Equipment Packet: Medical Ultrasound

UMDNS #: 14278

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Creator: Complied by Cassandra Stanco for Engineering World Health (EWH)

Equipment Packet Contents:

This packet contains information about the operation, maintenance, and repair of medical ultrasound.

Part I: External From the Packet:

1. **An Introduction to Ultrasound:** PowerPoint

Part II: Included in this Packet:

1. Operation and Use of Medical Ultrasound

Featured in this Section:

WHO. “Manual of Diagnostic Ultrasound, Second Edition.” *WHO*, 2011. Retrieved from: http://apps.who.int/medicinedocs/documents/s21383en/s21383en.pdf

WHO. “Scanning System, Ultrasonic.” From the publication: *Core Medical Equipment*. Geneva, Switzerland, 2011.

Wikipedia. “ Medical Ultrasound.” *Wikipedia*, pgs 1-15. Retrieved from: https://en.wikipedia.org/wiki/Medical_ultrasound

Scanning System, Ultrasonic

UMDNS	GMDN
15976 Scanning Systems, Ultrasonic, General-Purpose	40761 General-purpose ultrasound imaging system

Other common names:
Abdominal Ultrasound Scanners; Doppler Devices; General-Purpose Ultrasonic Scanners; Metal Detectors; Metal Detectors, Ultrasonic; Scanners, Ultrasonic, Dedicated Linear Array; Scanners, Ultrasonic, General-Purpose; Scanners, Ultrasonic, Pediatric; Ultrasound Scanners, Bladder; Ultrasound Scanners, General-Purpose; Ultrasound Scanners, Urology; Diagnostic imaging equipment, general use

Health problem addressed

These devices are used primarily for abdominal and OB/GYN scanning. Some systems include additional transducers to facilitate more specialized diagnostic procedures, such as cardiac, vascular, endovaginal, endorectal, or small-parts (e.g., thyroid, breast, scrotum, prostate) scanning.

Product description

General-purpose ultrasonic scanning systems provide two-dimensional (2-D) images of most soft tissues without subjecting patients to ionizing radiation. These systems typically consist of a beamformer, a central processing unit, a user interface (e.g., keyboard, control panel, trackball), several probes (transducers or scanheads), one or more video displays, some type of recording device, and a power system.

Principles of operation

Ultrasound refers to sound waves emitted at frequencies above the range of human hearing. For diagnostic imaging, frequencies ranging from 2 to 15 megahertz (MHz) are typically used. Ultrasonic probes contain one or more elements made of piezoelectric materials (materials that convert electrical energy into acoustic energy and vice versa). When the ultrasonic energy emitted from the probe is reflected from the tissue, the transducer receives some of these reflections and reconverts them into electrical signals. These signals are processed and converted into an image. Lower sound frequencies provide decreased resolution but greater tissue penetration, while higher frequencies improve resolution when deep penetration is not necessary.

Operating steps

To perform ultrasonic imaging, a probe is either placed on the skin (after an acoustic coupling gel is applied) or inserted into a body cavity. Scanned structures can be measured by ultrasound technicians using digital calipers (i.e., cursors electronically superimposed over the scanned cross-sectional image that calculate the size of the scanned structure). The caliper system can also be used by technicians to plot and measure the area, circumference, or volume of a structure. A data-entry keyboard permits information such as patient name, date, and type of study to be entered and displayed along with the scanned image.

Reported problems

Ultrasound diagnostic imaging appears to be risk-free when used properly. Ultrasound transducers should be handled carefully to avoid damage. Electromechanical problems, such as cracks in piezoelectric elements, can alter beam width and/or spatial pulse length, thereby affecting lateral and axial resolution. Errors in distance measurements can cause incorrect calculations.

Use and maintenance

User(s): Ultrasound technician

Maintenance: Medical staff; technician; biomedical or clinical engineer

Training: Initial training by manufacturer and manuals

Environment of use

Settings of use: Hospital radiology departments; private physician offices

Requirements: Stable power source

Product specifications

Approx. dimensions (mm): 1340x420x630

Approx. weight (kg): 75

Consumables: NA

Price range (USD): 25,000 -220,000

Typical product life time (years): 5

Shelf life (consumables): NA

Types and variations

General-purpose; OB/GYN; small parts; vascular; cardiology; endocavity

WHO. "Scanning System, Ultrasonic." From the publication: Core Medical Equipment. Geneva, Switzerland, 2011.

World Health Organization http://www.who.int/medical_devices/en/index.html

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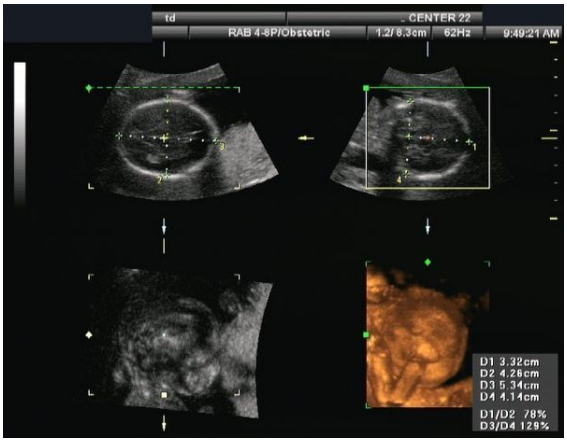
Introduction To Medical Ultrasound

Medical ultrasound

This article is about using ultrasound to image the human body. For imaging of animals in research, see Preclinical imaging. For therapeutic use of ultrasound, see High-intensity focused ultrasound.
"Sonography" redirects here. For the tactile alphabet called "sonography", see Night writing.

Medical ultrasound (also known as **diagnostic sonography** or **ultrasonography**) is a diagnostic imaging technique based on the application of ultrasound. It is used to see internal body structures such as tendons, muscles, joints, vessels and internal organs. Its aim is often to find a source of a disease or to exclude any pathology. The practice of examining pregnant women using ultrasound is called obstetric ultrasound, and is widely used.



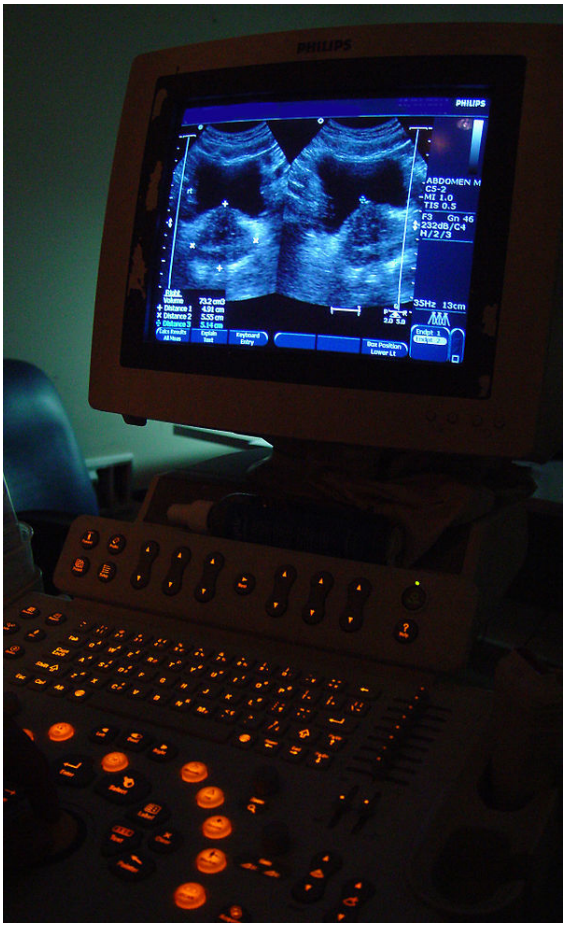
Orthogonal planes of a 3 dimensional sonographic volume with transverse and coronal measurements for estimating fetal cranial volume.[1][2]

Ultrasound is sound waves with frequencies which are higher than those audible to humans. Ultrasonic images also known as sonograms are made by sending pulses of ultrasound into tissue using a probe. The sound echoes off the tissue; with different tissues reflecting varying degrees of sound. These echoes are recorded and displayed as an image to the operator.

Many different types of images can be formed using sonographic instruments. The most well-known type is a B-mode image, which displays the acoustic impedance of a two-dimensional cross-section of tissue. Other types of image can display blood flow, motion of tissue over time, the location of blood, the presence of specific molecules, the stiffness of tissue, or the anatomy of a three-dimensional region.

Compared to other prominent methods of medical imaging, ultrasound has several advantages. It provides images in real-time, it is portable and can be brought to the bedside, it is substantially lower in cost, and it does not use harmful ionizing radiation. Drawbacks of ultrasonography include various limits on its field of view including patient cooperation and physique, difficulty imaging structures behind bone and air, and its dependence on a skilled operator.

