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Ultrasound Applications in Medical Sciences

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Abstract:** Ultrasound is becoming increasingly important in medicine both as a diagnostic tool, as a therapeutic modality and surgery. Most medical applications of ultrasound are based on the properties of longitudinal waves in the frequency range 1-15 MHz. Ultrasonic waves travel at similar velocities (about 1500 m s^{-1}) in most biological tissues and are absorbed in a rate of about 1 dB cm^{-1} MHz^{-1}. Absorption occurs chiefly due to relaxation processes. It leads to thermal effects in biological systems. Mechanical effects, such as streaming and cavitations, are also important in certain situations, particularly at low frequencies. Highly focused ultrasound is used in neurosurgery; it is the only method for producing trackless damage deep in the brain. Diagnostic imaging using ultrasound finds applications in all tissues. Although ultrasound has been used in medicine since the 1930's, it is only recently that these techniques have been widely used and their potential fully recognized. Medical ultrasonics is now in a period of rapid growth and is on the verge of making a significant impact on clinical medicine. This field offers an open proving ground to many technologies developed for other applications, gives inspiration to the development of new technological advances, and provides a host of challenging and important problems that are unique to medicine and biology. The future of ultrasound in medicine depends upon talented people from medicine and the physical sciences working in close collaboration and upon the emergence of a new breed of research scientist trained in both medicine and engineering and dedicated not to the technology of destruction but rather to the preservation of life and humanity. The object of this paper is to present a review of the principles of medical ultrasonic's and an introduction to a variety of its applications.

***Keywords:** Ultrasound, Diagnostics, Therapeutics, Surgery, Applications.*

I. INTRODUCTION

By definition, ultrasound is energy >20 kHz, which represents the upper-frequency limit of human hearing. Transducers, which are thin disc-shaped crystals made out of piezoelectric materials, generate acoustic energy when a voltage is applied to them. Acoustic vibrations (frequencies) are generated when those piezoelectric materials expand and contract. Early transducers were made from quartz. More recently, other materials have been introduced; including lithium sulfate, ceramics, and plastic polymers[1]. these newer materials enabled the development of transducers that produce higher frequencies, because the wavelengths of higher frequencies are smaller and, therefore, allow better resolution of small objects. Transducers used earlier for diagnostic purposes, such as imaging fetuses, used frequencies between 2MHz and 18 MHz. Transducers for the diagnosis of regional lymph nodes and soft-tissue tumors operate in the range of 7.5-15 MHz, and high-frequency transducers for the assessment of the skin in the range of 20-50 MHz.[2, 3]. Diagnostic ultrasound systems function much as sonar or radar technologies do as pulse-echo systems [8]. A burst of acoustic energy is emitted from the transducer. The rapid expansion and contraction of the transducer is transferred as a pulse to the adjacent fluid or tissue and propagates as a wave, which can be reflected or refracted at tissue boundaries. The returning war (the echo) reaches the transducer during breaks of impulse generation. These echoes are converted by the transducer into signals that are processed and stored by a computer system. Piezosurgery (Piezoelectric surgery applied to bone) is an ultrasound device introduced in medical practice in 1988 for different procedures in application to hard tissues, including periodontal surgery, per apical surgery [3,4], the removal of impacted teeth, implant surgery for facilitating bone ridge expansion or in bone regeneration techniques [5,6].

Resolution of ultrasound systems can refer to either axial or lateral resolution. The axial resolution is the smallest thickness that can be measured; it is related to the duration of a pulse. The shorter the pulse, the better the axial resolution. The lateral resolution refers to the width of the smallest structures that can be resolved; it is related to the width of the beam in the focus zone. In general, ultrasound systems convert the voltage changes recorded by the transducer and display these signals as images.

