gain Compensation) is the control that compensates for attenuation.
- The TGC amplifier applies increasing amplification to the returned echo signals based on their go-return times. Echoes having short go-return times must have returned from superficial structures. To these, the TGC applies only a small amount of amplification. Echoes having longer go-return times must have returned from deeper structures, to these, the TGC applies more amplification to compensate for the increased attenuation

This table lists the receiver controls that can be adjusted by the operator to optimize the image

Control	Effect
Overall gain	changes overall brightness of all displayed echoes
TGC	compensates for attenuation
Harmonics	reduces noise and clutter
Log compression/dynamic range	changes dynamic range; makes image more or less “contrasty”

Array Transducers

Array transducers contain an arrangement (an array) of multiple small elements. The elements in the array can be individually fired or fired together to form the beam. Using a combination of elements, the array transducer can form a much more precise beam than was possible with the old single-crystal mechanical transducers. There are three basic types of arrays:

1. linear arrays
2. phased arrays
3. annular arrays

1. Linear Arrays:

is the most commonly used type of array transducer.

There are two fundamental types of linear arrays:

a) rectangular linear arrays and

b) convex linear arrays.

Today, rectangular linear arrays are called "linear arrays" and convex linear arrays are called "convex arrays" or "curved arrays."

2. Phased Arrays:

Those transducers designed for echocardiography or any application with a limited acoustic window have considerably smaller footprints (typically 1to 2 cm).

The fundamental difference between a phased array and a linear array is the way in which the beam is fired. ln a phased array all the elements in the array are fired together to produce each pulse

3. Annular Arrays

Annular array transducers were constructed using a concentric ring of crystals. (The word annular means ring). Less used these days and replaced by phase or linear array.

Principal Display Modes

a) A-mode:

A-mode was the first form of echo display used in ultrasound instruments, Amplitude mode. ln this display format, echoes are presented as vertical spices along a horizontal baseline. A-mode has one dimension display, (Distance from the transducer).

b) B-Mode

It is similar to A-mode, B-mode was also a one-dimensional display with distance on the horizontal axis. However, in B-mode, the amplitude of the echo is not represented by a spike, but was represented by the brightness of a dot.

c) M-Mode

M… stands for motion. This mode was also called T-M mode (time-motion mode). M-mode is produced by taking a single B-mode scan line then displaying any changes to it in time along the horizontal axis.

d) Two-Dimensional (2D) Displays:

is also known as a B-scan. To produce a scan, the beam must be swept through the tissue to produce a series of Bmode scan lines

e) Three-Dimensional (3D) Displays:

As its name implies, 3D ultrasound adds a third dimension to the display. Now, not only can the axial and lateral location of the echo be displayed, but so can the elevation (Z axis) location of the echo.

f) Four-Dimensional (4D) Displays

4D ultrasound is the display of 3D ultrasound in real-time.

Reflection

Importance of Reflection:

—Allows generation of the ultrasound signal

—helps determine appearance of tissue

—can cause artefacts

Note:

• Whenever transmitted ultrasound crosses an interface between two tissues with different impedance, some ultrasound is reflected

• Amount depends on difference in impedance

• Ultrasound which is not reflected carries on and can be used to image deeper structures

Reflection - consequences

—Need coupling material between probe and patient skin

—Cannot see through bone

Pulse Repetition Frequency

—Relatively slow speed of ultrasound in tissue limits rate at which ultrasound information can be acquired

—Need to wait for each pulse to fade away before second transmitted

—If send second pulse too early, last returning echoes from first pulse with overlap with first returning echoes from second pulse

—The pulse repetition frequency (PRF) is set in order to allow time for the most distant echoes to return before sending next pulse

—PRF will be slower if trying to image larger area or trying to use grey scale and doppler at same time

— Reducing scan area can help increase PRF e.g., if trying to image fast moving structure

Ultrasound tips

• Use highest frequency for necessary depth penetration

• Use tissue harmonics for larger patients

• Try moving patient into different positions e.g., to move ribs apart/move bowel gas out of way

• Use ‘optimize’ button

• Reduce size of sector for improved resolution

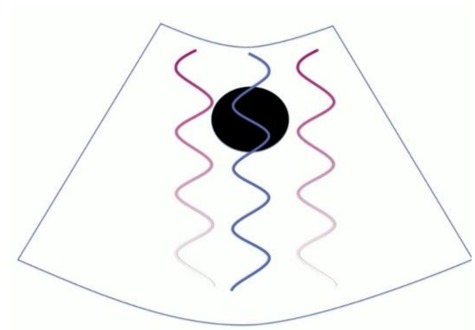
Artifacts

Ultrasound artifacts:

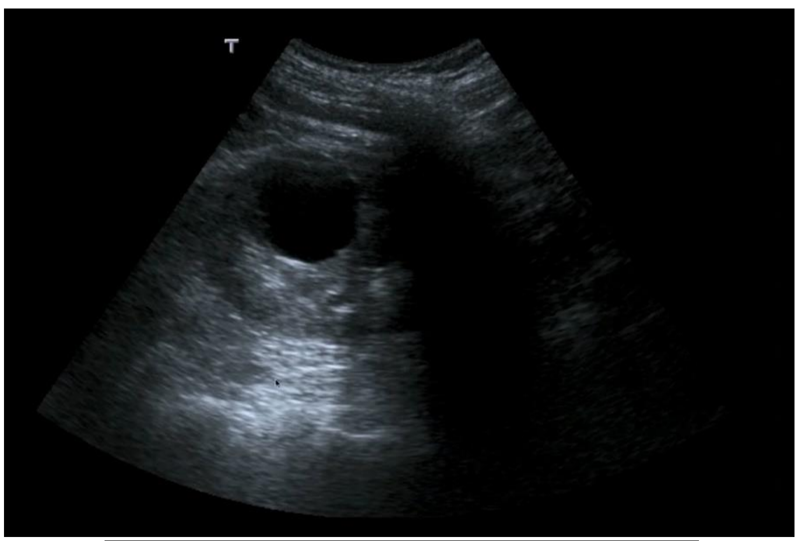
- Common occurrence in ultrasound
- Images, that do not represent anatomic structures correctly
- Structures appearing that are not present
- Structures missing that are present
- Structures in incorrect size, location or brightness
- Wrong information’s
- Helpful tools

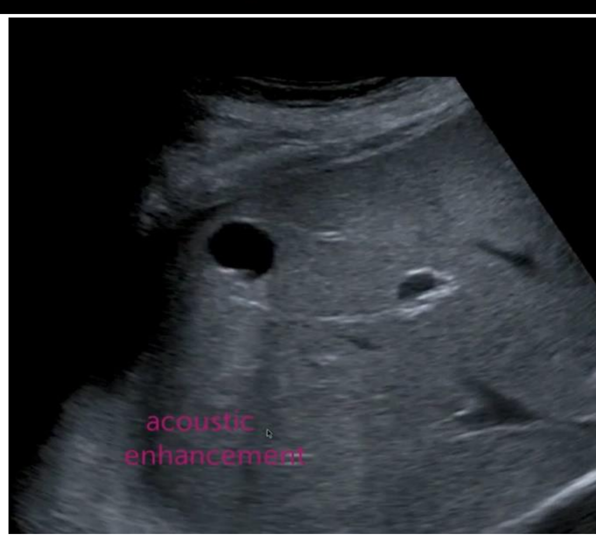
- Dorsal acoustic enhancement
- Acoustic shadowing
- Lateral shadowing
- Mirror artifacts
- Reverberation artifacts