1 Diagnostic applications



Urinary bladder (black butterfly-like shape) and hyperplastic prostate (BPH) visualized by medical sonographic technique

Typical sonographic instruments operate in the frequency range of 1 to 18 megahertz, though frequencies up to 50–100 megahertz have been used experimentally in a technique known as biomicroscopy in special regions, such as the anterior chamber of the eye.[3] The choice of fre-

Wikipedia. " Medical Ultrasound." Wikipedia, pgs 1-15. Retrieved from: https://en.wikipedia.org/wiki/Medical_ultrasound

quency is a trade-off between spatial resolution of the image and imaging depth: lower frequencies produce less resolution but image deeper into the body. Higher frequency sound waves have a smaller wavelength and thus are capable of reflecting or scattering from smaller structures. Higher frequency sound waves also have a larger attenuation coefficient and thus are more readily absorbed in tissue, limiting the depth of penetration of the sound wave into the body (for details, see Acoustic attenuation.)

Sonography (ultrasonography) 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 which are then typically interpreted by themselves or the radiologists, physicians who specialize in the application and interpretation of a wide variety of medical imaging modalities, or by cardiologists in the case of cardiac ultrasonography (echocardiography). Sonographers typically use a hand-held probe (called a transducer) that is placed directly on and moved over the patient. Increasingly, clinicians (physicians and other healthcare professionals who provide direct patient care) are using ultrasound in their office and hospital practices.

Sonography is effective for imaging soft tissues of the body. Superficial structures such as muscles, tendons, testes, breast, thyroid and parathyroid glands, 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 the study of many different systems:

Other types of uses include:

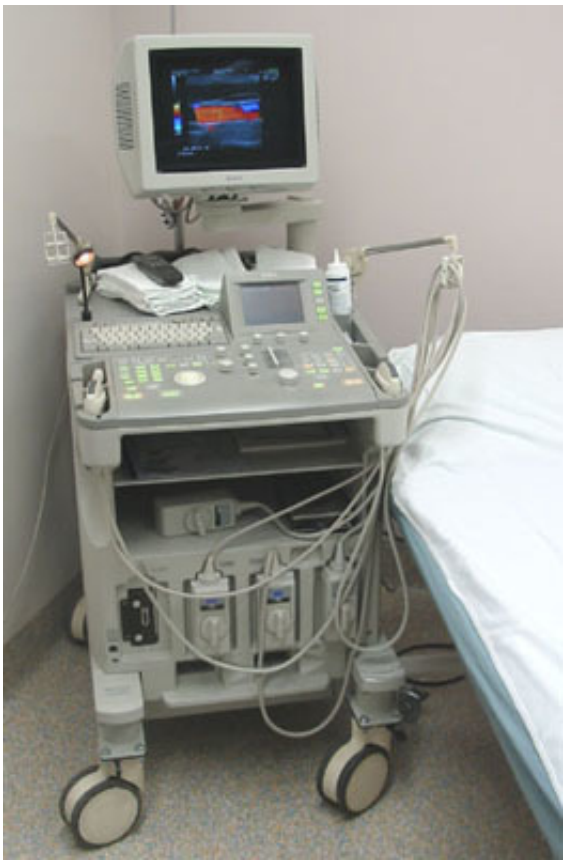
- Interventional ultrasonography; biopsy, emptying fluids, intrauterine Blood transfusion (Hemolytic disease of the newborn)
- Contrast-enhanced ultrasound

A general-purpose ultrasound scanner may 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.

2 From sound to image

The creation of an image from sound is done in three steps – producing a sound wave, receiving echoes, and interpreting those echoes.

2.1 Producing a sound wave



Medical ultrasound scanner

A sound wave is typically produced by a piezoelectric transducer encased in a plastic housing. Strong, short electrical pulses from the ultrasound machine drive the transducer at the desired frequency. The frequencies can be anywhere between 1 and 18 MHz. Older technology transducers focused their beam with physical lenses. Newer technology transducers use phased array techniques to enable the ultrasound machine to change the direction and depth of focus.

The sound is focused either by the shape of the transducer, a lens in front of the transducer, or a complex set of control pulses from the ultrasound scanner (Beamforming). This focusing produces an arc-shaped sound wave from the face of the transducer. The wave travels into the body and comes into focus at a desired depth.

Materials on the face of the transducer enable the sound to be transmitted efficiently into the body (often a rubbery

coating, a form of impedance matching). In addition, a water-based gel is placed between the patient's skin and the probe.

The sound wave is partially reflected from the layers between different tissues or scattered from smaller structures. Specifically, sound is reflected anywhere where there are acoustic impedance changes in the body: e.g. blood cells in blood plasma, small structures in organs, etc. Some of the reflections return to the transducer.

2.2 Receiving the echoes

The return of the sound wave to the transducer results in the same process as sending the sound wave, except in reverse. The returned sound wave vibrates the transducer and the transducer turns the vibrations into electrical pulses that travel to the ultrasonic scanner where they are processed and transformed into a digital image.

2.3 Forming the image

To make an image, the ultrasound scanner must determine two things from each received echo:

1. How long it took the echo to be received from when the sound was transmitted.

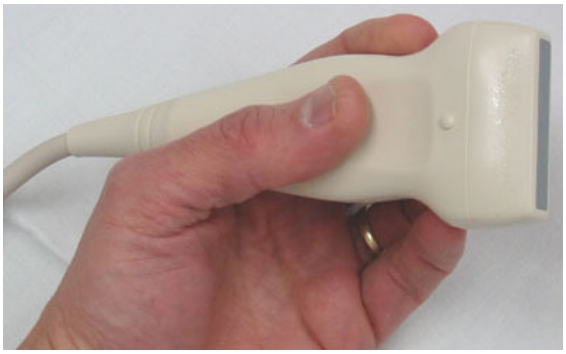
2. How strong the echo was.

Once the ultrasonic scanner determines these two things, it can locate which pixel in the image to light up and to what intensity.

Transforming the received signal into a digital image may be explained by using a blank spreadsheet as an analogy. First picture a long, flat transducer at the top of the sheet. Send pulses down the 'columns' of the spreadsheet (A, B, C, etc.). Listen at each column for any return echoes. When an echo is heard, note how long it took for the echo to return. The longer the wait, the deeper the row (1,2,3, etc.). The strength of the echo determines the brightness setting for that cell (white for a strong echo, black for a weak echo, and varying shades of grey for everything in between.) When all the echoes are recorded on the sheet, we have a greyscale image.

2.4 Displaying the image

Images from the ultrasound scanner are transferred and displayed using the DICOM standard. Normally, very little post processing is applied to ultrasound images.



Linear array transducer

3 Sound in the body

Ultrasonography (sonography) uses a probe containing multiple acoustic transducers to send pulses of sound into a material. Whenever a sound wave encounters a material with a different density (acoustical impedance), part of the sound wave is reflected back to the probe and is detected as an echo. The time it takes for the echo to travel back to the probe is measured and used to calculate the depth of the tissue interface causing the echo. The greater the difference between acoustic impedances, the larger the echo is. If the pulse hits gases or solids, the density difference is so great that most of the acoustic energy is reflected and it becomes impossible to see deeper.

The frequencies used for medical imaging are generally in the range of 1 to 18 MHz. Higher frequencies have a correspondingly smaller wavelength, and can be used to make sonograms with smaller details. However, the attenuation of the sound wave is increased at higher frequencies, so in order to have better penetration of deeper tissues, a lower frequency (3–5 MHz) is used.

Seeing deep into the body with sonography is very difficult. Some acoustic energy is lost every time an echo is formed, but most of it (approximately $0.5 \frac{\text{dB}}{\text{cm depth} \cdot \text{MHz}}$) is lost from acoustic absorption. (See also Acoustic attenuation for further details on modeling of acoustic attenuation and absorption.)

The speed of sound varies as it travels through different materials, and is dependent on the acoustical impedance of the material. However, the sonographic instrument assumes that the acoustic velocity is constant at 1540 m/s. An effect of this assumption is that in a real body with non-uniform tissues, the beam becomes somewhat defocused and image resolution is reduced.

To generate a 2D-image, the ultrasonic beam is swept. A transducer may be swept mechanically by rotating or swinging. Or a 1D phased array transducer may be used to sweep the beam electronically. The received data is processed and used to construct the image. The image is then a 2D representation of the slice into the body.