There exist a large variety of important applications of ultrasound (Fig.1) in medicine today. These applications can be divided into three major categories: surgical, therapeutic, and diagnostic [7]. For these categories, an important distinguishing physical feature is the intensity level utilized. Nearly all these applications employ sound in the frequency range of 0.8-15MHz the choice of frequency used in the specific applications is based on consideration of sound absorption, adequate penetration and in the diagnostic application, adequate resolution [8, 9].

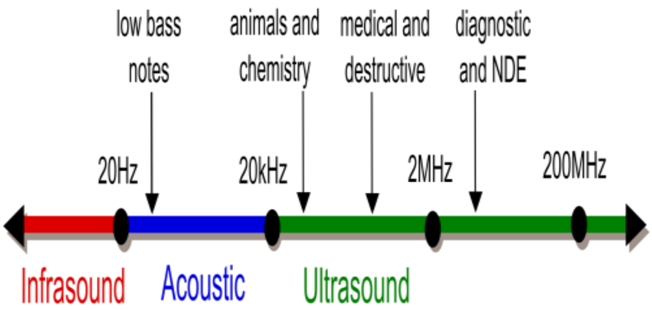

Fig. 1 Sound Spectrum

II. DIAGNOSTIC APPLICATIONS

As ultrasonic waves travel at similar velocities (about 1500 m s^{-1}) in most biological tissues and are absorbed in a rate of about 1 dB cm^{-1} MHz^{-1}. Absorption occurs chiefly due to relaxation processes. It leads to thermal effects in biological systems. Mechanical effects, such as streaming and cavitations, are also important in certain situations, particularly at low frequencies. Highly focused ultrasound is used in neurosurgery; it is the only method for producing trackless damage deep in the brain.

A. Sonography (ultrasonography)

It is widely used in medicine. It is possible to perform both diagnosis and therapeutic procedures, using ultrasound to guide interventional procedures (for instance biopsies or drainage of fluid collections). Sonographers are medical professionals who perform scans for diagnostic purposes. Sonographers typically use a hand-held probe (called a transducer) that is placed directly on and moved over the patient. A water-based gel is used to couple the ultrasound between the transducer and patient. Sonography (Fig.2) is effective for imaging soft tissues of the body.

Fig. 2 Ultrasonography

Superficial structures such as muscles, tendons, testes, breast and the neonatal brain are imaged at a higher frequency (7-18 MHz), which provides better axial and lateral resolution. Deeper structures such as liver and kidney are imaged at a lower frequency 1-6 MHz with lower axial and lateral resolution but greater penetration.

Medical Sonography is used in, for example:

- Abdominal ultrasound - views the organs of the abdomen
- Vascular ultrasound - views blood vessels, Intravascular ultrasound (e.g. ultrasound guided fluid aspiration, fine needle aspiration, guided injections)
- Obstetric ultrasound - views the fetus in the womb
- Gynecological ultrasound - views the female reproductive organs
- Neurosonography - views the brain, including the fetal brain and transcranial ultrasound, for assessing blood flow and stenoses in the carotid arteries and the big intracerebral arteries.
- Echocardiography - views the heart, including both the fetal and adult heart
- Ophthalmology; see A-scan ultrasonography, B-scan ultrasonography
- Interventional; biopsy, emptying fluids, intrauterine transfusion (Hemolytic disease of the newborn)
- Contrast-enhanced ultrasound.

A general-purpose sonographic machine may be able to be used for most imaging purposes. Usually, specialty applications may be served only by use of a specialty transducer. Most ultrasound procedures are done using a transducer on the surface of the body, but improved diagnostic confidence is often possible if a transducer can be placed inside the body. For this purpose, specialty transducers, including endovaginal, endorectal, and transesophageal transducers are commonly employed. At the extreme of this, very small transducers can be mounted on small diameter catheters and placed into blood vessels to image the walls and disease of those vessels. Obstetrical ultrasound is commonly used during pregnancy to check on the development of the fetus.