1. Dorsal acoustic enhancement



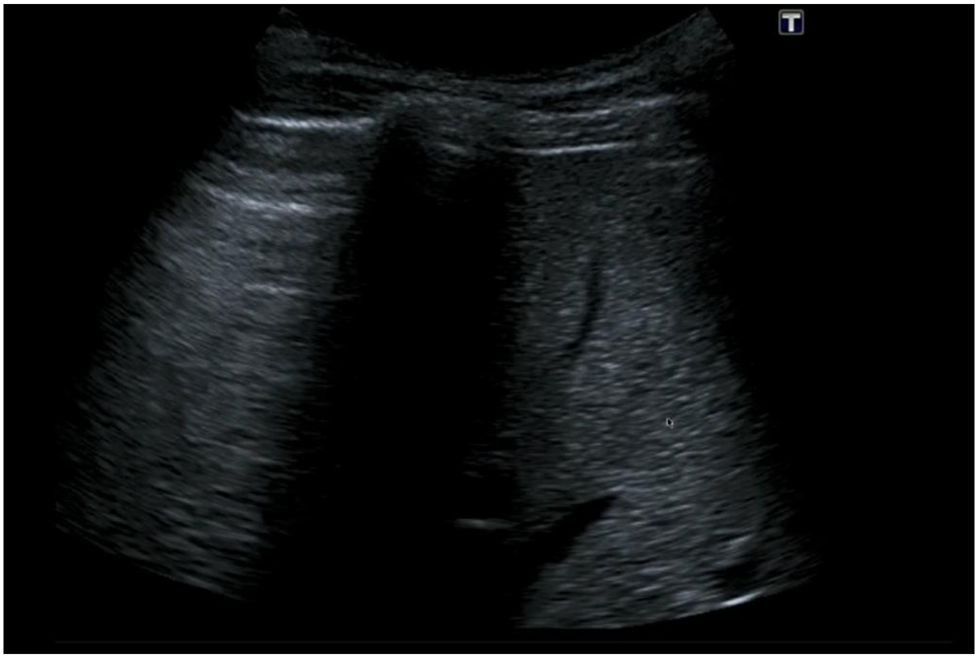
- Less attenuating material
- Transmission of ultrasound beam increased
- Higher echogenicity behind the structure
- Example: cysts

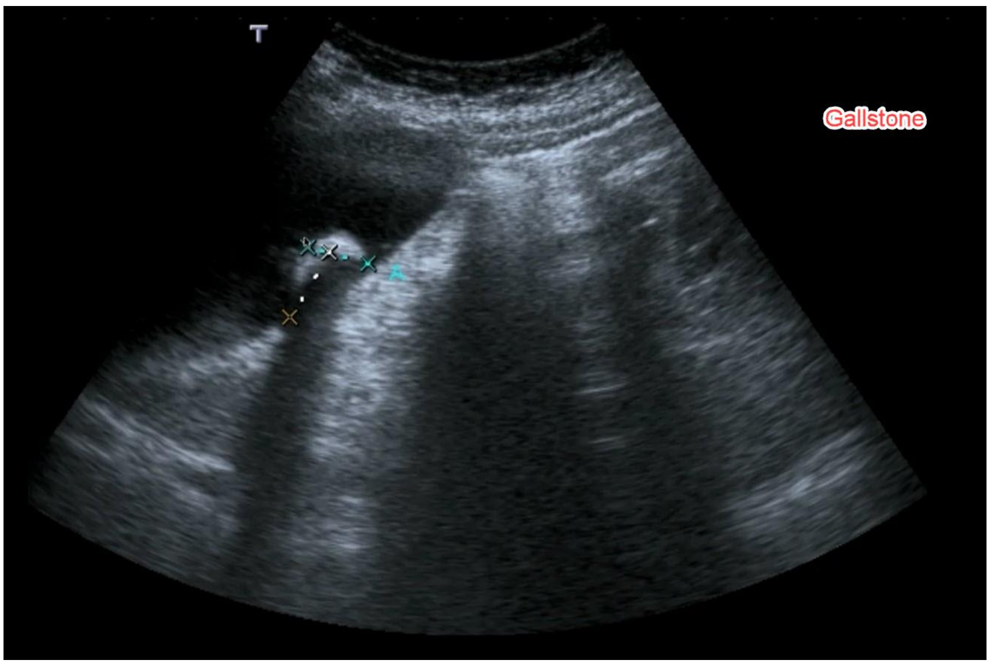




2. Acoustic shadowing

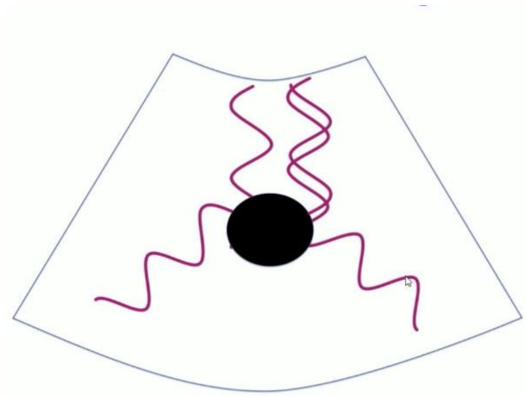
- Strongly attenuating material
- Due to absorption/reflection
- No signal or weak signal from structures beyond
- Examples: Stones, bones, colon gas