3D images can be generated by acquiring a series of ad-

jacent 2D images. Commonly a specialised probe that mechanically scans a conventional 2D-image transducer is used. However, since the mechanical scanning is slow, it is difficult to make 3D images of moving tissues. Recently, 2D phased array transducers that can sweep the beam in 3D have been developed. These can image faster and can even be used to make live 3D images of a beating heart.

Doppler ultrasonography is used to study blood flow and muscle motion. The different detected speeds are represented in color for ease of interpretation, for example leaky heart valves: the leak shows up as a flash of unique color. Colors may alternatively be used to represent the amplitudes of the received echoes.

4 Modes of sonography

Several modes of ultrasound are used in medical imaging.[7][8] These are:

- **A-mode**: A-mode (amplitude mode) is the simplest type of ultrasound. A single transducer scans a line through the body with the echoes plotted on screen as a function of depth. Therapeutic ultrasound aimed at a specific tumor or calculus is also A-mode, to allow for pinpoint accurate focus of the destructive wave energy.
- **B-mode or 2D mode**: In B-mode (brightness mode) ultrasound, a linear array of transducers simultaneously scans a plane through the body that can be viewed as a two-dimensional image on screen. More commonly known as 2D mode now.
- **C-mode**: A C-mode image is formed in a plane normal to a B-mode image. A gate that selects data from a specific depth from an A-mode line is used; then the transducer is moved in the 2D plane to sample the entire region at this fixed depth. When the transducer traverses the area in a spiral, an area of 100 cm^2 can be scanned in around 10 seconds.[8]
- **M-mode**: In M-mode (motion mode) ultrasound, pulses are emitted in quick succession – each time, either an A-mode or B-mode image is taken. Over time, this is analogous to recording a video in ultrasound. As the organ boundaries that produce reflections move relative to the probe, this can be used to determine the velocity of specific organ structures.
- **Doppler mode**: This mode makes use of the Doppler effect in measuring and visualizing blood flow
  - **Color Doppler**: Velocity information is presented as a color-coded overlay on top of a B-mode image
  - **Continuous Doppler**: Doppler information is sampled along a line through the body, and all velocities detected at each time point are presented (on a time line)
  - **Pulsed wave (PW) Doppler**: Doppler information is sampled from only a small sample volume (defined in 2D image), and presented on a timeline
  - **Duplex**: a common name for the simultaneous presentation of 2D and (usually) PW Doppler information. (Using modern ultrasound machines, color Doppler is almost always also used; hence the alternative name **Triplex**.)
- **Pulse inversion mode**: In this mode, two successive pulses with opposite sign are emitted and then subtracted from each other. This implies that any linearly responding constituent will disappear while gases with non-linear compressibility stand out. Pulse inversion may also be used in a similar manner as in **Harmonic mode**; see below:
- **Harmonic mode**: In this mode a deep penetrating fundamental frequency is emitted into the body and a harmonic overtone is detected. This way noise and artifacts due to reverberation and aberration are greatly reduced. Some also believe that penetration depth can be gained with improved lateral resolution; however, this is not well documented.

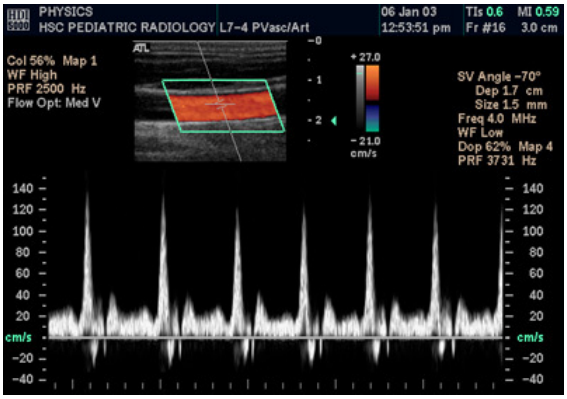
5 Expansions

An additional expansion or additional technique of ultrasound is **biplanar ultrasound**, in which the probe has two 2D planes that are perpendicular to each other, providing more efficient localization and detection.[9] Furthermore, an **omniplane** probe is one that can rotate 180° to obtain multiple images.[9] In 3D ultrasound, many 2D planes are digitally added together to create a 3-dimensional image of the object.

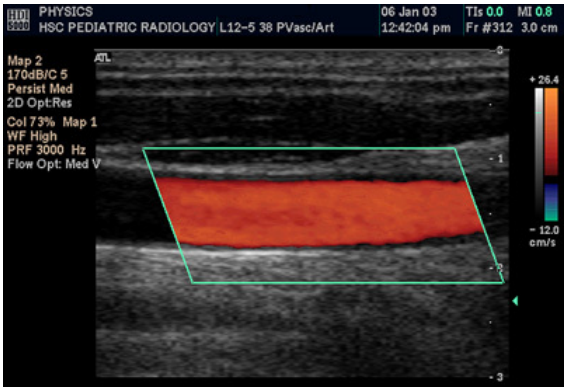
5.1 Doppler ultrasonography

See also: Doppler echocardiography

Sonography can be enhanced with Doppler measurements, which employ the Doppler effect to assess whether structures (usually blood)[10] are moving towards or away from the probe, and its relative velocity. By calculating the frequency shift of a particular sample volume, for example flow in an artery or a jet of blood flow over a heart valve, its speed and direction can be determined and visualised. This is particularly useful in cardiovascular studies (sonography of the vascular system and heart) and essential in many areas such as determining reverse blood flow in the liver vasculature in portal hypertension. The Doppler information is displayed graphically using



Spectral Doppler scan of the common carotid artery



Colour Doppler scan of the common carotid artery

spectral Doppler, or as an image using color Doppler (directional Doppler) or power Doppler (non directional Doppler). This Doppler shift falls in the audible range and is often presented audibly using stereo speakers: this produces a very distinctive, although synthetic, pulsating sound.

All modern ultrasound scanners use pulsed Doppler to measure velocity. Pulsed wave machines transmit and receive series of pulses. The frequency shift of each pulse is ignored, however the relative phase changes of the pulses are used to obtain the frequency shift (since frequency is the rate of change of phase). The major advantages of pulsed Doppler over continuous wave is that distance information is obtained (the time between the transmitted and received pulses can be converted into a distance with knowledge of the speed of sound) and gain correction is applied. The disadvantage of pulsed Doppler is that the measurements can suffer from aliasing. The terminology "Doppler ultrasound" or "Doppler sonography", has been accepted to apply to both pulsed and continuous Doppler systems despite the different mechanisms by which the velocity is measured.

It should be noted here that there are no standards for the display of color Doppler. Some laboratories show arteries as red and veins as blue, as medical illustrators usually show them, even though some vessels may have portions flowing towards and portions flowing away from the transducer. This results in the illogical appearance of a vessel being partly a vein and partly an artery. Other laboratories use red to indicate flow toward the transducer and blue away from the transducer. Still other laboratories prefer to display the sonographic Doppler color map more in accord with the prior published physics with the red shift representing longer waves of echoes (scattered) from blood flowing away from the transducer; and with blue representing the shorter waves of echoes reflecting from blood flowing toward the transducer. Because of this confusion and lack of standards in the various laboratories, the sonographer must understand the underlying acoustic physics of color Doppler and the physiology of normal and abnormal blood flow in the human body (see Red shift[11][12][13]).

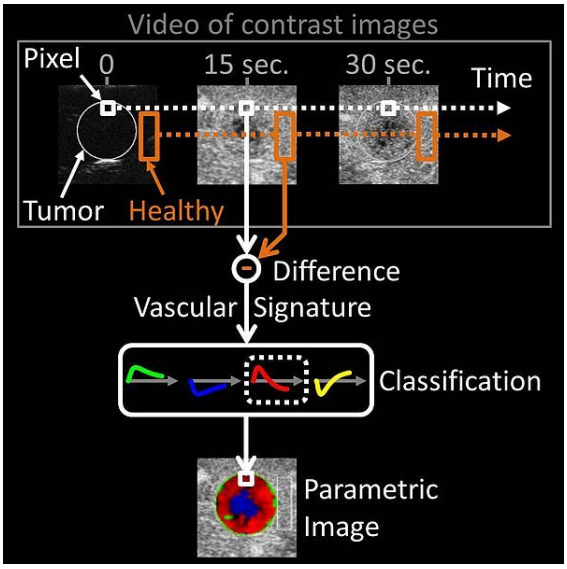
Although Angiography and Venography which both use X-ray and contrast injection material are more accurate than Doppler Sonography, Doppler Sonography may be chosen because it is faster, less expensive, and non-invasive.[14]

5.2 Contrast ultrasonography (ultrasound contrast imaging)

Main article: Contrast-enhanced ultrasound

A contrast medium for medical ultrasonography is a formulation of encapsulated gaseous microbubbles[15] to increase echogenicity of blood, discovered by Dr Raymond Gramiak in 1968[16] and named contrast-enhanced ultrasound. This contrast medical imaging modality is clinically used throughout the world,[17] in particular for echocardiography in the USA and for ultrasound radiology in Europe and Asia.