B. In a pelvic sonogram

Organs of the pelvic region are imaged in the Pelvic sonogram. This includes the uterus and ovaries or urinary bladder. Men are sometimes given a pelvic sonogram to check on the health of their bladder and prostate. There are two methods of performing a pelvic Sonography - externally or internally. The internal pelvic sonogram is performed either Transvaginally (in a woman) or transrectally (in a man). Sonographic imaging of the pelvic floor can produce important diagnostic information regarding the precise relationship of abnormal structures with other pelvic organs and it represents a useful hint to treat patients with symptoms related to pelvic prolapsed, double incontinence and obstructed defecation.

C. In abdominal Sonography

The solid organs of the abdomen such as the pancreas, aorta, inferior vena cava, liver, gall bladder, bile ducts, kidneys, and spleen are imaged. Sound waves are blocked by gas in the bowel; therefore there are limited diagnostic capabilities in this area. The appendix can sometimes be seen when inflamed e.g.: appendicitis.

D. Ultrasound in dermatology

Ultrasonic imaging was first proposed as an addition to the dermatologic toolbox in the late 1970s when it was used to measure skin thickness [10]. Since then, the role of ultrasound in dermatology (Fig.3) has expanded. Whether searching for the presence of foreign bodies in a soft-tissue traumatic wound, evaluating the inflammatory response to a patch test, or estimating tumor volume in no melanoma skin cancer (NMSC), techniques in ultrasound are currently being refined to provide an extra clinical hand, especially as an adjunct to surgical exploration. Ultrasound has been used for the diagnosis and evaluation of benign and malignant neoplasm's, inflammatory diseases, infectious diseases, and in the forum of cosmetic dermatology.

Fig. 3 Dermatologic Ultrasound

E. Doppler Sonography

This is the most advanced technique (Fig.4) uses reflected sound waves to measure blood flow in different parts of your baby's body. (The machine used to listen to your baby's heartbeat throughout pregnancy, Doppler Sonography is most often used during the third trimester in women with high-risk pregnancies, and it can also be used during a transvaginal ultrasound for gynecological reasons. It may be used to check on an ovarian cyst, for example, or to help diagnose an ectopic pregnancy.

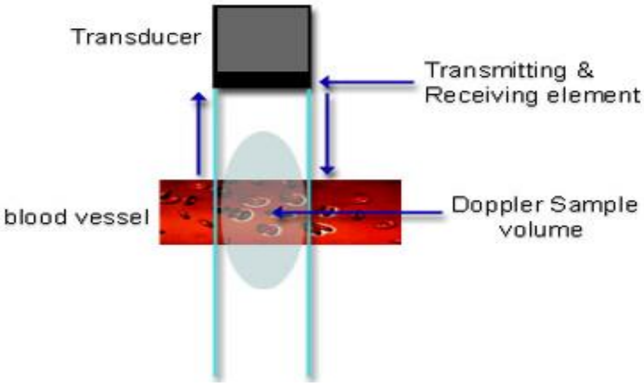

Fig. 4 Pulsed Doppler Sonography

III. APPLICATIONS

A. Therapeutic Applications

1) Therapeutic applications use ultrasound to bring heat or agitation into the body. Therefore much higher energies are used than in diagnostic ultrasound. In many cases, the range of frequencies used is also very different. Ultrasound may be used to clean teeth in dental hygiene
2) Ultrasound sources may be used to generate regional heating and mechanical changes in biological tissue, e.g. in occupational therapy, physical therapy, and cancer treatment. However, the use of ultrasound in the treatment of musculoskeletal conditions has fallen out of favor.[4][5]
3) Focused ultrasound may be used to generate highly localized heating to treat cysts and tumors (benign or malignant), this is known as Focused Ultrasound Surgery (FUS) or High Intensity Focused Ultrasound (HIFU). These procedures generally use lower frequencies than medical diagnostic ultrasound (from 250 kHz to 2000 kHz), but significantly higher energies. HIFU treatment is often guided by MRI.
4) Focused ultrasound may be used to break up kidney stones by lithotripsy.
5) Ultrasound may be used for cataract treatment by phacoemulsification. Additional physiological effects of low-intensity ultrasound have recently been discovered, e.g. its ability to stimulate bone growth and its potential to disrupt the blood-brain barrier for drug delivery. Procoagulant at 5-12MHz.

