ULTRASOUND EQUIPMENT TECHNIQUES

(Ultrasound waves)

LECTURE [9]

Intensity and Power

Acoustic Power is the amount of acoustic energy generated per unit time. Energy is measured in joules (J) with joules being the amount of heat generated by the energy in question. The unit is the Watt (W) with 1W = 1J/s. The biological effects of ultrasound in terms of power are in the milliwatt range. Therefore, the **power** is the rate of energy transfer and is expressed in the units of **watts**. Intensity is the rate at which power passes through a specified area. It is the amount of power per unit area and is expressed in the units of watts per square centimeter. Intensity is the rate at which ultrasound energy is applied to a specific tissue location within the patient's body. It is the quantity that must be considered with respect to producing biological effects and safety. The intensity of most diagnostic ultrasound beams at the transducer surface is on the order of a few milliwatts per square centimeter. Intensity is the power density or concentration of power within an area expressed as W/m2 or mW/cm2. Intensity varies specially within the beam and is greatest in the center. In a pulsed beam it varies temporally as well as specially. Therefore, the **intensity** is related to the pressure amplitude of the individual pulses and the pulse rate. Since the pulse rate is fixed in most systems, the intensity is determined by the pulse amplitude.

The relative intensity of two pulses (I1 and I2) can be expressed in the units of decibels by:

$$\textbf{Relative Intensity} = {}_{10}\log I_2/I_1$$

Note that when intensities are being considered, a factor of 10 appears in the equation rather than a factor of 20, which is used for relative amplitudes. This is because intensity is proportional to the square of the pressure amplitude, which introduces a factor of 2 in the logarithmic relationship.

The intensity of an ultrasound beam is not constant with respect to time nor uniform with respect to spatial area, as shown in the following figure. This must be taken into consideration when describing intensity. It must be determined if it is the peak intensity or the average intensity that is being considered.

2.11.1 Temporal Characteristics

The figure 14 shows two sequential pulses. Two important time intervals are the pulse duration and the pulse repetition period. The ratio of the pulse duration to the pulse repetition period is the duty factor. The duty factor is the fraction of time that an ultrasound pulse is actually being produced. If the ultrasound is produced as a continuous wave (CW), the duty factor will have a value of 1. Intensity and power are proportional to the duty factor. Duty factors are relatively small, less than 0.01, for most pulsed imaging applications.

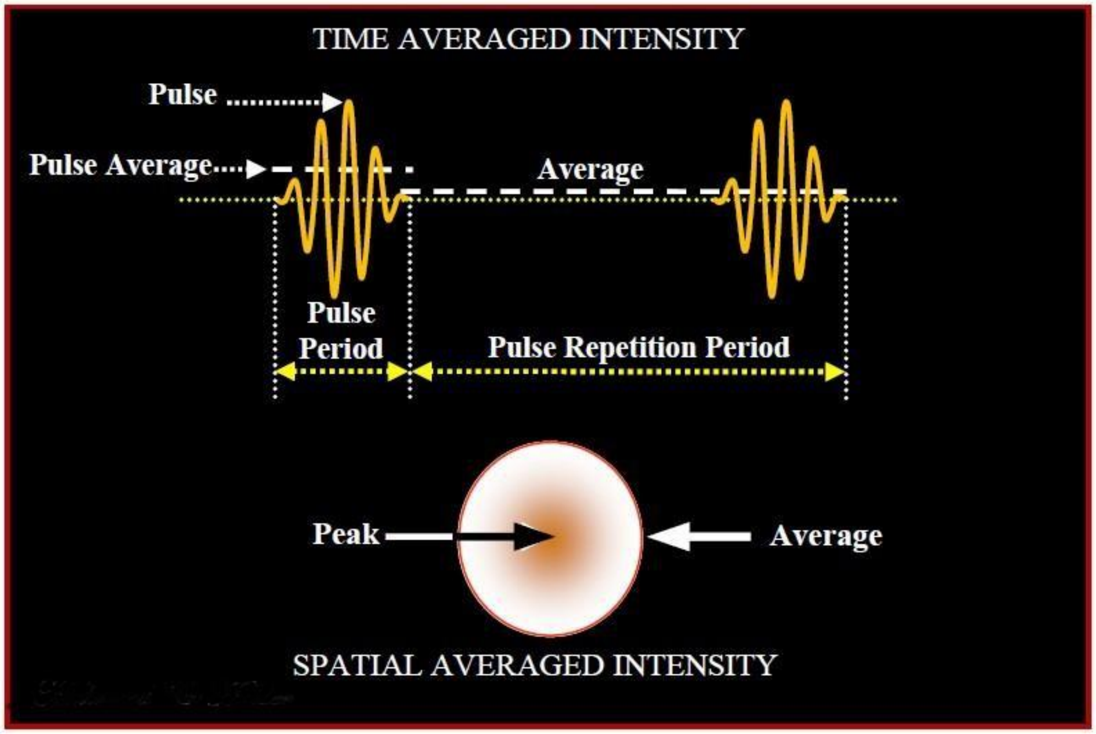

Figure 14: Temporal and Spatial Characteristics of Ultrasound Pulses That Affect Intensity Values.