Microbubbles-based contrast media is administrated intravenously in patient blood stream during the medical ultrasonography examination. The microbubbles being too large in diameter, they stay confined in blood vessels and cannot extravasate towards the interstitial fluid. An ultrasound contrast media is therefore purely intravascular, making it an ideal agent to image organ microvascularization for diagnostic purposes. A typical clinical use of contrast ultrasonography is detection of a hypervascular metastatic tumor, which exhibits a contrast uptake (kinetics of microbubbles concentration in blood circulation) faster than healthy biological tissue surrounding the tumor.[18] Other clinical applications using contrast exist, such as in echocardiography to improve delineation of left ventricle for visually checking contractibility of heart after a myocardial infarction. Finally, applications in quantitative perfusion[19] (relative measurement of blood flow [20]) emerge for identifying early patient response to an anti-cancerous drug treatment (methodology and clinical study by Dr Nathalie Lassau in 2011[21]), enabling to determine the best oncological therapeutic options.[22]



Parametric imaging of vascular signatures (diagram)

In oncological practice of medical contrast ultrasonography, clinicians use the method of parametric imaging of vascular signatures[23] invented by Dr Nicolas Rognin in 2010.[24] This method is conceived as a cancer aided diagnostic tool, facilitating characterization of a suspicious tumor (malignant versus benign) in an organ. This method is based on medical computational science [25][26] to analyze a time sequence of ultrasound contrast images, a digital video recorded in real-time during patient examination. Two consecutive signal processing steps are applied to each pixel of the tumor:

1. calculation of a vascular signature (contrast uptake difference with respect to healthy tissue surrounding the tumor);
2. automatic classification of the vascular signature into a unique parameter, this last coded in one of the four following colors:
    - green for continuous hyper-enhancement (contrast uptake higher than healthy tissue one),
    - blue for continuous hypo-enhancement (contrast uptake lower than healthy tissue one),
    - red for fast hyper-enhancement (contrast uptake before healthy tissue one) or
    - yellow for fast hypo-enhancement (contrast uptake after healthy tissue one).

Once signal processing in each pixel completed, a color spatial map of the parameter is displayed on a computer monitor, summarizing all vascular information of the tumor in a single image called parametric image (see last figure of press article [27] as clinical examples). This parametric image is interpreted by clinicians based on predominant colorization of the tumor: red indicates a suspicion of malignancy (risk of cancer), green or yellow – a high probability of benignity. In the first case (suspicion of malignant tumor), the clinician typically prescribes a biopsy to confirm the diagnostic or a CT scan examination as a second opinion. In the second case (quasi-certain of benign tumor), only a follow-up is needed with a contrast ultrasonography examination a few months later. The main clinical benefits are to avoid a systematic biopsy (risky invasive procedure) of benign tumors or a CT scan examination exposing the patient to X-ray radiation. The parametric imaging of vascular signatures method proved to be effective in humans for characterization of tumors in the liver.[28] In a cancer screening context, this method might be potentially applicable to other organs such as breast[29] or prostate.

5.3 Molecular ultrasonography (ultrasound molecular imaging)

The future of contrast ultrasonography is in molecular imaging with potential clinical applications expected in cancer screening to detect malignant tumors at their earliest stage of appearance. Molecular ultrasonography (or ultrasound molecular imaging) uses targeted microbubbles originally designed by Dr Alexander Klibanov in 1997;[30][31] such targeted microbubbles specifically bind or adhere to tumoral microvessels by targeting biomolecular cancer expression (overexpression of certain biomolecules occurs during neo-angiogenesis[32][33] or inflammation[34] processes in malignant tumors). As a result, a few minutes after their injection in blood circulation, the targeted microbubbles accumulate in the malignant tumor; facilitating its localization in a unique ultrasound contrast image. In 2013, the very first exploratory clinical trial in humans for prostate cancer was completed at Amsterdam in the Netherlands by Dr Hessel Wijkstra.[35]

In molecular ultrasonography, the technique of acoustic radiation force (also used for shear wave elastography) is applied in order to literally push the targeted microbubbles towards microvessels wall; firstly demonstrated by Dr Paul Dayton in 1999.[36] This allows to maximize binding to the malignant tumor; the targeted microbubbles being in more direct contact with cancerous biomolecules expressed at the inner surface of tumoral microvessels. At the stage of scientific preclinical research, the technique of acoustic radiation force was implemented as a prototype in clinical ultrasound systems and validated *in vivo* in 2D[37] and 3D[38][39] imaging modes.

5.4 Elastography (ultrasound elasticity imaging)

Main article: Elastography

Ultrasound is also used for elastography, which is a rela-

tively new imaging modality that maps the elastic properties of soft tissue.[40][41] This modality emerged in the last two decades. Elastography is useful in medical diagnoses as it can discern healthy from unhealthy tissue for specific organs/growths. For example, cancerous tumors will often be harder than the surrounding tissue, and diseased livers are stiffer than healthy ones.[40][41][42][43]

There are many ultrasound elastography techniques.[41] The most prominent are: Quasistatic Elastography/Strain Imaging, Shear Wave Elasticity Imaging (SWEI), Supersonic Shear Imaging (SSI), Acoustic Radiation Force Impulse imaging (ARFI), and Transient Elastography. The steadily growing clinical use of ultrasound elastography is a result of the implementation of technology in clinical ultrasound machines. Currently, an increase of activities in the field of elastography is observed demonstrating successful application of the technology in various areas of medical diagnostics and treatment monitoring.

5.5 Compression ultrasonography

Compression ultrasonography is a simplified technique used for quick deep vein thrombosis diagnosis. The examination is limited to common femoral vein and popliteal vein only, instead to spend time performing the full examination, lower limbs venous ultrasonography. It is performed using only one test: vein compression.[44]

Compression ultrasonography has both high sensitivity and specificity for detecting proximal deep vein thrombosis only in symptomatic patients. Results are not reliable when the patient is symptomless and must be checked, for example in high risk postoperative patients mainly in orthopedic patients.[45][46]

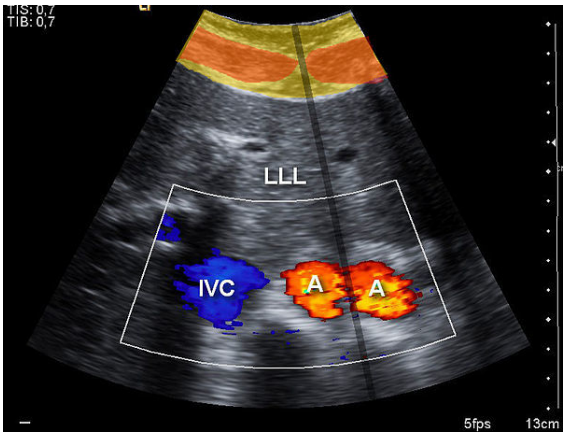
6 Attributes

As with all imaging modalities, ultrasonography has its list of positive and negative attributes.

6.1 Strengths

- It images muscle, soft tissue, and bone surfaces very well and is particularly useful for delineating the interfaces between solid and fluid-filled spaces.
- It renders "live" images, where the operator can dynamically select the most useful section for diagnosing and documenting changes, often enabling rapid diagnoses. Live images also allow for ultrasound-guided biopsies or injections, which can be cumbersome with other imaging modalities.
- It shows the structure of organs.
- It has no known long-term side effects and rarely causes any discomfort to the patient.
- Equipment is widely available and comparatively flexible.
- Small, easily carried scanners are available; examinations can be performed at the bedside.
- Relatively inexpensive compared to other modes of investigation, such as computed X-ray tomography, DEXA or magnetic resonance imaging.
- Spatial resolution is better in high frequency ultrasound transducers than it is in most other imaging modalities.
- Through the use of an Ultrasound research interface, an ultrasound device can offer a relatively inexpensive, real-time, and flexible method for capturing data required for special research purposes for tissue characterization and development of new image processing techniques

6.2 Weaknesses



Double aort artifact in sonography due to difference in velocity of sound waves in muscle and fat.