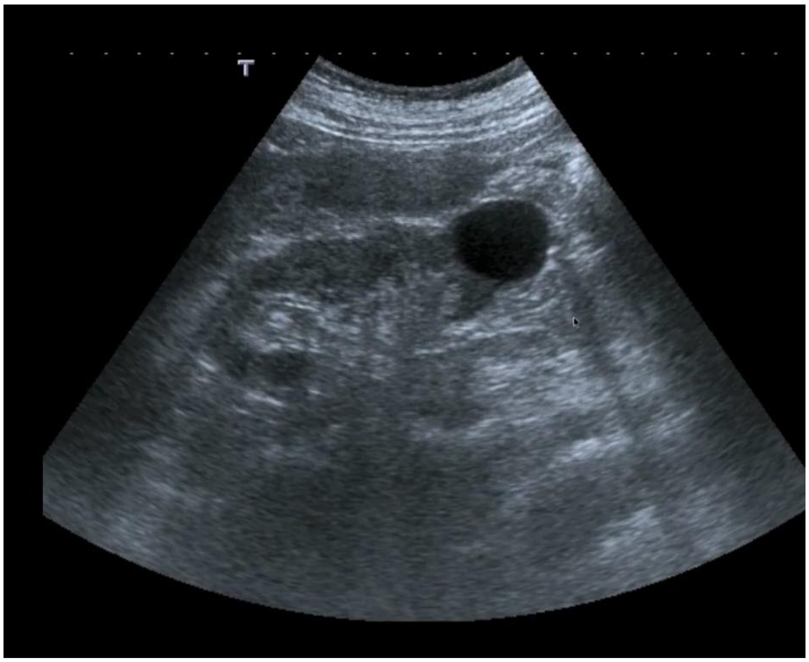




3. Lateral shadowing

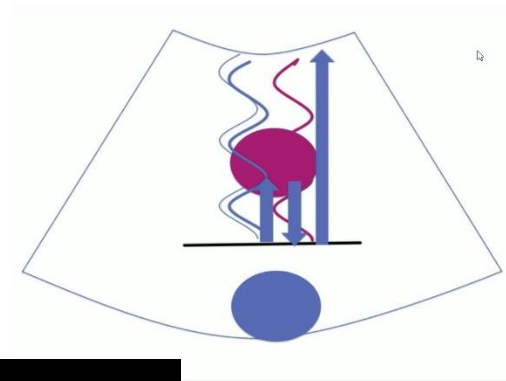
- Appearing at the edges of round structures
- Reflection and refraction of ultrasound beam
- Caused by rounded edges and two different materials
- Example: Cysts

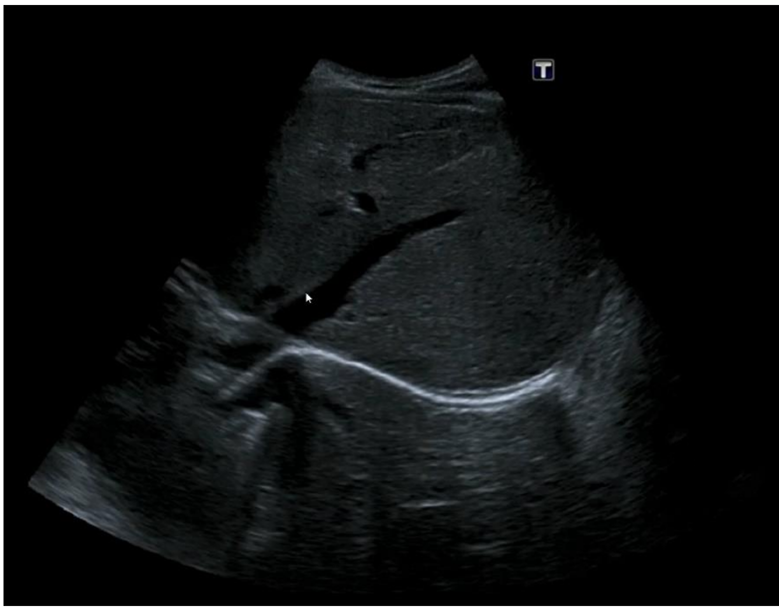




4. Mirror artifacts

- Highly reflective surfaces acting as reflector
- Structures displayed twice
- Like a mirror
- Example: mirror image of liver





5. Reverberation artifact

- Two highly reflective interfaces
- Ultrasound beam running between them
- Repeated echos are displayed
- Example: Urinary bladder