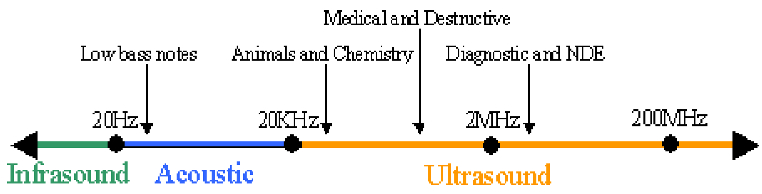
Ultrasound

Ultrasound is cyclic sound pressure with a frequency greater than the upper limit of human hearing. Although this limit varies from person to person, it is approximately 20 kilohertz (20,000 hertz) in healthy, young adults and thus, 20 kHz serves as a useful lower limit in describing ultrasound. The production of ultrasound is used in many different fields, typically to penetrate a medium and measure the reflection signature or supply focused energy. The reflection signature can reveal details about the inner structure of the medium, a property also used by animals such as bats for hunting. The most well known application of ultrasound is its use in sonography to produce pictures of fetuses in the human womb. There are a vast number of other applications as well.[1]

Ability to hear ultrasound



Approximate frequency ranges corresponding to ultrasound, with rough guide of some applications

The upper frequency limit in humans (approximately 20 kHz) is due to limitations of the middle ear, which acts as a low-pass filter. Ultrasonic hearing can occur if ultrasound is fed directly into the skull bone and reaches the cochlea through bone conduction without passing through the middle ear.

A fetus in its mother's womb, viewed in a sonogram (brightness scan)

It is a fact in psychoacoustics that children can hear some high-pitched sounds that older adults cannot hear, because in humans the upper limit pitch of hearing tends to become lower with age.[2] A cell phone company has used this to create ring signals supposedly only able to be heard by younger humans;[3] but many older people claim to be able to hear it, which is likely given the considerable variation of age-related deterioration in the upper hearing threshold.

An ultrasound examination in East Germany, 1990

Some animals — such as dogs, cats, dolphins, bats, and mice — have an upper frequency limit that is greater than that of the human ear and thus can hear ultrasound, which is how a dog whistle works.

Diagnostic sonography


Sonogram of a fetus at 14 weeks (profile)


Head of a fetus, aged 29 weeks, in a "3D ultrasound"

Medical sonography (**ultrasonography**) is an ultrasound-based diagnostic medical imaging technique used to visualize muscles, tendons, and many internal organs, to capture their size, structure and any pathological lesions with real time tomographic images. Ultrasound has been used by sonographers to image the human body for at least 50 years and has become one of the most widely used diagnostic tools in modern medicine. The technology is relatively inexpensive and portable, especially when compared with other techniques, such as magnetic resonance imaging (MRI) and computed tomography (CT). Ultrasound is also used to visualize fetuses during routine and emergency prenatal care. Such diagnostic applications used during pregnancy are referred to as obstetric sonography.

As currently applied in the medical field, properly performed ultrasound poses no known risks to the patient.[4] Sonography is generally described as a "safe test" because it does not use mutagenic ionizing radiation, which can pose hazards such as chromosome breakage and cancer development. However, ultrasonic energy has two potential physiological effects: it enhances inflammatory response; and it can heat soft tissue. Ultrasound energy produces a mechanical pressure wave through soft tissue. This pressure wave may cause microscopic bubbles in living tissues and distortion of the cell membrane, influencing ion fluxes and intracellular activity. When ultrasound enters the body, it causes molecular friction and heats the tissues slightly. This effect is typically very minor as normal tissue perfusion dissipates most of the heat, but with high intensity, it can also cause small pockets of gas in body fluids or tissues to expand and contract/collapse in a phenomenon called cavitation; however this is not known to occur at diagnostic power levels used by modern diagnostic ultrasound units.

