LECTURE 6

TOPIC: BIOPHYSICAL BASICS OF ULTRASOUND IMAGING
TIME: 2 HOURS

Ultrasound is a term given to inaudible, high frequency sound waves and is also the generic name given to the imaging modality that uses ultrasonic energy.

CHARACTERISTICS OF SOUND

SOUND - is a mechanical energy propagates through a continous, elastic medium by the *compression* and *rarefaction* of "particles" that comprise it

compression - is a mechanical deformation induced by an external energy force with a resultant increase in pressure on the medium
rarefaction - is a compression of particles transfer, which adjacents particles with the subsequent reduction in pressure

PARAMETERS OF SOUND

wavelength - is a distance (usually expressed in units of milimeters or micrometers) between compressions or rarefactions, or between any two points that repeat on the sinusoidal wave of pressure amplitude

frequency - is a number of times the wave repeats itself (i.e. a cycle) over one second

< 15 Hz - infrasound
15 Hz - 20 kHz (20000 Hz) - audible sound
>20 kHz - ultrasound

Medical uses of ultrasound requires frequencies in the range of 2 MHz (2 000 000 Hz) to 10 MHz (10 000 000 Hz), and catherer based endoluminal sources extend to 50 MHz (50 000 000 Hz)

period - is a time required for one complete cycle of sound to pass by particular point and is equal $1/v$, where v is the frequency

propagation speed - is a distance traveled per unit time (usually per second) of the energy pulse and is equal to the wavelenght divided by the period (or therefore multiplied by the frequency)

This relationship presents:

propagation speed = wavelength / frequency

The speed of sound in air is very low (*330* meters/second), while the speed of sound in soft tissue is moderate (*1540* meters/second) and in the bone is high (*4000* meters/second)

Speed of sound in clinically relevant materials

MATERIAL	SPEED [meters per second]
air	*331*
water	*1430*
sea water	*1510*
fat	*1410*
soft tissue	*1540*
blood	*1570*
muscle	*1585*
bone - skull	*4080*
metal	*5000*

pressure difference - is a sound energy causes particle displacement to occur in the propagation medium

Sometimes a pressure difference can be measured as <u>an amplitude (up and down travel)</u>

intensity - is an amount of power per unit area deposited in the tissue

<u>PRODUCTION OF ULTRASOUND</u>

The ultrasound is produced through the conversion of electrical into mechanical energy and id detected by the reverse process by converting mechanical into electrical energy. The transducer is a device that is both a transmitter and receiver of the ultrasound signal and it serves a dual role in pulse echo imaging

The transducer uses a **piezoelectric crystal**, which converts electrical stimuli to sound energy and vice versa. Piezoelectric (a term meaning electricity from pressure)_compounds are a somewhat compressible material and have a molecular structure composed of a well - defined arrangement of electrical dipoles. When mechanically deformed by an applied pressure, the alignment of the dipoles is disturbed from the equilibrium position and this causes an imbalance of the charge distribution, resulting in an electrical potential to be formed across the crystal surfaces. A net negative voltage on one crystal surface and an equal positive voltage on the other occurs. Surface electrodes connected to electronic circuitry sense the potential difference across the crystal, whose magnitude is proportional to the incident mechanical pressure. Conversely, the application of a voltage applied externally through the electrodes induces the mechanical expansion and contraction of the crystal. Finally, when a high DC voltage is applied to the crystal surface, it is produced ultrasound beam.

<u>CHARACTERITICS OF THE ULTRASOUND BEAM</u>

The ultrasound beam propagates as a longitudinal wavefront from the transducer face into the medium.

☑ near field (for 1.5 cm diameter crystal element at 3.5 MHz the near field extends to 12.5 cm)

far field

<u>INTERACTIONS OF ULTRASOUND WITH MATTER</u>

As ultrasound propagates through a medium there are 3 possible interactions that take place:
* reflection
* refraction
* attenuation

reflection - is a return of the incident ultrsound energy, as an echo directly back to the transducer when interacting at a boundary with normal incidence

Reflection of ultrasound arises as a result of differencies in acoustic impedance. **The intensity reflection coefficient R**, for perpendicular impedance to a boundary is given by:

$$R = \{Z1 - Z2 / Z1 + Z2\}^2$$

where the subscripts 1 and 2 represent different tissues of a given acoustic impedance. This is the fraction of energy transmitted between two media is given by: **1 - R**

