Technology of ultrasound scans

2. 1 Ultrasound

2. 1. 1 Physics of Ultrasound

Sound is a mechanical wave that travels through an elastic medium. Ultrasound (US) is sound at a frequency beyond 20 000 Hz, the limit of human hearing. Bats orientate themselves with the help of US waves at 100 000 Hz. Ultrasound at frequencies of 200 000 Hz is used for navigation. The frequency range of diagnostic US is between 1 and 20 MHz.

When sound encounters a boundary between two media of different densities some of the sound bounces back as an echo, a phenomenon called reflection. The rest of the sound continues through the medium but is deflected from its original path, this is called refraction. Acoustic impedance is the resistance of a medium to the propagation of sound and decides how much sound will be reflected at the interface between the media. Some of the energy of the sound is converted by friction into heat when propagating, this loss of energy is called absorption.

When ultrasound waves encounter a surface, a small part of their energy is scattered away in random directions while most of the sound continues to propagate, a phenomenon called scatter. Reflection, refraction, impedance, absorption and scatter are all phenomena important for image formation in diagnostic ultrasound use. Artifacts, echoes that do not correspond to an anatomic structure but result from the physical properties of ultrasound propagation in the tissues, are also important to be aware of when using ultrasound. This phenomenon can also be of diagnostic help. One example is the acoustic shadowing of a gallstone, caused by total absorption of the sound by the stone.

Diagnostic ultrasound is based on the pulse-echo principle. The smallest functional units of the transducer are the piezoelectric crystals. The crystals are embedded in the probe, and each crystal has a specific frequency. A pulse is initiated from each crystal in the probe and a longitudinal sound wave propagates through the body. Some of the energy is absorbed in the tissue and some is reflected. The reflected energy is received by the probe, which calculates the depth of the interface by measuring the time taken to return.

We can say that the human body is composed of three basic materials differing in acoustic impedance: gas with a very low impedance, bone with a very high impedance and soft tissue with an impedance somewhere in between. The large mismatch between air and bone and tissue (“ impedance mismatch”) causes 100% of the sound to be reflected at air/tissue interfaces and almost all the sound at bone/tissue interfaces. There is a small mismatch between different soft tissues in impedance, a fact that is the basis for diagnostic ultrasound.

Different frequencies of ultrasound are used for different diagnostic examinations. Higher US frequencies (7-16 MHz) have higher resolution but are strongly absorbed by soft tissue and are therefore used for superficial structures. Very high frequencies (16- 20 MHz) will only travel for a few millimeters within tissue and are limited to intravascular and ocular examinations. Lower frequencies (3-7 MHz) are used for deeper structures, being less strongly absorbed and of lower resolution.

There are different modes of displaying the amplitude of reflected sound waves: A- mode, M-mode and B-mode. A-mode (amplitude) calculates only the depth of the interface and is mainly of historical interest. M-mode (motion) is used to display moving structures and is used in cardiac ultrasound. B-mode (brightness) is the routine US image for most surgical applications. Here the returning echoes are displayed as shades of grey with the echo amplitudes represented by a grey level ranging from black to white. The individual image lines are stored, assessed and assembled on the monitor to create a two-dimensional B-mode image.

Doppler ultrasound uses the Doppler effect. When US is reflected from a moving structure (i. e. blood) the frequencies of the waves change and the amount of frequency change is determined by the speed and direction of blood flow. The use of Doppler is obvious in vascular US but is also of use in other areas of diagnostic ultrasound.

2. 1. 2 History of Ultrasound

Scientists, including Aristoteles, Leonardo da Vinci, Galileo Galilei, Sir Isaac Newton and Leonard Euler, have been studying the phenomena of acoustics, echoes and sound waves for many centuries. It was though not until 1877 that John William Strutt, also known as Lord Rayleigh, published a description of sound as a mathematical equation in “ The theory of sound” which became the foundation for the science of ultrasound. Some years later, 1880, Jaques and Pierre Curie discovered the piezo-electric effect; that an electric potential is generated when mechanical pressure is applied to a quartz crystal, an important discovery that eventually led to the development of the modern- day ultrasound transducer which contains piezoelectric crystals.