In 2008, the AIUM published a 130-page report titled "American Institute of Ultrasound in Medicine Consensus Report on Potential Bioeffects of Diagnostic Ultrasound"[5] stating that there are indeed some potential risks to administering ultrasound tests, which include "postnatal thermal effects, fetal thermal effects, postnatal mechanical effects, fetal mechanical effects, and bioeffects considerations for ultrasound contrast agents."[6] The long-term effects of tissue heating and cavitation have shown decreases in the size of red blood cells in cattle when exposed to intensities higher than diagnostic levels.[7] However, long term effects due to ultrasound exposure at diagnostic intensity is still unknown.[8]

There are several studies that indicate the harmful side effects on animal fetuses associated with the use of sonography on pregnant mammals. A Yale study in 2006 suggested exposure to ultrasound affects fetal brain development in mice. A typical fetal scan, including evaluation for fetal malformations, typically takes 10–30 minutes.[9] The study showed that rodent brain cells failed to migrate to their proper positions and remained scattered in incorrect parts of the brain. This misplacement of brain cells during their development is linked to disorders ranging from "mental retardation and childhood epilepsy to developmental dyslexia, autism spectrum disorders and schizophrenia." However, this effect was only detectable after 30 minutes of continuous scanning. No link has yet been made between the test results on animals such as mice and the possible effects on humans. Although the possibility exists that biological effects on humans may be identified in the future, currently most doctors feel that based on available information the benefits to patients outweigh the risks.[10] Also the ALARA (As Low As Reasonably Achievable) principle has been advocated for an ultrasound examination; that is keeping the scanning time and power settings as low as possible but consistent with diagnostic imaging; and that is the priciple by which non-medical uses which by definition are not necessary are actively discouraged.

Obstetric ultrasound can be used to identify many conditions that would be harmful to the mother and the baby. Many health care professionals consider the risk of leaving these conditions undiagnosed to be much greater than the very small risk, if any, associated with undergoing an ultrasound scan. According to Cochrane Review, routine ultrasound in early pregnancy (less than 24 weeks) appears to enable better gestational age assessment, earlier detection of multiple pregnancies and earlier detection of clinically unsuspected fetal malformation at a time when termination of pregnancy is possible.[11]

Sonography is used routinely in obstetric appointments during pregnancy, but the FDA discourages its use for non-medical purposes such as fetal keepsake videos and photos, even though it is the same technology used in hospitals.

Obstetric ultrasound is primarily used to:

- Date the pregnancy (gestational age)
- Confirm fetal viability
- Determine location of fetus, intrauterine vs ectopic
- Check the location of the placenta in relation to the cervix
- Check for the number of fetuses (multiple pregnancy)
- Check for major physical abnormalities.
- Assess fetal growth (for evidence of intrauterine growth restriction (IUGR))
- Check for fetal movement and heartbeat.
- Determine the sex of the baby

Unfortunately, results are occasionally wrong, producing a false positive (the Cochrane Collaboration is a relevant effort to improve the reliability of health care trials). False detection may result in patients being warned of birth defects when no such defect exists. Sex determination is only accurate after 12 weeks gestation. When balancing risk and reward, there are recommendations to avoid the use of routine ultrasound for low risk pregnancies. In many countries ultrasound is used routinely in the management of all pregnancies.

According to the European Committee of Medical Ultrasound Safety (ECMUS) "Ultrasonic examinations should only be performed by competent personnel who are trained and updated in safety matters. Ultrasound produces heating, pressure changes and mechanical disturbances in tissue. Diagnostic levels of ultrasound can produce temperature rises that are hazardous to sensitive organs and the embryo/fetus. Biological effects of non-thermal origin have been reported in animals but, to date, no such effects have been demonstrated in humans, except when a microbubble contrast agent is present."[12] Nonetheless, care should be taken to use low power settings and avoid pulsed wave scanning of the fetal brain unless specifically indicated in high risk pregnancies.

It should be noted that obstetrics is not the only use of ultrasound. Soft tissue imaging of many other parts of the body is conducted with ultrasound. Other scans routinely conducted are cardiac, renal, liver and gallbladder (hepatic). Other common applications include musculo-skeletal imaging of muscles, ligaments and tendons, ophthalmic ultrasound (eye) scans and superficial structures such as testicle, thyroid, salivary glands and lymph nodes. Because of the real time nature of ultrasound, it is often used to guide interventional procedures such as fine needle aspiration FNA or biopsy of masses for cytology or histology testing in the breast, thyroid, liver, kidney, lymph nodes, muscles and joints.