EXAMPLE:
Intensity of 40 mW/cm2 is incident on boundary with a reflection coefficient of 0.02, then
40 x 0.02 = 0.8 mW/cm2

Various tissue interfaces and reflection coefficient values

fat --- muscle (0.011)
muscle --- air (0.999)
skull --- brain (0.410)

refraction - is a change in direction of the transmitted ultrasound energy that occurs at a boundary interface

attenuation - is a loss of intensity of ultrasound beam resulting from absorption and scattering events

Attenuation is characterized by the attenuation coefficient in units dB/cm, which is a measure of the log relative energy intensity loss per centimeter of travel.

Attenuation coefficient for selected tissues at 1 MHz

TISSUE	ATTENUATION COEFFICIENT dB/cm
FAT	0.6 - 0.65
LIVER	0.7 - 0.94
KIDNEY	0.9 - 1.0
BRAIN	0.5 - 1.0

IMAGE DATE ACQUISITION

Understanding ultrasonic image formation requires knowledge of ultrasound propagation, production and interaction characteristics. An ultrasound imaging system is composed of:
- pulse generator
- transducer
- amplifier
- scan converter
- image memory
- display system
- recording system
- control panel

The heart of the ultrasound system is the **transducer assembly**, which transmits an ultrasonic pulse into the tissue under exemination at a known position and direction and receives returning echoes after a propagation delay resulting from the acoustic properties of the underlying tissues.These echoes creates the final view on the oscillscope (monitor)

TYPE OF ULTRASONOGRAPHY IMAGING

A mode - is a recording of amplitude of returning echoes versus time. It is the most basic mode of data acquisition. As echoes return from tissue at perpendicular incidence, their impact on the transducer crystal produces a voltage that is proportional to the echoe intensity, which in turn is a function of the acoustic impedance differences between the tissue boundaries. Since round - trip time equates to depth, the tissue interfaces along the path of the ultrasound beam can be separated and distances can be determination. A mode data are useful to investigative brain tumors and identify pathological areas like cancer.

M mode - is a mode in motion, which converts the variations in signal amplitude of the A mode line into series of dots along a display oscilloscope. It is useful in heart beating imaging.

B mode - is a brightness mode used for mapping the acoustic impedance variations of the tissues into a two - dimensional display. To create 2 - D display, the transducer is scanned along the object or transducer is pivoted about an axis to gather data in a determined sector of the patients. Old, early B mode scanners were articulation arm systems and static display.

Modern ones are equiped in dynamic scannig and display.

Doppler ultrasound - is an unique technique because has the potential to offer information related to function of an organ through blood flow studies and not just morphology. Doppler ultrasound is based on the shift of frequency in the carrier ultrasound wave caused by a moving reflector.
This is the same effect that causes a siren on a fire truck to initially sound high pitched as it is coming toward the listener (the waves are compressed) and a shift to a low pitched sound as it passes by and continues on (the waves are expanded).
The moving reflectors in the body are the blood cells. By comparing the incident ultrasound frequency with reflected ultrasound frequency from the blood cells, it is possible to discern the velocity and the direction of the blood. Not only can blood velocity (and indirectly blood flow) be measured, but the information provided by the Doppler techniques can be used to create color blood flow maos of vasculature. The interpretation of Doppler signals, in clinical practice require the extraction of information about the blood flow from the potential confounding aspects ralated to the technique itself.

IMAGE ARTIFACTS

- ☑ SHADOWING (hypointense signal area distal to an object)
- ☑ ENHANCEMENT (is opposite of shadowing and occurs distal to objects with very low attenuation, such a fluids - filled cavities - bladder and cysts)
- ☑ REVERBERATION (many echoes generated as a result of 2 closely spaced interfaces that reflect energy back and forth during the acquisition of the signal and before the next pulse)
- ☑ SPEED ARTIFACT (variability of propagation speed in different tissues, most notably fat)
- ☑ MIRROR IMAGE (highly reflective surfaces can find their way back to the transducer)

AMBIGUITY ARTIFACTS (too high pulse repetition frequency)

LITERATURE

1. Patterson H, The encyclopaedia of medical imaging, Isis Medical Media, 1988

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