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With respect to time there are three possible power (intensity) values. One is the peak power, which is associated with the time of maximum pressure. Another is the average power within a pulse. The lowest value is the average power over the pulse repetition period for an extended time. This is related to the duty factor.

2.11.2 Spatial Characteristics

The energy or intensity is generally not distributed uniformly over the area of an ultrasound pulse. It can be expressed either as the peak intensity, which is often in the center of the pulse, for as the average intensity over a designated area.

2.11.3 Temporal/Spatial Combinations

There is some significance associated with each of the intensity expressions. However, they are not all used to express the intensity with respect to potential biological effects. Thermal effects are most closely related to the spatial-peak and temporal-average intensity (**ISPTA**). This expresses the maximum intensity delivered to any tissue averaged over the duration of the exposure. Thermal effects (increase in temperature) also depend on the duration of the exposure to the ultrasound. Mechanical effects such as cavitation are more closely related to the spatial-peak, pulse-average intensity (ISPPA).

2.12 Interactions of Ultrasound with Tissue

As an ultrasound pulse passes through matter, such as human tissue, it interacts in several different ways. Some of these interactions are necessary to form an ultrasound image, whereas others absorb much of the ultrasound energy or produce artifacts and are generally undesirable in diagnostic examinations. The ability to conduct and interpret the results of an ultrasound examination depends on a thorough understanding of these ultrasound interactions.

Interaction between ultrasound and the medium, such as human tissue, is in several different ways which can be described by attenuation, reflection, scattering, refraction and diffraction (all well-known optical phenomena). Together with absorption, they cause attenuation of an ultrasound beam on its way through the medium. The total attenuation in a medium is expressed in terms of the distance within the medium at which the intensity of ultrasound is reduced to 50% of its initial level, called the half-value thicknesses.

Energy is lost as the wave overcomes the natural resistance of the particles in the medium to displacement, i.e. the viscosity of the medium. Thus, absorption increases with the viscosity of the medium and contributes to the attenuation of the ultrasound beam. Absorption increases with the frequency of the ultrasound.

In soft tissue, attenuation by absorption is approximately **0.5 decibels** (dB) **per centimeter of tissue and per megahertz**. Attenuation limits the depth at which examination with ultrasound of a certain frequency is possible; this distance is called the '**penetration depth**'. In this connection, it should be noted that the reflected ultrasound echoes also have to pass back out through the same tissue to be detected. Energy loss suffered by distant reflected echoes must be compensated for in the processing of the signal by the ultrasound unit using echo gain techniques (**depth gain compensation** (DGC) or **time gain compensation** (TGC)) to construct an image with homogeneous density over the varying depth of penetration.

2.12.1 Attenuation

Attenuation generally indicates that the ultrasound wave constantly lose energy (decreasing intensity) when transmitted through the medium. It is the result of absorption of ultrasound energy by conversion to heat, as well as **reflection**, **refraction** and **scattering** that occurs between the boundaries of tissue with different densities. The rate at which an ultrasound wave is absorbed generally depends on two factors:

(1) the material through which it is passing, and

(2) *the frequency of the ultrasound.*

This means that the attenuation increases (and hence penetration of the beam reduced) by:

- Increased distance from the transducer
- Less homogenous medium to traverse due to increased acoustic impedance mismatch
- Higher frequency (shorter wavelength) transducers

Air forms a virtually impenetrable **barrier** to ultrasound, while **fluid** offers the least resistance.
Attenuation (absorption) rate is described in terms of **attenuation coefficient** of tissues. It is the relation of attenuation to distance; therefore, it is measure **decibels per centimeter** units, and depends on the tissues traversed and the frequency of the ultrasound wave. So, it is necessary specify the frequency when an attenuation rate is given due to the attenuation in tissue increases with frequency. Through a thickness of material, ***x***, the attenuation is given by:

$$\textbf{Attenuation (dB)} = (\alpha)\,(f)\,(x)$$

where α is the attenuation coefficient (in decibels per centimeter at 1 MHz), and ***f*** is the ultrasound frequency, in megahertz?
Attenuation coefficient values in the table 2.2, it is clear that there is considerable variation in the rate of attenuation from material to material. All materials mentioned, water and produces far less attenuation. This means that the water is a very good conductor of ultrasound. So, attenuation is low in fluid-filled structures as the case in cysts and bladder. Most of the soft tissues in the body contain the attenuation coefficient values of about 1 dB per cm in MHz, with the exception of fat and muscle which have high attenuation rate. Muscle has a set of values that depend on the direction of ultrasound with respect to the muscle fibers. Lung has a much higher proportion of tissue attenuation either air or soft. This is because the small pockets of air in the alveoli are very effective in scattering ultrasound energy. Because of this, and normal lung structure is very difficult to penetrate with ultrasound. Compared with the soft tissues of the body, attenuation rate is high in the bones. Higher frequency waves are subject to greater attenuation than lower frequency ones.

To compensate for attenuation, returning signals can be amplified by the ultrasound system, known as gain.