Ultrasound scanners have different Doppler-techniques to visualize arteries and veins. The most common is colour doppler or power doppler, but also other techniques like b-flow are used to show bloodflow in an organ. By using pulsed wave doppler or continuous wave doppler bloodflow velocities can be calculated.

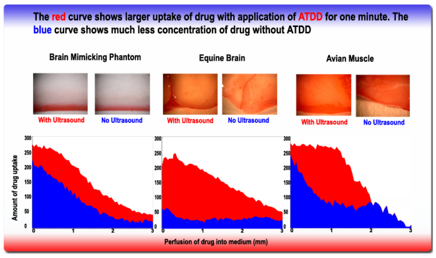
Figures released for the period 2005-2006 by UK Government (Department of Health) show that non-obstetric ultrasound examinations constituted more than 65% of the total number of ultrasound scans conducted.

Ultrasound is also increasingly being used in trauma and first aid cases, with emergency ultrasound becoming a staple of most EMT response teams.

Biomedical ultrasonic applications

Ultrasound also has therapeutic applications, which can be highly beneficial when used with dosage precautions:[13]

- According to RadiologyInfo,[14] ultrasounds are useful in the detection of pelvic abnormalities and can involve techniques known as abdominal (transabdominal) ultrasound, vaginal (transvaginal or endovaginal) ultrasound in women, and also rectal (transrectal) ultrasound in men.
- Focused high-energy ultrasound pulses can be used to break calculi such as kidney stones and gallstones into fragments small enough to be passed from the body without undue difficulty, a process known as lithotripsy.
- Treating benign and malignant tumors and other disorders via a process known as high intensity focused ultrasound (HIFU), also called *focused ultrasound surgery* (FUS). In this procedure, a generally lower frequencies than medical diagnostic ultrasound is used (250–2000 kHz), but significantly higher time-averaged intensities. The treatment is often guided by magnetic resonance imaging (MRI)—this is called *Magnetic resonance-guided focused ultrasound* (MRgFUS). Delivering chemotherapy to brain cancer cells and various drugs to other tissues is called acoustic targeted drug delivery (ATDD).[15] These procedures generally use high frequency ultrasound (1-10 MHz) and a range of intensities (0-20 watts/cm^2). The acoustic energy is focused on the tissue of interest to agitate its matrix and make it more permeable for therapeutic drugs.[16] [17]



Enhanced drug uptake using acoustic targeted drug delivery (ATDD).

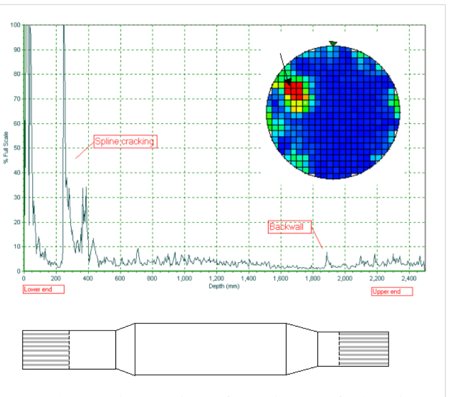
- Therapeutic ultrasound, a technique that uses more powerful ultrasound sources to generate cellular effects in soft tissue has fallen out of favor as research has shown a lack of efficacy[18] and a lack of scientific basis for proposed biophysical effects.[19] Ultrasound has been used in cancer treatment.
- Cleaning teeth in dental hygiene.
- Focused ultrasound sources may be used for cataract treatment by phacoemulsification.
- Additional physiological effects of low-intensity ultrasound have recently been discovered, e.g. the ability to stimulate bone-growth and its potential to disrupt the blood-brain barrier for drug delivery.
- Ultrasound is essential to the procedures of ultrasound-guided sclerotherapy and endovenous laser treatment for the non-surgical treatment of varicose veins.
- Ultrasound-assisted lipectomy is lipectomy assisted by ultrasound. Liposuction can also be assisted by ultrasound.
- Doppler ultrasound is being tested for use in aiding tissue plasminogen activator treatment in stroke sufferers in the procedure called ultrasound-enhanced systemic thrombolysis.
- Low intensity pulsed ultrasound is used for therapeutic tooth and bone regeneration.
- Ultrasound can also be used for elastography. This can be useful in medical diagnoses, as elasticity can discern healthy from unhealthy tissue for specific organs/growths. In some cases unhealthy tissue may have a lower system Q, meaning that the system acts more like a large heavy spring as compared to higher values of system Q (healthy tissue) that respond to higher forcing frequencies. Ultrasonic elastography is different from conventional ultrasound, as a transceiver (pair) and a transmitter are used instead of only a transceiver. One transducer acts as both the transmitter and receiver to image the region of interest over time. The extra transmitter is a very low frequency transmitter, and perturbs the system so the unhealthy tissue oscillates at a low frequency and the healthy tissue does not. The transceiver, which operates at a high frequency (typically MHz) then measures the displacement of the unhealthy tissue (oscillating at a much lower frequency). The movement of the slowly