- Sonographic devices have trouble penetrating bone. For example, sonography of the adult brain is very limited though improvements are being made in transcranial ultrasonography.
- Sonography performs very poorly when there is a gas between the transducer and the organ of interest, due to the extreme differences in acoustic impedance. For example, overlying gas in the gastrointestinal tract often makes ultrasound scanning of the pancreas difficult, and lung imaging is not possible (apart from demarcating pleural effusions).
- Even in the absence of bone or air, the depth penetration of ultrasound may be limited depending on the frequency of imaging. Consequently, there might be difficulties imaging structures deep in the body, especially in obese patients.

- Physique has a large influence on image quality. Image quality and accuracy of diagnosis is limited with obese patients, overlying subcutaneous fat attenuates the sound beam and a lower frequency transducer is required (with lower resolution)
- The method is operator-dependent. A high level of skill and experience is needed to acquire good-quality images and make accurate diagnoses.
- There is no scout image as there is with CT and MRI. Once an image has been acquired there is no exact way to tell which part of the body was imaged.

7 Risks and side-effects

Ultrasonography is generally considered a safe imaging modality.[47]

Diagnostic ultrasound studies of the fetus are generally considered to be safe during pregnancy. This diagnostic procedure should be performed only when there is a valid medical indication, and the lowest possible ultrasonic exposure setting should be used to gain the necessary diagnostic information under the "as low as reasonably practicable" or ALARP principle.

World Health Organizations technical report series 875 (1998).[48] supports that ultrasound is harmless: "Diagnostic ultrasound is recognized as a safe, effective, and highly flexible imaging modality capable of providing clinically relevant information about most parts of the body in a rapid and cost-effective fashion". Although there is no evidence ultrasound could be harmful for the fetus, US Food and Drug Administration views promotion, selling, or leasing of ultrasound equipment for making "keepsake fetal videos" to be an unapproved use of a medical device.

Medical ultrasonography should not be performed without a medical indication to perform it. To do otherwise would be to perform unnecessary health care to patients, which bring unwarranted costs and may lead to other testing. Overuse of ultrasonography is reported in the United States, especially as routine screening for deep vein thrombosis after orthopedic surgeries in patients who are not at heightened risk for having that condition.[49]

7.1 Studies on the safety of ultrasound

- A meta-analysis of several ultrasonography studies published in 2000 found no statistically significant harmful effects from ultrasonography, but mentioned that there was a lack of data on long-term substantive outcomes such as neurodevelopment.[50]
- A study at the Yale School of Medicine published in 2006 found a small but significant correlation between prolonged and frequent use of ultrasound and abnormal neuronal migration in mice.[51]
- A study performed in Sweden in 2001[52] has shown that subtle effects of neurological damage linked to ultrasound were implicated by an increased incidence in left-handedness in boys (a marker for brain problems when not hereditary) and speech delays.[53][54]
  - The above findings, however, were not confirmed in a later follow-up study.[55]
  - A later study, however, performed on a larger sample of 8865 children, has established a statistically significant, albeit weak association of ultrasonography exposure and being non-right handed later in life.[56] (See Handedness#Ultrasound).

8 Obstetric ultrasound

Main article: Obstetric ultrasonography

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.

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.[57]

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

Its results are occasionally incorrect, 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)[58]

> 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.

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.

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 the UK Government (Department of Health) show that non-obstetric ultrasound examinations constituted more than 65% of the total number of ultrasound scans conducted.

8.1 Society and Culture

Recent studies have stressed the importance of framing "reproductive health matters cross-culturally", particularly when understanding the "new phenomenon" of "the proliferation of ultrasound imaging" in developing countries.[59] In 2004, Tine Gammeltoft interviewed 400 women in Hanoi's Obstetrics and Gynecology Hospital; each "had an average of 6.6 scans during her pregnancy", much higher than five years ago when "a pregnant woman might or might not have had a single scan during her pregnancy" in Vietnam.[59] Gammeltoft explains that "many Asian countries" see "the foetus as an ambiguous being" unlike in Western medicine where it is common to think of the foetus as "materially stable".[59] Therefore, although women, particularly in Asian countries, "express intense uncertainties regarding the safety and credibility of this technology", it is overused for its "immediate reassurance".[59]

9 Regulation

Diagnostic and therapeutic ultrasound equipment is regulated in the USA by the Food and Drug Administration, and worldwide by other national regulatory agencies. The FDA limits acoustic output using several metrics; generally, other agencies accept the FDA-established guidelines.

Currently, New Mexico is the only US state which regulates diagnostic medical sonographers. Certification examinations for sonographers are available in the US from three organizations: the American Registry for Diagnostic Medical Sonography, Cardiovascular Credentialing International and the American Registry of Radiologic Technologists.

The primary regulated metrics are Mechanical Index (MI), a metric associated with the cavitation bio-effect, and Thermal Index (TI) a metric associated with the tissue heating bio-effect. The FDA requires that the machine not exceed established limits, which are reasonably conservative so as to maintain diagnostic ultrasound as a safe imaging modality. This requires self-regulation on the part of the manufacturer in terms of the machine's calibration.[60]

Ultrasound-based pre-natal care and sex screening technologies were launched in India in the 1980s. With concerns about its misuse for sex-selective abortion, the Government of India passed the Pre-natal Diagnostic Techniques Act (PNDT) in 1994 to regulate legal and illegal uses of ultrasound equipment.[61] The law was further amended into the Pre-Conception and Pre-natal Diagnostic Techniques (Regulation and Prevention of Misuse) (PCPNDT) Act in 2004 to deter and punish prenatal sex screening and sex selective abortion.[62] It is currently illegal and a punishable crime in India to determine or disclose the sex of a fetus using ultrasound equipment.[63]

10 History

Ultrasonic energy was first applied to the human body for medical purposes by Dr George Ludwig at the Naval Medical Research Institute, Bethesda, Maryland in the late 1940s.[64][65] English-born physicist John Wild (1914–2009) first used ultrasound to assess the thickness of bowel tissue as early as 1949; he has been described as the "father of medical ultrasound".[66] Subsequent advances in the field took place concurrently in several countries.

10.1 France

In his book "L'investigation vasculaire par ultrasonographie Doppler" (Ed Masson, 1977) [10] Dr Claude Franceschi laid down the Doppler Ultrasound fundamentals of the hemodynamics semiotics, which are still in use in current Doppler arterial and venous Duplex Ultrasound investigations.

10.2 Scotland

Parallel developments in Glasgow, Scotland by Professor Ian Donald and colleagues at the Glasgow Royal Maternity Hospital (GRMH) led to the first diagnostic applications of the technique. Donald was an obstetrician with a self-confessed "childish interest in machines, electronic and otherwise", who, having treated the wife of one of the company's directors, was invited to visit the Research Department of boilermakers Babcock & Wilcox at Renfrew, where he used their industrial ultrasound equipment to conduct experiments on various morbid anatomical specimens and assess their ultrasonic characteristics. Together with the medical physicist Tom Brown and fellow obstetrician Dr John MacVicar, Donald refined the equipment to enable differentiation of pathology in live volunteer patients. These findings were reported in *The Lancet* on 7 June 1958[67] as "Investigation of Abdominal Masses by Pulsed Ultrasound" – possibly one of the most important papers ever published in the field of diagnostic medical imaging.

At GRMH, Professor Donald and Dr James Willocks then refined their techniques to obstetric applications including fetal head measurement to assess the size and growth of the fetus. With the opening of the new Queen Mother's Hospital in Yorkhill in 1964, it became possible to improve these methods even further. Dr Stuart Campbell's pioneering work on fetal cephalometry led to it acquiring long-term status as the definitive method of study of foetal growth. As the technical quality of the scans was further developed, it soon became possible to study pregnancy from start to finish and diagnose its many complications such as multiple pregnancy, fetal abnormality and *placenta praevia*. Diagnostic ultrasound has since been imported into practically every other area of medicine.

10.3 Sweden

Medical ultrasonography was used in 1953 at Lund University by cardiologist Inge Edler and Carl Hellmuth Hertz, the son of Gustav Ludwig Hertz, who was a graduate student at the department of nuclear physics.

Edler had asked Hertz if it was possible to use radar to look into the body, but Hertz said this was impossible. However, he said, it might be possible to use ultrasonography. Hertz was familiar with using ultrasonic reflectoscopes for nondestructive materials testing, and together they developed the idea of using this method in medicine.