6) Another form of medical Sonography is HIFU, or high intensity focused ultrasound, which is a much newer field of ultrasound. In this specialty, especially high-frequency ultrasound is used against cancer cells. This is still being tested and utilized with positive results against prostate cancer, where the probe can be placed in close proximity to the cancer cells.
7) Ultrasound can be used to examine body organs and systems including the heart, pancreas, urinary system, brain, spinal cord, bladder, and cysts. In females, it can be used to view the ovaries, peritoneal cavity, and a fetus in its amniotic sac. It can also be used to guide surgical procedures, for example during the insertion of a biopsy needle into a particular area. Doppler ultrasound is used to measure blood flow. Air, bone and other calcified tissues absorb nearly all the ultrasound beam, so it cannot be used to examine the bones or lungs.

B. Surgical Ultrasound Applications

1) *Laparoscopic ultrasound:* General surgeons are increasingly using advanced technology to accomplish operative procedures or assist in determining the need for such procedures. Ultrasound is currently used by surgeons to varying degrees based on geographic location, practice patterns, a traditional delegation of use, and evolving procedures. Ultrasound transducers function to convert electrical energy to sound wave energy via piezoelectric crystals. The sound waves are disseminated in a parallel (linear transducers) or radial (sector transducers) pattern. The ultrasound waves (Fig.5) variably penetrate tissues and tissue interfaces, with some energy being reflected back to the transducer at such interfaces. The transducer converts the signal of such reflected waves to continuous grayscale images on the ultrasound monitor. Transducers are designed to produce ultrasound waves of different frequencies. The higher the frequency of the waves, the greater resolution of the image conveyed to the screen. Thus a 10 MHz transducer will produce a significantly clearer image than a 5 MHz transducer. The disadvantage to higher MHz transducers is that the ultrasound waves of higher frequencies are more rapidly attenuated with tissue penetration. 10 MHz transducer cannot penetrate more than approximately 5 cm into the parenchyma of a solid organ such as the liver and does not yield satisfactory images of intraabdominal structures if it is applied transabdominal. Intraoperative use of an ultrasound probe, where the abdominal wall thickness is not an issue, allows the use of higher MHz ultrasound transducers since the transducer is placed directly on the surface of the organ to be imaged. Therefore, intraoperative ultrasound images are much sharper and well defined than those obtained through a transabdominal approach.

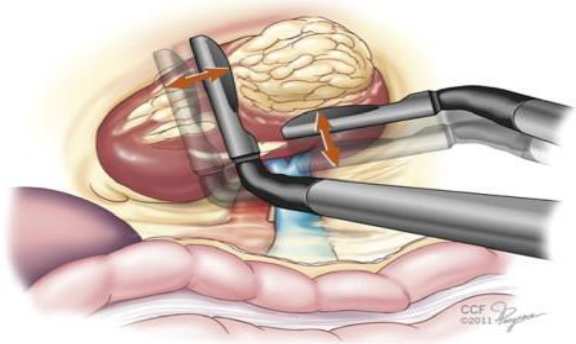

Fig. 5 Laparoscopic Ultrasound

2) *Ultrasound surgery –healing without cuts*: Imagine having a surgery with no knives involved. At TEDMED, Yoav Medan shares a technique that uses MRI to find trouble spots and focused ultrasound on treating such issues as brain lesions, uterine fibroids and several kinds of cancerous growths.