The first study of the application of ultrasound as a medical diagnostic tool was published by the Austrian brothers Karl and Friedrich Dussik in 1942. They attempted to locate brain tumours and the cerebral ventricles by measuring ultrasound transmission through the skull and concluded that if imaging of the ventricles was possible, the interior of the human body could also be visualized using ultrasound. Unfortunately it was later determined by Guttner, in 1952, that the images produced by the Dussiks were variations in bone thickness. Nevertheless, their scientific work marked the beginning of diagnostic ultrasonography in the medical field and Dussik wrote in an article a decade later: " As knife and forceps in surgery, the chemical agent in chemotherapy, the high frequency electric field in diathermy and X-ray application, so has medicine taken on a new physical tool in the last decade: the ultrasonic field".

George Döring Ludwig, working together with Francis Struther, was the first scientist to visualize gallstones, implanted in the muscles and gallbladders of dogs, with ultrasound. His studies also resulted in the finding that the mean velocity of ultrasound in soft tissue is 1540 m/sec, a discovery that was to prove very important for future research. Much of his work was however considered restricted information, because he was employed by the military, and therefore not published in medical journals.

John Julian Wild and Douglass Howry were also important pioneers in the ultrasound field. Wild was a surgeon who was able to visualize bowel wall thickness with ultrasound, and he also discovered a difference in echogenicity between benign and malignant tissue. Wild also developed transrectal and transvaginal transducers and a scanning device for screening patients for breast cancer. Howry built the first B- mode scanner in 1949 and, together with the two engineers Bliss and Posanky, he also developed the first linear contact scanner. The somascope, the first circumferential scanner, built in 1954, was also developed by Howry. The problem with these scanners was that the patient had to be immobilized and immersed for a long time. In the period 1957-58 an ultrasound scanner was developed by Howry and his colleagues where the patient was strapped to the plastic window of a semicircular pan filled with saline solution. Although not immersed, the patient had still to be immobilized for a long time. Finally, in the early 1960s, Howry developed the first hand-held contact scanner, together with Wright and E Myers.

During the same time Ian Donald was carrying out ultrasound research in England and 1958 he published an article that came to be a landmark, (" Investigation of abdominal masses by pulsed ultrasound"), where he describes how ultrasound changed the treatment of a woman diagnosed with advanced gastric cancer dramatically by diagnosing a cystic mass with ultrasound; the mass was later resected and found to be a benign ovarian cyst. Donald contributed significantly to the field of obstetric and gynecological ultrasound for example by discovering the urinary bladder to be a natural acoustic window for the pelvic organs and by measuring the biparietal diameter of the fetus for the first time.

A century earlier the Doppler effect had been discovered by the famous Austrian scientist Christian Andreas Doppler and presented in 1842 in a paper called " Über das farbige Licht der Doppelsterne und einiger anderer Gestirne des Himmels" (" On the colored light of the double stars and certain other stars of the heavens"). In Lund, Sweden, the principal pioneers of echocardiography Inge Edler and Carl Hellmuth Hertz, developed the first echocardiogram in October 195323 . Subsequently Hertz and Åsberg invented the first two-dimensional real-time cardiac imaging machine 1967 and Edler and Lindström registred the first simultaneous M-mode and intracardiac Doppler blood flow recordings at about the same time.

Ultrasound has in the last decades developed quickly and the first digital scanners were released onto the market in 1976, providing better and reproducible images.

Interventional ultrasonography dates back to 1969 when Kratochwill proposed the use of ultrasound for percutaneous drainage. Regarding ultrasound for trauma the first report of the method for evaluating blunt trauma was dated 1971, by Kristenson in Germany.

The development is still going on and in the light of advances in technology leading to smaller available machines combined with the prices of machines decreasing rapidly speculations have been made about the possibility that doctors in the future will routinely be equipped with their own ultrasound stethoscope for use in their daily clinical work.