oscillating tissue is used to determine the elasticity of the material, which can then be used to distinguish healthy tissue from the unhealthy tissue.

- Ultrasound has been shown to act synergistically with antibiotics in bacterial cell killing.[20]
- Ultrasound has been postulated to allow thicker eukaryotic cell tissue cultures by promoting nutrient penetration.[21]
- Ultrasound in the low MHz range in the form of standing waves is an emerging tool for contactless separation, concentration and manipulation of microparticles and biological cells, a method referred to as acoustophoresis. The basis is the acoustic radiation force, a non-linear effect which causes particles to be attracted to either the nodes or anti-nodes of the standing wave depending on the acoustic contrast factor, which is a function of the sound velocities and densities of the particle and of the medium in which the particle is immersed.

Industrial ultrasound

Ultrasonic testing is a type of nondestructive testing commonly used to find flaws in materials and to measure the thickness of objects. Frequencies of 2 to 10 MHz are common but for special purposes other frequencies are used. Inspection may be manual or automated and is an essential part of modern manufacturing processes. Most metals can be inspected as well as plastics and aerospace composites. Lower frequency ultrasound (50–500 kHz) can also be used to inspect less dense materials such as wood, concrete and cement.



Non-destructive testing of a swing shaft showing spline cracking

Ultrasound can also be used for heat transfer in liquids. Researchers recently employed ultrasound in dry corn milling plant to enhance ethanol production.[22]

Ultrasonic manipulation and characterization of particles

A researcher at the Industrial Materials Research Institute, Alessandro Malutta, devised an experiment that demonstrated the trapping action of ultrasonic standing waves on wood pulp fibers diluted in water and their parallel orienting into the equidistant pressure planes.[23] The time to orient the fibers in equidistant planes is measured with a laser and an electro-optical sensor. This could provide the paper industry a quick on-line fiber size measurement system. A somewhat different implementation was demonstrated at Penn State University using a microchip which generated a pair of perpendicular standing surface acoustic waves allowing to position particles equidistant to each other on a grid. This experiment, called "acoustic tweezers", can be used for applications in material sciences, biology, physics, chemistry and nanotechnology.

Ultrasonic cleaning

Ultrasonic cleaners, sometimes mistakenly called *supersonic cleaners*, are used at frequencies from 20 to 40 kHz for jewellery, lenses and other optical parts, watches, dental instruments, surgical instruments, diving regulators and industrial parts. An ultrasonic cleaner works mostly by energy released from the collapse of millions of microscopic cavitations near the dirty surface. The bubbles made by cavitation collapse forming tiny jets directed at the surface.