The first successful measurement of heart activity was made on October 29, 1953 using a device borrowed from the ship construction company Kockums in Malmö. On December 16 the same year, the method was used to generate an echo-encephalogram (ultrasonic probe of the brain). Edler and Hertz published their findings in 1954.[68]

10.4 United States

In 1962, after about two years of work, Joseph Holmes, William Wright, and Ralph Meyerdirk developed the first compound contact B-mode scanner. Their work had been supported by U.S. Public Health Services and the University of Colorado. Wright and Meyerdirk left the University to form Physionic Engineering Inc., which launched the first commercial hand-held articulated arm compound contact B-mode scanner in 1963. This was the start of the most popular design in the history of ultrasound scanners.[69]

In the late 1960s Dr Gene Strandness and the bioengineering group at the University of Washington conducted research on Doppler ultrasound as a diagnostic tool for vascular disease. Eventually, they developed technologies to use duplex imaging, or Doppler in conjunction with B-mode scanning, to view vascular structures in real-time, while also providing hemodynamic information.[70]

The first demonstration of color Doppler was by Geoff Stevenson, who was involved in the early developments and medical use of Doppler shifted ultrasonic energy.[71]

11 See also

- Doppler fetal monitor
- Polybiography
- Radiographer
- Ultrasound transmission tomography

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13 External links

- About the discovery of medical ultrasonography
- History of medical sonography (ultrasound)
- Procedures in Ultrasound (Sonography)
- Elastography

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14.1 Text

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2

Examination technique: general rules and recommendations

Range of application

All body regions that are not situated behind expanses of bone or air-containing tissue, such as the lungs, are accessible to transcutaneous ultrasound. Bone surfaces (fractures, osteolytic lesions) and the surfaces of the lungs or air-void parts can also be demonstrated. Examinations through thin, flat bones are possible at lower frequencies. It is also possible to bypass obstacles with endoprobes (endoscopic sonography). Thus, transcutaneous ultrasound is used mainly for evaluating:

- neck: thyroid gland, lymph nodes, abscesses, vessels (angiology);
- chest: wall, pleura, peripherally situated disorders of the lung, mediastinal tumours and the heart (echocardiography);
- abdomen, retroperitoneum and small pelvis: parenchymatous organs, fluid-containing structures, gastrointestinal tract, great vessels and lymph nodes, tumours and abnormal fluid collections; and
- extremities (joints, muscles and connective tissue, vessels).

General indications (B-scan and duplex techniques)

The general indications are:

- presence, position, size and shape of organs;
- stasis, concretions and dysfunction of hollow organs and structures;
- tumour diagnosis and differentiation of focal lesions;
- inflammatory diseases;
- metabolic diseases causing macroscopic alterations of organs;
- abnormal fluid collection in body cavities or organs, including ultrasound-guided diagnostic and therapeutic interventions;
- evaluating transplants;
- diagnosis of congenital defects and malformations.

Additionally, ultrasound is particularly suitable for checks in the management of chronic diseases and for screening, because it is risk-free, comfortable for patients and cheaper than other imaging modalities.

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Preparation

In general, no preparation is needed for an ultrasound examination; however, for certain examinations of the abdomen, a period of fasting is useful or necessary. To avoid problems due to meteorism, dietary restrictions (no gas-producing foods), physical exercise (walking before the examination) and even premedication (antifoaming agents) are recommended. Special preparation is only necessary for certain examinations and these are discussed in the relevant chapters of this manual.

Positioning

The ultrasound examination is usually carried out with the patient in the supine position. As further described in the specific chapters, it is often useful to turn the patient in an oblique position or to scan from the back in a prone position, e.g. when scanning the kidneys. Ultrasound also allows examination of the patient in a sitting or standing position, which may help in certain situations to diagnose stones or fluid collection (e.g. pleural effusion).

Coupling agents

A coupling agent is necessary to ensure good contact between the transducer and the skin and to avoid artefacts caused by the presence of air between them. The best coupling agents are water-soluble gels, which are commercially available. Water is suitable for very short examinations. Disinfectant fluids can also be used for short coupling of the transducer during guided punctures. Oil has the disadvantage of dissolving rubber or plastic parts of the transducer.

The composition of a common coupling gel is as follows:

- 10.0 g carbomer
- 0.25 g ethylenediaminetetraacetic acid (EDTA)
- 75.0 g propylene glycol
- 12.5 g trolamine and up to 500 ml demineralized water.

Dissolve the EDTA in 400 ml of water. When the EDTA has dissolved, add the propylene glycol. Then add the carbomer to the solution and stir, if possible with a high-speed stirrer, until the mixture forms a gel without bubbles. Add up to 500 ml of demineralized water to the gel.

Precaution: Be careful not to transmit infectious material from one patient to the next via the transducer or the coupling gel. The transducer and any other parts that come into direct contact with the patient must be cleaned after each examination. The minimum requirements are to wipe the transducer after each examination and to clean it with a suitable disinfectant every day and after the examination of any patient who may be infectious.

A suitable method for infectious patients, e.g. those infected with human immunodeficiency virus (HIV) and with open wounds or other skin lesions, is to slip a disposable glove over the transducer and to smear some jelly onto the active surface of the transducer.

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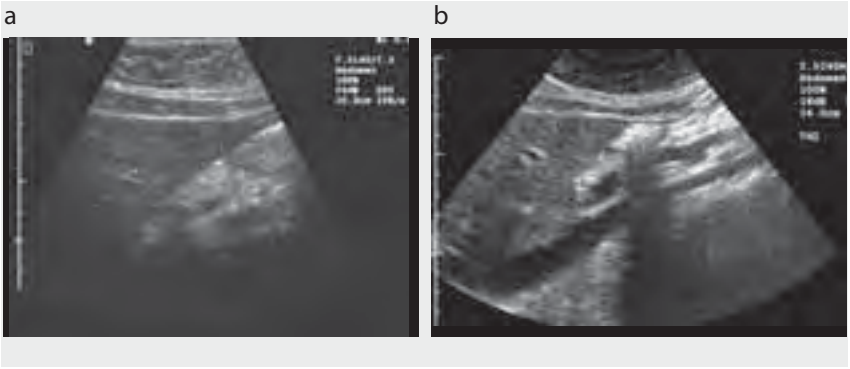
Equipment

Generally, modern ultrasound equipment consists of 'all-round scanners'. Two transducers, usually a curved array for the range 3–5 MHz and a linear array for the range greater than 5 MHz to 10 MHz, as a 'small-part scanner' can be used as 'general-purpose scanners' for examination of all body regions with the B-scan technique (Fig. 2.1).

Fig. 2.1. Choice of transducer and frequency. Generally, superficial structures are examined at 7.5 MHz; however, this frequency is not in general suitable for abdominal work and is limited to examination of superficial structures. (a) At 7.5 MHz, only the ventral surface of the liver can be displayed. (b) The liver and the adjacent structures can be examined completely at 3.5 MHz



Examinations of the skin and eyes and the use of endoprobes require special transducers and more expensive equipment to enable the use of higher frequencies. For echocardiography, different transducers, i.e. electronic sector scanners (phased array technique) are required.

An integrated Doppler technique is necessary for echocardiography and angiology, and is also useful for most other applications. Special software is needed for the use of contrast agents.

Adjustment of the equipment

Correct adjustment of an ultrasound scanner is not difficult, as the instruments offer a wide range of possible settings. Most instruments have a standard setting for each transducer and each body region. This standard can be adapted to the needs of each operator.

When starting with these standards, only slight adaptation to the individual patient is necessary.

- The choice of frequency (and transducer) depends on the penetration depth needed. For examination of the abdomen, it may be useful to start with a lower frequency (curved array, 3.5 MHz) and to use a higher frequency if the region of interest is close to the transducer, e.g. the bowel (Fig. 2.1, Fig. 11.26).
- Adaptation to the penetration depth needed: the whole screen should be used for the region of interest (Fig. 2.2).
- The mechanical index should be as low as possible (< 0.7 in adults).

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- The time gain compensation (TGC) setting must compensate for attenuation, e.g. depending on the abdominal wall, to obtain a homogeneous image. It is useful to find a good TGC setting when scanning a homogeneous section of the tissue, e.g. the right liver lobe in the abdomen, before moving the transducer to the region of interest (Fig. 2.3, Fig. 2.4, Fig. 2.5).
- The focus, or zone of best resolution, should always be adjusted to the point of interest.