2. 1. 3 Ultrasound Instruments

It is important to have a basic knowledge in which an ultrasound image is produced. The components of scanner include

1. Transmitter: Emits electrical impulses that strike the transducer piezoelectric crystals and cause them to vibrate thus producing ultrasound wave.
2. Transducer: Transducer is one which converts one form of energy to another. In ultrasound it converts electric energy to mechanical energy and viceversa. It converts the electrical energy provided by the transmitter to the acoustic pulses directed into the patient. It serves as the receiver of reflected echoes, converting weak pressure changes into electric signals for processing.
3. Receiver: When returning echoes strike the transducer face, minute voltages are produced across the piezoelectric elements. The receiver detects and amplifies these weak signals and provides a means for compensating for the differences in echo strength which result from attenuation by different tissue thickness by control of time depth compensation. Another important function of receiver is the compression of the wide range of amplitudes returning to the transducer into a range that can be displayed to the user.
4. Scan Processor: Processor detects and amplifies the back scattered energy and manipulates the reflected signals for display.
5. Control Console
6. Display: Display presents the ultrasound image or data in a form suitable for analysis and interpretation. Over the years imaging has

evolved from simple A mode display to high resolution real time gray scale imaging.

7. Recording Device: Interpretation of images and archival storage of images may be in the form of transparencies printed on film by optical or laser cameras and printers, videotape or through use of digital picture archiving and communications system (PACS). Increasingly digital storage is being used for archiving of ultrasound images.

2. 1. 4 Transabdominal Ultrasound, Use and Limitations

Transabdominal ultrasound of the female pelvis has been the conventional approach in imaging of the female pelvis. With this approach) a full urinary bladder is required to provide a window for imaging and to displace bowel gas. Transabdominal scanning (TAS) therefore required deeper penetration and a lower frequency transducer, usually 3 -5 MHz, must be used. The resolution of images is limited by the relatively lower frequency transducer that is required, and it also has great limitations in the obese lady, especially in the elderly who often cannot hold a full bladder. In the study of uterine hemodynamics in patients who are pregnant, these disadvantages may not be very significant, because the uterine arterial signal from these patients are usually strong. However, in the non-pregnant state, especially in postmenopausal ladies, studies of uterine hemodynamics with TAS could be very difficult.

2. 1. 5 Transvaginal Ultrasound, Advantages and Disadvantages

Widespread availability of ultrasound imaging in the past two decades has dramatically changed the practice of obstetrics and gynecology. These specialists rely heavily upon this technology to make major decisions about management of their patients.

Transabdominal sonography (TAS) images the pelvic organs through the anterior abdominal wall in the supra-pubic region. A distended urinary bladder is essential to displace the bowel loops and to provide an acoustic window. There are two major limitations of TAS. First is the need to use lower frequencies for imaging due to the longer distance between the transducer and the pelvic organs. Other disadvantage is the beam degrading effect of the anterior abdominal wall especially in obese patients. Both these limitations lead to degradation in image quality.

To overcome these limitations of TAS special transducers, which could be introduced in the vagina, were designed in 1985. The vaginal approach reduces the distance between the probe and the pelvic structures allowing the use of higher frequencies. Trans-vaginal sonography (TVS) produces greatly improved resolution as compared to TAS, primarily due to the higher frequencies employed and also due to the absence of beam deformation by the anterior abdominal wall, Major advantages of TVS over TAS are better image quality and avoidance of patient discomfort due to full urinary bladder. Comparison of TVS and TAS is given in Table 2. 1.

2. 1. 5. 1 Indications of TVS

TVS is indicated whenever a better look at the pelvic structures is required. Common indications include the following

- Early pregnancy
- Lower uterine segment in late pregnancy

- Ectopic pregnancy
- Pelvic masses
- Retroverted or retroflexed uterus
- Obese or gaseous patient
- Emergency cases when bladder is empty
- Follicle monitoring
- Oocyte retrieval
- Endometrial study to assess suitability in IVF ET techniques
- Cervical canal mucous
- Doppler examination of pelvic organs
- Interventional procedures

The list is not exhaustive and newer indications are continuously being added.

