How Ultrasound Works

by Craig C. Freudenrich, Ph.D.

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There are many situations in which ultrasound is performed. Perhaps you are pregnant, and your obstetrician wants you to have an ultrasound to check on the developing baby or determine the due date. Maybe you are having problems with blood circulation in a limb or your heart, and your doctor has requested a Doppler ultrasound to look at the blood flow. Ultrasound has been a popular medical imaging technique for many years.

Photo courtesy Philips Research
Ultrasound examination during pregnancy

In this edition of **How Stuff Works**, we will look at how ultrasound works, what type of ultrasound techniques are available and what each technique can be used for.

What is Ultrasound?

Ultrasound or **ultrasonography** is a medical imaging technique that uses high frequency sound waves and their echoes. The technique is similar to the echolocation used by bats, whales and dolphins, as well as SONAR used by submarines. In ultrasound, the following events happen:

1. The ultrasound machine transmits high-frequency (1 to 5 megahertz) sound pulses into your body using a probe.
2. The sound waves travel into your body and hit a boundary between tissues (e.g. between fluid and soft

tissue, soft tissue and bone).
3. Some of the sound waves get reflected back to the probe, while some travel on further until they reach another boundary and get reflected.
4. The reflected waves are picked up by the probe and relayed to the machine.
5. The machine calculates the distance from the probe to the tissue or organ (boundaries) using the speed of sound in tissue (5,005 ft/s or1,540 m/s) and the time of the each echo's return (usually on the order of millionths of a second).
6. The machine displays the distances and intensities of the echoes on the screen, forming a two dimensional image like the one shown below.

Photo courtesy Karim and Nancy Nice

Ultrasound image of a growing fetus (approximately 12 weeks old) inside a mother's uterus. This is a side view of the baby, showing (right to left) the head, neck, torso and legs.

In a typical ultrasound, millions of pulses and echoes are sent and received each second. The probe can be moved along the surface of the body and angled to obtain various views.

The Ultrasound Machine

A basic ultrasound machine has the following parts:

- **transducer probe -** probe that sends and receives the sound waves
- **central processing unit (CPU) -** computer that does all of the calculations and contains the electrical power supplies for itself and the transducer probe
- **transducer pulse controls -** changes the amplitude, frequency and duration of the pulses emitted from the transducer probe
- **display -** displays the image from the ultrasound data processed by the CPU
- **keyboard/cursor -** inputs data and takes measurements from the display
- **disk storage device** (hard, floppy, CD) **-** stores the acquired images
- **printer -** prints the image from the displayed data