Fig. 2.2. Use of the screen. (a) Incorrect adaptation of the screen: the region of interest fills only a small part of the screen. (b) Correct adaptation of the screen

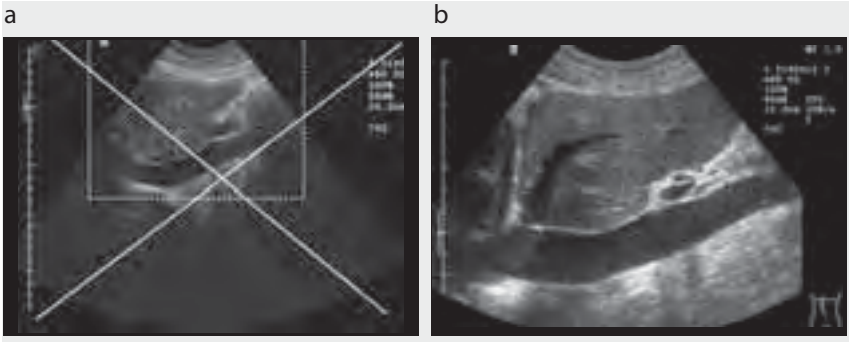

Fig. 2.3. (a) Operating console of an ultrasound machine. Control knobs must be adjusted for each patient. R (range), penetration depth; F (focus), region of best resolution; TGC, time (depth) gain compensation (see Fig. 2.4); Z (zoom), enlarges regions of interest; G, Doppler gain; V, Doppler velocity (pulse repetition frequency). (b) B-image (not the same equipment as in (a)), shows correct (homogeneous pattern of normal liver tissue), TGC curve (arrow) and focus zone, which should be slightly deeper and level with the focal nodular hyperplasia lesion. The thermal index (TIS) and the mechanical index (MI) are indicated. Note that these indices are considerably higher in the colour Doppler image (B-scan 0.6 and 0.5, respectively, versus Doppler 2.3 and 0.8). (c) The Doppler velocity and the Doppler window are correctly adjusted to the size of the lesion and the expected velocity range in the vessels

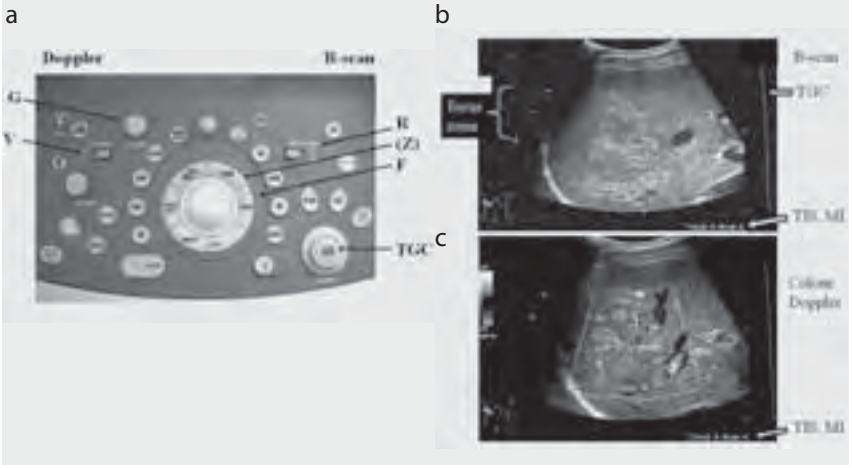

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Fig. 2.4. Time gain compensation (TGC). The TGC is always adjusted according to each patient's circumstances. (a) An overall gain in compensation (B-mode: gain) and gradual regulation are possible. (b) The loss of intensity, or decline in the echoes at a greater distance, is compensated for by the TGC, as shown in the diagram and (c) the ultrasound image with the displayed TGC line (arrow) for 3.5 MHz. This compensation is not sufficient for 7 MHz (see Fig. 2.1)

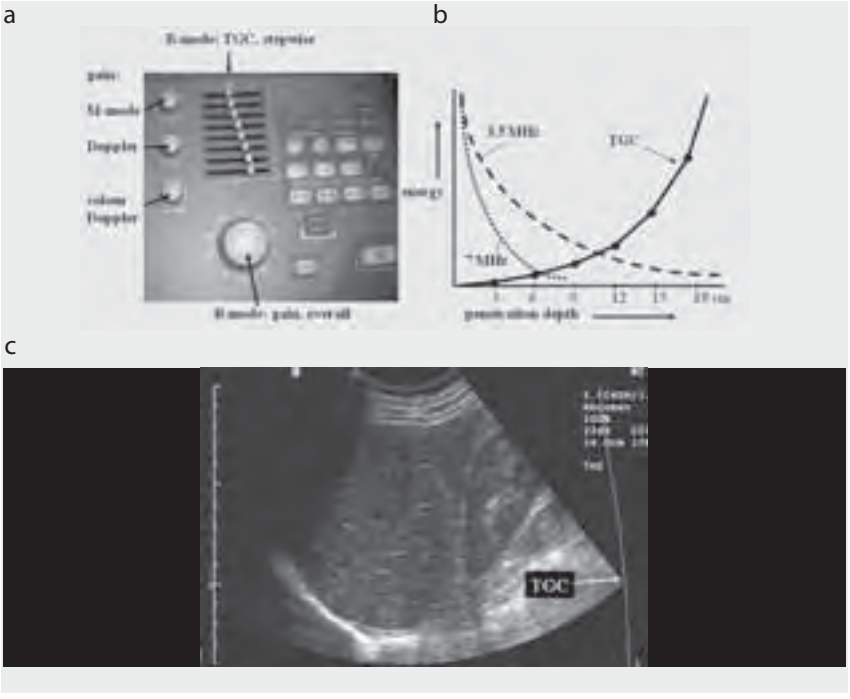
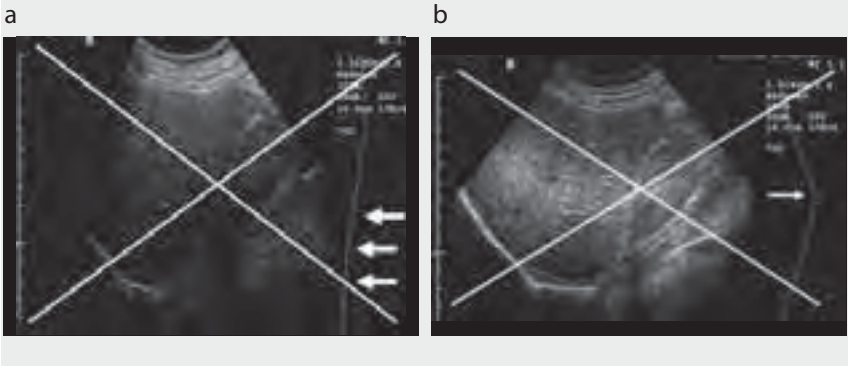


Fig. 2.5. TGC adjustment. Two examples of incorrect adjustment: (a) The lower part of the ultrasound image is too dark because the TGC adjustment is too weak, whereas in (b) the adjustment for the middle part is too high, causing an inhomogeneous image of the liver with a zone that is too bright in the middle part



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- The zoom should be used mainly for the final investigation of detail and for preparing the documentation.
- If there are problems, use of the image optimizer knob and returning to the standard settings may help.

Guidelines for the examination

- Know the patient's problem and medical history. An advantage of ultrasound is that the patient's doctor can carry out the examination, and this provides a good opportunity to talk to the patient about his or her problem.
- Make sure that the settings of the equipment and the orientation of the transducer are correct in relation to the image. This will avoid misinterpretations due to inhomogeneous images with areas that are too dark or too bright and with artefacts.
- Conduct a systematic and complete examination of the whole body region, even if there is an obvious palpable mass or a localized point of pain.
- Start with an anatomically constant area and move to the more variable area (e.g. from the liver to the region of the pancreas or the intestine).
- Move the transducer in a slow constant pattern, while maintaining the defined scanning plane. Hold the transducer motionless when the patient moves, e.g. during respiration. It is possible to move a transducer in many directions by tilting it in the scanning plane and moving it perpendicularly, but with a combination of all these movements the less experienced operator will lose the orientation of the image (Fig. 2.6, Fig. 2.7).
- Use anatomically constant, easily visualized structures for orientation (e.g. liver, aorta or fluid-filled bladder) and normal structures for comparison (e.g. right and left kidney or kidney and liver).
- Examine each organ, structure or tumour in at least two planes. **In this way, one can avoid missing small lesions or misinterpreting artefacts as real alterations.**
- Use palpation to displace fluid or gas from the bowel, to test the consistency of tumours and organs and to localize points of pain.
- Continue the entire examination even if pathological conditions are found. Only a complete examination will avoid that only a less important alteration (e.g. gallstones) is found but the main diagnosis (e.g. pancreatic cancer) is missed.
- In clinically difficult situations or when the findings are doubtful, repeat the examination a short time later. Such repeat examinations can be carried out even at the bedside. This is particularly useful with trauma patients and patients in intensive care.

