Ultrasound Physics

Jesse Shriki, DO, MS, RDMS[a,b]

KEYWORDS

- Ultrasound physics • Frequency • Period • Transducer • Instrumentation
- Doppler shift

KEY POINTS

- This article introduces the physics essential for understanding diagnostic medical ultrasound.
- This article discusses the differences between continuous wave and pulsed wave ultrasound.
- The basics of ultrasound instrumentation, such as transducers and display modes, are explained.
- Ultrasound techniques, such as Doppler imaging, are introduced.
- An understanding of key concepts, such as resolution and artifact, are discussed.

INTRODUCTION

Point-of-care emergency ultrasound has become the modern-day physician's stethoscope equivalent. The concepts fundamental to ultrasound physics are critical in both understanding point-of-care ultrasound and obtaining the best possible images. Without knowledge of how the ultrasound system interprets and acquires sound waves, understanding the perceived anatomy can be difficult at best. Knowing how the images are created can help practitioners determine if an image produced is an accurate depiction of the anatomy or if artifacts are confounding (or contributing) to the acquired images.

BASIC SOUND

In order to understand diagnostic ultrasound, sound should be thought of as more than just the familiar sense of hearing. Rather, sound should be thought of as the interaction of energy and matter. In contradistinction to electromagnetic energy, sound is mechanical energy transmitted by pressure waves in a medium,[1] which means that sound exists in the form of particles moving in a medium. A sound source, such as a tuning fork, acts like a piston pushing waves of vibration longitudinally through

The author listed has identified no professional or financial affiliations.
[a] Department of Emergency Medicine, Scottsdale Emergency Associates, 7400 E Osborn Avenue, Scottsdale, AZ 85251, USA; [b] The University of Arizona, Tucson, AZ 85721, USA
E-mail address: Shrikido@gmail.com

Crit Care Clin 30 (2014) 1–24
http://dx.doi.org/10.1016/j.ccc.2013.08.004 criticalcare.theclinics.com
0749-0704/14/$ – see front matter

tissue. The sound wave produced has areas of high pressure (or high density) and low pressure (or low density). The high-pressure areas (compression) are where the sound waves are compressed together and the low-pressure areas (rarefaction) are where the sound waves are spaced apart (**Fig. 1**).

Sound particles should be thought of as elements of transverse and longitudinal waveforms moving in a medium. In diagnostic ultrasound, the media can be air, blood, or soft tissue. In the absence of media (ie, a vacuum), sound cannot propagate. In a transverse wave, displacement of the medium is perpendicular to the direction of propagation of the wave, as in a ripple on a pond. In longitudinal waves, the displacement of the medium is parallel to the propagation of the wave, moving like a Slinky or caterpillar back and forth (**Fig. 2**). Only longitudinal waves effectively traverse distances and, therefore, only longitudinal waves are important in diagnostic ultrasound.

SOUND SOURCE

The production of sound requires an oscillating or vibrating source. A tuning fork is a good example of how sound is produced by oscillation and vibration (see **Fig. 1**). When a tuning fork vibrates, it moves adjacent air molecules causing them, in turn, to vibrate. Sound spreads throughout the medium, air, as a wave in all directions.

In the ultrasound system, the sound source is a piezoelectric crystal, such as quartz. Modern transducers typically use a lead zirconate titanate (PZT) amalgam. The piezoelectric effect allows for these crystals to vibrate when an electrical voltage is applied across it and subsequently creates sound waves. Conversely, piezoelectric crystals also can convert sound waves back into electrical energy so that the sound waves can be converted into data that can be processed into anatomic images.

WAVES

A single-frequency sound wave is commonly conceptualized as a single sine wave causing alternating pressure variations in the air (**Fig. 4**). Ultrasound waves are rarely, however, waves of a single frequency and are generally made up of multiple frequencies. Accordingly, these waves can interfere with each other either constructively or destructively (**Fig. 3**).[1]

ACOUSTIC PARAMETER AND VARIABLES

To understand the basic physics of ultrasound, acoustic parameters and acoustic variables must be defined; they are the basis of describing waves. In physics nomenclature,

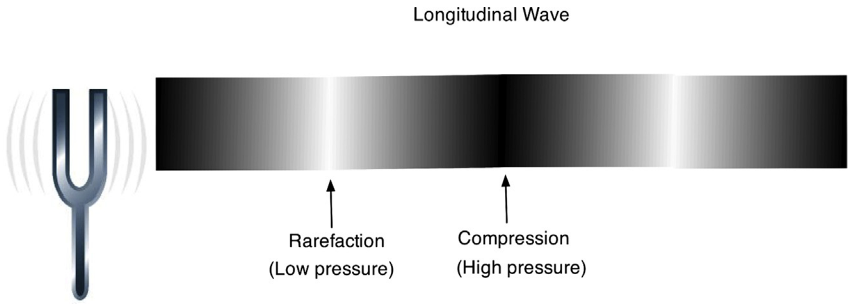

Fig. 1. The tuning fork acts like a piston, creating sound waves of areas of high pressure (represented by the *black areas*) and low pressure (represented by *white areas*).