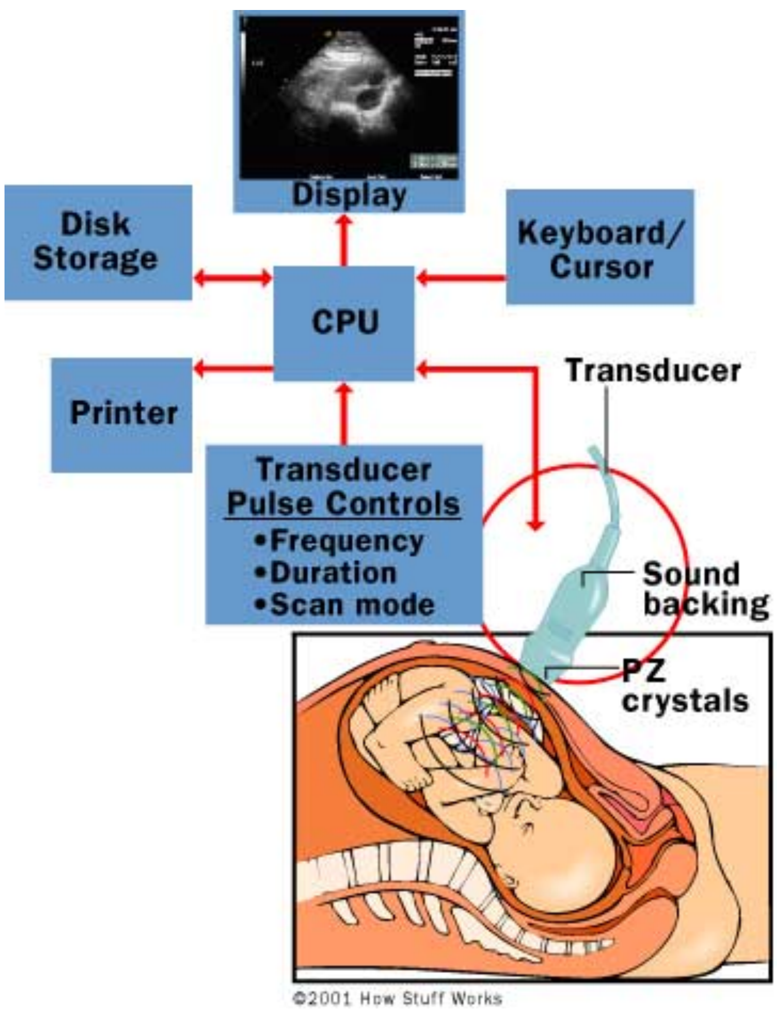

Photo courtesy Dynamic Imaging Limited

Transducer Probe

The transducer probe is the main part of the ultrasound machine. The transducer probe makes the sound waves and receives the echoes. It is, so to speak, the mouth and ears of the ultrasound machine. The transducer probe generates and receives sound waves using a principle called the **piezoelectric (pressure electricity) effect**, which was discovered by Pierre and Jacques Curie in 1880. In the probe, there are one or more quartz crystals called **piezoelectric crystals**. When an electric current is applied to these crystals, they change shape rapidly. The rapid shape changes, or vibrations, of the crystals produce sound waves that travel outward. Conversely, when sound or pressure waves hit the crystals, they emit electrical currents. Therefore, the same crystals can be used to send and receive sound waves. The probe also has a sound absorbing substance to eliminate back reflections from the probe itself, and an acoustic lens to help focus the emitted sound waves.

Ultrasound machine with various transducer probes

Transducer probes come in many shapes and sizes, as shown in the photo above. The shape of the probe determines its field of view, and the frequency of emitted sound waves determines how deep the sound waves penetrate and the resolution of the image. Transducer probes may contain one or more crystal elements; in multiple-element probes, each crystal has its own circuit. Multiple-element probes have the advantage that the ultrasounc beam can be "steered" by changing the timing in which each element gets pulsed; steering the beam is especially important for cardiac ultrasound (see Basic Principles of Ultrasound for details on transducers). In addition to probes that can be moved across the surface of the body, some probes are designed to be inserted through various openings of the body (vagina, rectum, esophagus) so that they can get closer to the organ being examined (uterus, prostate gland, stomach); getting closer to the organ can allow for more detailed views.



The parts of an ultrasound machine

Central Processing Unit (CPU)

The CPU is the brain of the ultrasound machine. The CPU is basically a computer that contains the microprocessor, memory, amplifiers and power supplies for the microprocessor and transducer probe. The CPU sends electrical currents to the transducer probe to emit sound waves, and also receives the electrical pulses from the probes that were created from the returning echoes. The CPU does all of the calculations involved in processing the data. Once the raw data are processed, the CPU forms the image on the monitor. The CPU can also store the processed data and/or image on disk.

Transducer Pulse Controls

The transducer pulse controls allow the operator, called the **ultrasonographer**, to set and change the frequency and duration of the ultrasound pulses, as well as the scan mode of the machine. The commands from the operator are translated into changing electric currents that are applied to the piezoelectric crystals in the transducer probe.

Display

The display is a computer monitor that shows the processed data from the CPU. Displays can be black-and-white or color, depending upon the model of the ultrasound machine.

Keyboard/Cursor

Ultrasound machines have a keyboard and a cursor, such as a trackball, built in. These devices allow the operator to add notes to and take measurements from the data.

Disk Storage

The processed data and/ or images can be stored on disk. The disks can be hard disks, floppy disks, compact discs (CDs) or digital video discs (DVDs). Typically, a patient's ultrasound scans are stored on a floppy disk and archived with the patient's medical records.

Printers

Many ultrasound machines have thermal printers that can be used to capture a hard copy of the image from the display.

Different Types of Ultrasound

The ultrasound that we have described so far presents a two dimensional image, or "slice," of a three dimensional object (fetus, organ). Two other types of ultrasound are currently in use, **3D ultrasound imaging** and **Doppler ultrasound**.

3D Ultrasound Imaging

In the past two years, ultrasound machines capable of three-dimensional imaging have been developed. In these machines, several two-dimensional images are acquired by moving the probes across the body surface or rotating inserted probes. The two-dimensional scans are then combined by specialized computer software to form 3D images.