3) *Ultrasound in dentistry:* Ultrasound was first applied in dentistry in 1952, specifically for preparing dental cavities, though in this context the technique was subsequently displaced by the introduction of high-speed rotary instruments. its applications in other areas gradually increased over the years. Piezosurgery(Piezoelectric surgery applied to bone) is an ultrasound device introduced in medical practice in 1988 for different procedures in application to hard tissues, including periodontal surgery, per apical surgery, the removal of impacted teeth, implant surgery for facilitating bone ridge expansion or in bone regeneration techniques), inferior dental nerve lateralization and transposition. The instrument used in our study operates at a frequency of 25-29 kHz, with an advanced oscillation control module that introduces pauses in the high-frequency vibrations.

4) *Ultrasound in ophthalmology*: Ultrasound has also been very helpful in the surgical treatment cataracts. In this an ultrasound instrument (phacoemulsifier) employing a vibrating needle oscillating at 20-40 KHz is introduced into eye and used to emulsify the diseased lens. It has been successful in the treatment of Mwniere's disease. This is the disorder of the vestibular organ in the inner ear and causes severe vertigo.

5) *Ultrasound Physiotherapy*: ultrasound has been employed in physical therapy for over 40 years. It is used in the treatment of a number of joint and soft tissue ailments such as arthritis, bursitis muscle spasms, traumatic soft tissue injuries, and certain collagen diseases .the aim of this technique is to relieve pain, decrease soft tissue stiffness and accelerate healing .most of the benefits of ultrasound as a therapeutic agent reside in its ability to heat deep tissues selectively.

6) *Other surgical applications* of ultrasound have included hypophysectomy, ablation of the substantia nigra in the treatment of Parkinson's disease, removal of warts and treatment of laryngeal papillomatosis.

7) *Focused ultrasound surgery*: This is a non-invasive surgical application (Fig.6) which combines high intensity focused ultrasound tissue ablation with MRI for image guidance. Focused ultrasound surgery is a very modern surgical method that:

- Is non-invasive – No cutting is involved
- Minimizes complications, adverse events and recovery time
- Involves no ionizing radiation
- Is easy to recover from
- Ablates targeted tissue without damaging surrounding tissue

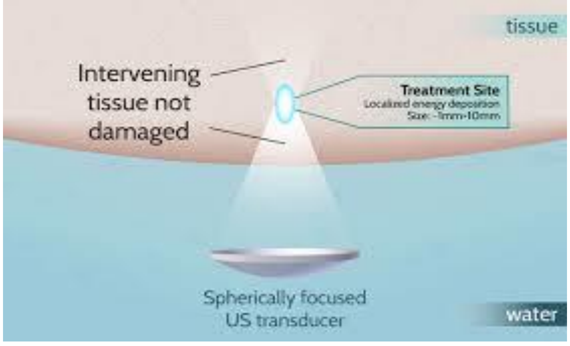

Fig. 6 Focused Ultrasound

CONCLUSIONS

Ultrasound consists of mechanical oscillations at frequencies imperceptible to the human ear, i.e. in excess of 20 kHz. In biological soft tissue, ultrasound propagates in the form of longitudinal waves. In the process particles move in the direction of wave propagation, leading to alternating phases of positive and negative pressure. Sonography is based on the principle of sonar; it provides a visual display of the echo as it bounces off tissue boundaries, determining spatial positions according to the distances travelled. The range of frequencies used depends on the depth of examination required and the spatial resolution; it typically lies between approx. 2 MHz and 20 MHz. Frequencies ranging from 20 kHz to several 100 kHz (low-frequency ultrasound) and approx. 0.8 MHz to 4 MHz (high-frequency ultrasound) are used in medical treatment; The thermal, mechanical, and cavitation-related effects of ultrasound are also used for treatment purposes. The most well-known are applications in the area of physiotherapy and in the treatment of chronic wounds, as well as HIFU e. g. in tumor therapy Ultrasound is generally used in physiotherapy and orthopedic contexts for the treatment of musculoskeletal pain (e. g. chronic back pain, arthrosis, tendinopathy, musculopathy, arthritis).

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