Ultrasonic disintegration

Similar to ultrasonic cleaning, biological cells including bacteria can be disintegrated. High power ultrasound produces cavitation that facilitates particle disintegration or reactions. This has uses in biological science for analytical or chemical purposes (Sonication and Sonoporation) and in killing bacteria in sewage. Dr. Samir Khanal of Iowa State University employed high power ultrasound to disintegrate corn slurry to enhance liquefaction and saccharification for higher ethanol yield in dry corn milling plants.[24] [25] Similar to these findings was Dr. Oleg Kozyuk able to improve ethanol yield with hydrodynamic cavitation.[26] [27]

Ultrasonic humidifier

The ultrasonic humidifier, one type of nebulizer (a device that creates a very fine spray), is a popular type of humidifier. It works by vibrating a metal plate at ultrasonic frequencies to nebulize (sometimes incorrectly called "atomize") the water. Because the water is not heated for evaporation, it produces a cool mist. The ultrasonic pressure waves nebulize not only the water but also materials in the water including calcium, other minerals, viruses, fungi, bacteria,[28] and other impurities. Illness caused by impurities that reside in a humidifier's reservoir fall under the heading of "Humidifier Fever".

Ultrasound Identification (USID)

Ultrasound Identification (USID) is a Real Time Locating System (RTLS) or Indoor Positioning System (IPS) technology used to automatically track and identify the location of objects in real time using simple, inexpensive nodes (badges/tags) attached to or embedded in objects and devices, which then transmit an ultrasound signal to communicate their location to microphone sensors.

Ultrasonic welding

In ultrasonic welding of plastics, high frequency (15 kHz to 40 kHz) low amplitude vibration is used to create heat by way of friction between the materials to be joined. The interface of the two parts is specially designed to concentrate the energy for the maximum weld strength.

Ultrasound and animals

Bats

Bats use a variety of ultrasonic ranging (echolocation) techniques to detect their prey. They can detect frequencies as high as 100 kHz, although there is some disagreement on the upper limit.[29]

Bats use ultrasounds to move in the darkness.

Rodents/insects

There is evidence that ultrasound in the range emitted by bats causes flying moths to make evasive manoeuvres because bats eat moths. Ultrasonic frequencies trigger a reflex action in the noctuid moth that cause it to drop a few inches in its flight to evade attack.[30]

Tiger moths also emit clicks which jam bats' echolocation.[31] [32]

Ultrasound generator/speaker systems are sold with claims that they frighten away rodents and insects, but there is no scientific evidence that the devices work.

Dogs

Dogs can hear sound at higher frequencies than humans can. A dog whistle exploits this by emitting a high frequency sound to call to a dog. Many dog whistles emit sound in the upper audible range of humans, but some, such as the **silent whistle**, emit ultrasound at a frequency in the range 18–22 kHz.

Dolphins and whales

It is well known that some whales can hear ultrasound and have their own natural sonar system. Some whales use the ultrasound as a hunting tool (for both detection of prey and as an attack).[33]

Fish

Several types of fish can detect ultrasound. In the order Clupeiformes, members of the subfamily Alosinae (shad), have been shown to be able to detect sounds up to 180 kHz, while the other subfamilies (e.g. herrings) can hear only up to 4 kHz.[34]

Horses

Diagnostic ultrasound is used externally in the equine for evaluation of soft tissue and tendon injuries, and internally in particular for reproductive work - evaluation of the reproductive tract of the mare and pregnancy detection[35] . It may also be used in an external manner in stallions for evaluation of testicular condition and diameter as well as internally for reproductive evaluation (deferent duct etc.).[36]

Cattle

Starting at the turn of the century, ultrasound technology began to be used by the beef cattle industry to improve animal health and the yield of cattle operations.[37] Ultrasound is used to evaluate fat thickness, rib eye area, and intramuscular fat in living animals.[38] It is also used to evaluate the health and characteristics of unborn calves.

Ultrasound technology provides a means for cattle producers to obtain information that can be used to improve the breeding and husbandry of cattle. The technology can be expensive, and it requires a substantial time commitment for continuous data collection and operator training.[38] Nevertheless, this technology has proven useful in managing and running a cattle breeding operation.[37]

Sonochemistry

Power ultrasound in the 20–100 kHz range is used in chemistry. The ultrasound does not interact directly with molecules to induce the chemical change, as its typical wavelength (in the millimeter range) is too long compared to the molecules. Instead:

