1 General Considerations in Operative Ultrasound

How Is the Ultrasound Image Formed?

Sounds are pressure waves which are propagated at variable speeds, depending on the elastic properties of the medium in which they are travelling. These pressure waves produce a reflection on striking an obstacle (an interface between two mediums with different elastic properties), which can be sensed by a receiving device. These reflections are termed echoes.

Ultrasound waves are high-frequency signals which exceed 15000 cycles per second (15000Hz). Ultrasound frequencies used in abdominal scanning vary from $2 \times 10^6$ to $10 \times 10^6$ Hz or 2 to 10 MHz. This range of frequencies is not chosen arbitrarily, but is limited by the following physical constraints:

1. The primary goal in scanning is to obtain the greatest possible precision; i.e., to identify the smallest possible objects. For physical reasons the smallest detail one can observe is of the order of several multiples of the wavelength being utilized. (In water the maximal resolution is 0.5 mm per 3 MHz.) The use of a short wavelength implies a high frequency, since they have an inverse relationship.

2. The maximal wavelength which can be used is limited by the loss of energy by the signal as it passes through the medium, a loss which increases with increasing frequency. For these reasons, the depth of the area which can be scanned is limited by the frequency of the signal.

For scanning, the ideal system must represent a compromise between two opposing factors. Since operative ultrasound permits the placement of the probe directly on the organ to be scanned, it allows greater accuracy than percutaneous scanning. A higher-frequency signal is used, since the sound wave does not have to travel through the layers of the abdominal wall.

The probe, termed a transducer, is both a transmitter and a receiver of the ultrasound signal. It is applied directly to the surface of the organ to be scanned and emits an ultrasound beam of short duration. After the emission the transducer receives the echoes, which are then transformed into electrical signals and presented as points on a cathode ray screen by the pulse-processing system. The position of the point on the screen is proportional to the amount of time which elapses between emission and reception, and therefore represents the distance between the probe and the structure being visualized. The brightness of the point on the screen, which ranges from white to black through a spectrum of grey, is related to the amplitude of the reflection. This is called B-mode ultrasound.

There are two different imaging techniques:

1. In contact ultrasound, the image is constructed one line at a time. Time is required to form and fix each image.

2. In real-time ultrasound, the probe is constructed with multiple transducers, whose firing sequence is coordinated in a continuous cycle. This permits the immediate reconstruction of the image and thus the possibility of dynamic imaging.

Two types of probe exist for real-time imaging:

1. If the multiple transducers have a linear arrangement, an image is produced which is composed of multiple parallel lines and forms a wide sweep.
2. If the transducers have a radial arrangement, a sector scan is produced which constructs a pie-shaped image. A similar image can be produced by a single transducer either with a set of mirrors or a motor which rapidly moves the transducer through an arc.

In both cases a cross-sectional image is produced of the area being scanned. The image reconstructed on the cathode ray screen can be reproduced on photographic film or on video tape. By convention the images are recorded using white on a black background with the upper portion of the image representing the area closest to the probe. In transverse sections the left of the image corresponds to the patient’s right (Fig. 1). In longitudinal sections, the left is superior, the right inferior.

**Operation of the Ultrasound Equipment**

**The Gain Curve**

Depending on the frequency of the ultrasound beam and the characteristics of the medium, a progressive loss of energy occurs with increasing depth. This loss of energy is a function of the density of the medium. Modern ultrasound equipment compensates for this attenuation by using a system which regulates the intensity of the beam as a function of the depth of imaging. This regulation, which is termed time-gain compensation, varies in complexity between different types of equipment: near gain, far gain, overall gain, and the slope of the gain curve (dB/cm). These are simple systems which are controlled manually. More complex systems can provide a continuous modification of gain during imaging. This regulation is of fundamental importance for obtaining interpretable images: for good imaging a gain setting is chosen which produces a uniform tone of grey over the entire depth of an area of homogeneous echodensity (Fig. 2).

![Fig. 1. A The ultrasound image is not a strict reconstruction of the object as it appears in reality, but rather a representation of the acoustic interfaces which reflect or refract sound waves depending on their intrinsic properties. B The liver of Piacenza, an Etruscan model, more than 2000 years old](image)