Photo courtesy Philips Research
3D ultrasound images

3D imaging allows you to get a better look at the organ being examined and is best used for:

- Early detection of cancerous and benign tumors
  - examining the prostate gland for early detection of tumors
  - looking for masses in the colon and rectum
  - detecting breast lesions for possible biopsies
- Visualizing a fetus to assess its development, especially for observing abnormal development of the face and limbs
- Visualizing blood flow in various organs or a fetus

Doppler Ultrasound

Doppler ultrasound is based upon the **Doppler Effect**. When the object reflecting the ultrasound waves is moving, it changes the frequency of the echoes, creating a higher frequency if it is moving toward the probe and a lower frequency if it is moving away from the probe. How much the frequency is changed depends upon how fast the object is moving. Doppler ultrasound measures the change in frequency of the echoes to calculate how fast an object is moving. Doppler ultrasound has been used mostly to measure the rate of blood flow through the heart and major arteries.

Photo courtesy Philips Research
Doppler ultrasound used to measure blood flow through the heart. The

direction of blood flow is shown in different colors on the screen.

Major Uses of Ultrasound

Ultrasound has been used in a variety of clinical settings, including obstetrics and gynecology, cardiology and cancer detection. The main advantage of ultrasound is that certain structures can be observed without using radiation. Ultrasound can also be done much faster than X-rays or other radiographic techniques. Here is a short list of some uses for ultrasound:

- **Obstetrics and Gynecology**
  - measuring the size of the fetus to determine the due date
  - determining the position of the fetus to see if it is in the normal head down position or breech
  - checking the position of the placenta to see if it is improperly developing over the opening to the uterus (cervix)
  - seeing the number of fetuses in the uterus
  - checking the sex of the baby (if the genital area can be clearly seen)
  - checking the fetus's growth rate by making many measurements over time
  - detecting ectopic pregnancy, the life-threatening situation in which the baby is implanted in the mother's Fallopian tubes instead of in the uterus
  - determining whether there is an appropriate amount of amniotic fluid cushioning the baby
  - monitoring the baby during specialized procedures - ultrasound has been helpful in seeing and avoiding the baby during amniocentesis (sampling of the amniotic fluid with a needle for genetic testing). Years ago, doctors use to perform this procedure blindly; however, with accompanying use of ultrasound, the risks of this procedure have dropped dramatically.
  - seeing tumors of the ovary and breast
- **Cardiology**
  - seeing the inside of the heart to identify abnormal structures or functions
  - measuring blood flow through the heart and major blood vessels
- **Urology**
  - measuring blood flow through the kidney
  - seeing kidney stones
  - detecting prostate cancer early

In addition to these areas, there is a growing use for ultrasound as a rapid imaging tool for diagnosis in emergency rooms.

Dangers of Ultrasound

There have been many concerns about the safety of ultrasound. Because ultrasound is energy, the question becomes "What is this energy doing to my tissues or my baby?" There have been some reports of low birthweight babies being born to mothers who had frequent ultrasound examinations during pregnancy. The two major possibilities with ultrasound are as follows:

- development of **heat** - tissues or water absorb the ultrasound energy which increases their temperature locally
- formation of **bubbles (cavitation)** - when dissolved gases come out of solution due to local heat caused by ultrasound

However, there have been no substantiated ill-effects of ultrasound documented in studies in either humans or animals. This being said, ultrasound should still be used only when necessary (i.e. better to be cautious).

An Ultrasound Examination

For an ultrasound exam, you go into a room with a technician and the ultrasound machine. The following happens:

1. You remove your clothes (all of your clothes or only those over the area of interest).
2. The ultrasonographer drapes a cloth over any exposed areas that are not needed for the exam.
3. The ultrasonographer applies a mineral oil-based jelly to your skin -- this jelly eliminates air between the probe and your skin to help pass the sound waves into your body.
4. The ultrasonographer covers the probe with a plastic cover.
5. He/she passes the probe over your skin to obtain the required images. Depending upon the type of exam, the probe may be inserted into you.
6. You may be asked to change positions to get better looks at the area of interest.
7. After the images have been acquired and measurements taken, the data is stored on disk. You may get a hard copy of the images.
8. You are given a towelette to clean up.
9. You get dressed.

The Future of Ultrasound

As with other computer technology, ultrasound machines will most likely get faster and have more memory for storing data. Transducer probes may get smaller, and more insertable probes will be developed to get better images of internal organs. Most likely, 3D ultrasound will be more highly developed and become more popular. The entire ultrasound machine will probably get smaller, perhaps even hand-held for use in the field (e.g. paramedics, battlefield triage). One exciting new area of research is the development of ultrasound imaging combined with heads-up/virtual reality-type displays that will allow a doctor to "see" inside you as he/she is performing a minimally invasive or non-invasive procedure such as amniocentesis or biopsy.