TVSTAS

Full bladder

Not essential

Essential

Probe frequency

5-7. 5 MHz

3-5 MHz

Resolution

Very high

Moderate

Field of view Small

Large

ContraindicationsVirgins, Vaginal obstruction

Premature rupture of membraneNone

interventional uses

Many usesLimited role

Table 2. 1 Comparison of TAS and TVS

2. 1. 5. 2 Scan Technique

Once the probe and the patient have been prepared, the transducer is gradually inserted while monitoring the ultrasound image. The urinary bladder's normally consistent position in the pelvis relative to much more variable position of the uterus and the ovaries makes it a good landmark to use when making initial assessment of the transducer orientation.

Three basic scanning manoeuvres of the probe are useful to scan the pelvic organs comprehensively:

- Sagittal imaging with side to side movements,
- 90° rotation to obtain semi-coronal images with angulation of probe in vertical plane,

- Variation in the depth of probe insertion to bring different parts within field of view/focal zone.

A pelvic survey should be done first to ascertain quickly the relative position of the uterus and ovaries as well as to identify any obvious masses. This is obtained by slowly sweeping the beam in a sagittal plane from the midline to the lateral pelvic side walls followed by turning the probe 90 degrees into corona’ plane and sweeping the beam from cervix to the fundus. In multi-frequency probes proper selection is important for best results. Setting of appropriate focus in electronic arrays is equally important. In mechanical sector fixed focus probes the organ of interest is brought in the focal zone by changing the depth of insertion of the probe. Proper selection of frame averaging is also important. It should be low for fast moving structures like foetal heart and high for studying solid immobile tissues.

For Doppler studies a steady probe position is essential and it helps if the examiner’s forearm is well supported.

2. 1. 5. 3 Dynamic uses of the TVS probe

The ultrasonographic examination can be enhanced by placing a hand over the lower abdomen to bring pelvic structures within the field of view/focal range of the probe. Localisation of the point of maximal tenderness by the probe will help in identifying the cause of pain. Dense pelvic adhesions can be diagnosed by the ‘ sliding organ sign’. In the absence of adhesions, the organs move freely past each other and the pelvic wall in response to pressure by the TVS probe tip. Absence of this free movement may suggest pelvic adhesions.

2. 1. 5. 4 Interventional uses of TVS

There are many interventional uses of transvaginal sonography. Newer indications are constantly being added to the list. Some of the more common ones are given below:-

- aspiration of ova for in vitro fertilisation (IVF)
- aspiration of ovarian cyst
- drainage of pelvic collection
- multi-foetal pregnancy reduction
- non-surgical etopic pregnancy management
- early amniocentesis
- chorion villous sampling
- transvaginal embryo transfer
- sonohysterosalpingigraphy

2. 1. 5. 5 Limitation of TVS

It should be remembered that TVS provides a more limited field of view than TAS. A survey trans-abdominal scan usually be performed prior to the TVS to rule out the possibility of overlooking a mass lying outside the field of view of the TVS transducer. To avoid the need of a full bladder it has been suggested that a TVS examination may be followed by a TAS scan with bladder empty. The rationale behind this approach is that a mass lying outside the field of view of the TVS probe will be sufficient in size to be seen trans-abdominally even if the bladder is empty.

The advent of the transvaginal sonography in 1985 has had a tremendous impact on the practice of obstetrics and gynaecology. The pelvic organs can now be imaged with a resolution not possible earlier. The management of infertility due to female factors depends mainly on the TVS. Addition of Colour Doppler to TVS now gives added information about the vascular supply of various pelvic organs. Details of foetal anatomy that can be depicted by TVS are far superior to that shown by TAS. As a new technique TVS has proved very useful and has a bright future.