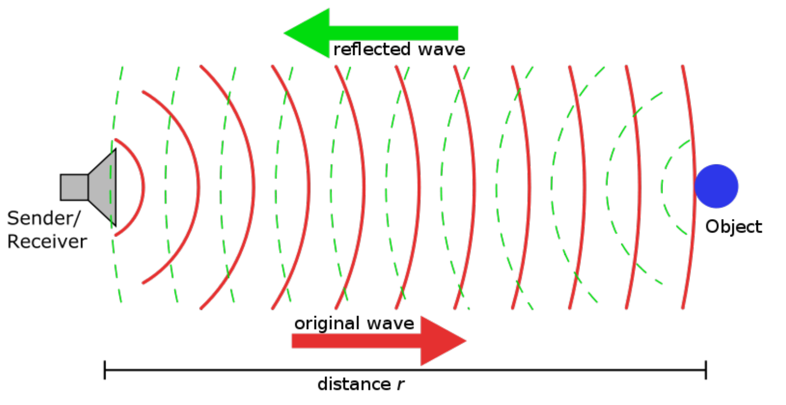
- It causes cavitation which causes local extremes of temperature and pressure in the liquid where the reaction happens.
- It breaks up solids and removes passivating layers of inert material to give a larger surface area for the reaction to occur over.

Both of these make the reaction faster.

- It is used in extraction, using different frequencies.

Ultrasonic range finding

A common use of ultrasound is in range finding; this use is also called SONAR, (sound navigation and ranging). This works similarly to RADAR (radio detection and ranging): An ultrasonic pulse is generated in a particular direction. If there is an object in the path of this pulse, part or all of the pulse will be reflected back to the transmitter as an echo and can be detected through the receiver path. By measuring the difference in time between the pulse being transmitted and the echo being received, it is possible to determine how far away the object is.



Principle of an active sonar

The measured travel time of SONAR pulses in water is strongly dependent on the temperature and the salinity of the water. Ultrasonic ranging is also applied for measurement in air and for short distances. Such method is capable for easily and rapidly measuring the layout of rooms.

Although range finding underwater is performed at both sub-audible and audible frequencies for great distances (1 to several kilometers), ultrasonic range finding is used when distances are shorter and the accuracy of the distance measurement is desired to be finer. Ultrasonic measurements may be limited through barrier layers with large salinity, temperature or vortex differentials. Ranging in water varies from about hundreds to thousands of meters, but can be performed with centimeters to meters accuracy.

Other uses

Ultrasound when applied in specific configurations can produce short bursts of light in an exotic phenomenon known as sonoluminescence. This phenomenon is being investigated partly because of the possibility of bubble fusion (a nuclear fusion reaction hypothesized to occur during sonoluminescence).

Researchers have successfully used ultrasound to regenerate dental material[39] .

Ultrasound is used when characterizing particulates through the technique of ultrasound attenuation spectroscopy or by observing electroacoustic phenomena.

In rheology, an acoustic rheometer relies on the principle of ultrasound. In fluid mechanics, fluid flow can be measured using an ultrasound flow meter.

Ultrasound also plays a role in Sonic weaponry.

High and ultra high ultrasound waves are used in Acoustic microscopy

Audio can be propagated by modulated ultrasound.

Nonlinear propagation effects

Because of their high amplitude to wavelength ratio, ultrasonic waves commonly display nonlinear propagation.

Safety

Occupational exposure to ultrasound in excess of 120 dB may lead to hearing loss. Exposure in excess of 155 dB may produce heating effects that are harmful to the human body, and it has been calculated that exposures above 180 dB may lead to death.[40]

See also

- Acoustics
- Bat detector
- Infrasound — sound at extremely low frequencies
- Light
- Medical ultrasonography
- Picosecond Ultrasonics
- Sound
- Sound from ultrasound (also known as Hypersonic sound)
- Waves
- Sonomicrometry
- Zone sonography technology

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- Guidelines for the Safe Use of Ultrasound [41]: valuable insight on the boundary conditions tending towards abuse of ultrasound.
- High-frequency hearing risk for operators of industrial ultrasonic devices [42]:
- Safety Issues in Fetal Ultrasound [43]:
- Damage to red blood cells induced by acoustic cavitation(ultrasound) [44]:

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