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Fig. 2.6. Movements of a transducer. The transducer can be moved in its scanning plane in a longitudinal direction (a), turned about itself (b), or tilted in the scanning plane (c) or in a perpendicular direction (d)

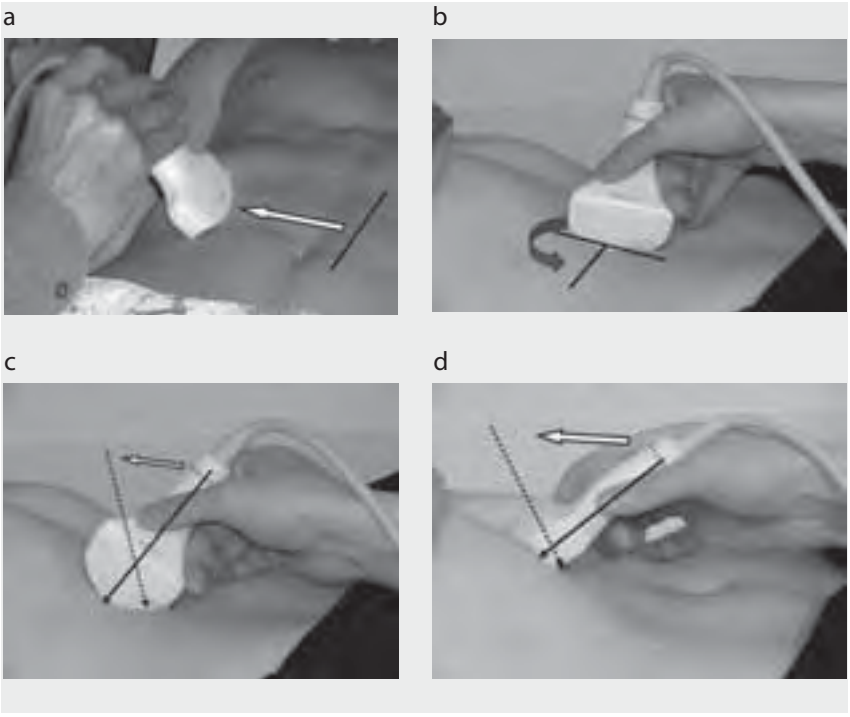
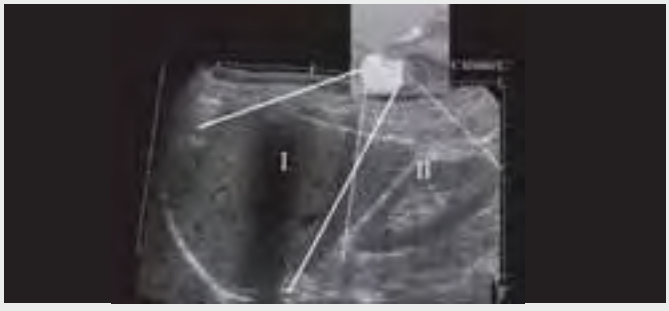


Fig. 2.7. Imaging of the right liver lobe and the right kidney obtained by tilting the transducer in different directions (I and II)



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Documentation

As a rule, both a written report and pictorial documentation should be prepared for each ultrasound examination.

The written report should include:

- a description of the problem that led to the examination;
- a list of the organs (region) examined (generally, it is not necessary to describe normal findings but to note measurements only);
- a description of pathological findings (the descriptions should be concise and clear, but without over-interpretation.); and
- the diagnosis or decision.

Pictorial documentation of pathological findings in two planes is necessary, but documentation of a normal finding (one representative scan of the organ or body region examined) is also useful, e.g. for later check-up examinations.

Interpretation of the ultrasound image

Organs, structures within organs, vessels, tumours and fluid collections are evaluated by B-scan in terms of their:

- presence (aplasia?);
- position (displaced?);
- outer contour or border (which gives information about the surface of an organ or tumour as well as about its relation to the adjacent structures*)*;
- mobility (fixed?);
- consistency (palpation under ultrasonic observation);
- echo pattern; and
- attenuation.

Evaluation of the **presence**, **position** and **size** of an organ is based on the known normal anatomy. A simple determination of organ diameter is sufficient for most routine evaluations, provided the shape is normal. The volume (V) of round- or oval-shaped organs is calculated on the basis of their three perpendicular diameters a, b and c, following the formula for an ellipsoid:

$$V = 0.5 \cdot a \cdot b \cdot c \qquad (2.1)$$

Formulas for special problems, e.g. pleural effusion, are discussed in specific chapters of this book. The volume of organs and structures with complicated shapes can be calculated by the 3D technique.

Evaluation of the **contour** of an organ, and particularly of a neoplastic lesion, should give information about both the smooth or irregular surface and any sharp or blurred (ill-defined) demarcation lines (Fig. 2.8, Fig. 2.9, Fig. 2.10). The latter should include the relation to the surrounding tissue, e.g. any overlap with a natural border, such as a capsule, or infiltration into adjacent structures. The possibilities of contour evaluation are limited by the imaging geometry of ultrasound. The fine surface irregularities of a cirrhotic liver, for example, can be shown, especially since the surface

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Fig. 2.8. Evaluation of the margin or contour of a lesion (e.g. in the liver). The margin of both lesions is sharp. The cyst (a) is echo free, the haemangioma (b) shows a homogeneous echo-rich pattern

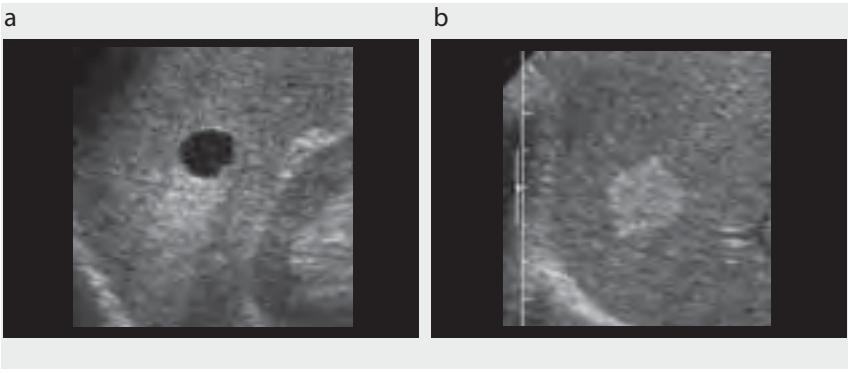
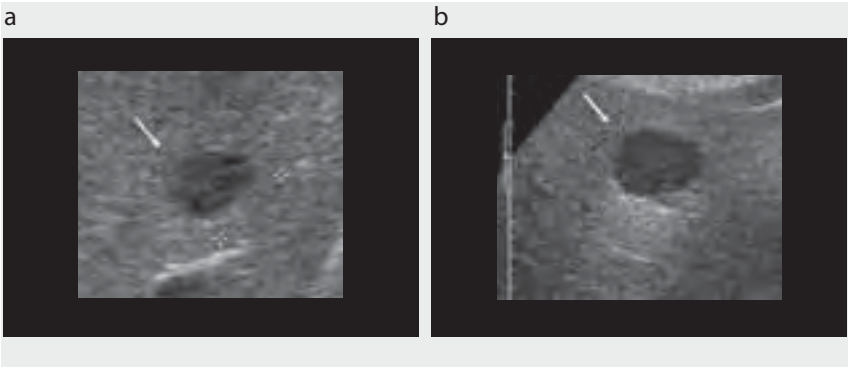


Fig. 2.9. Evaluation of the contour (margin) of two echo-poor liver lesions. (a) The echo-poor metastasis has a blurred outline, particularly at the cranial side (arrow), whereas the malignant lymphoma (b) shows a partial (dorsal side), rather sharp but altogether irregular outline. Slight echo enhancement is seen behind the lymphoma



is approximately perpendicular to the ultrasound beam (Fig. 2.11). The contour of an organ such as the pancreas, however, may appear to be irregular, particularly on the sides, as a result of the coarse boundary echoes.

Evaluation of the **echo pattern** (also known as echo structure, echo texture, echogenicity) of an organ, tissue or tumour is based on an analysis of the intensity and distribution of the internal echoes that are not due to discernible anatomical structures, such as vessels, septa or ducts. Single echoes are either weak, average or strong (Fig. 2.12).

The **echo pattern** is analysed on the basis of the number and strength of the echoes and their distribution (Fig. 2.13):

- echo free – echo poor (hypoechogenic) – average – echo rich (hyperechogenic); and
- homogeneous or inhomogeneous.

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Fig. 2.10. Contour sign. (a) The lesion in the liver has a smooth outline and a tangential artefact (see Fig. 1.24), but is nevertheless a hepatocellular carcinoma (HCC), probably with a capsule. The pattern is average, similar to that of the surrounding liver tissue. (b) The metastasis in the abdominal wall shows an irregular shape and an echo-poor pattern

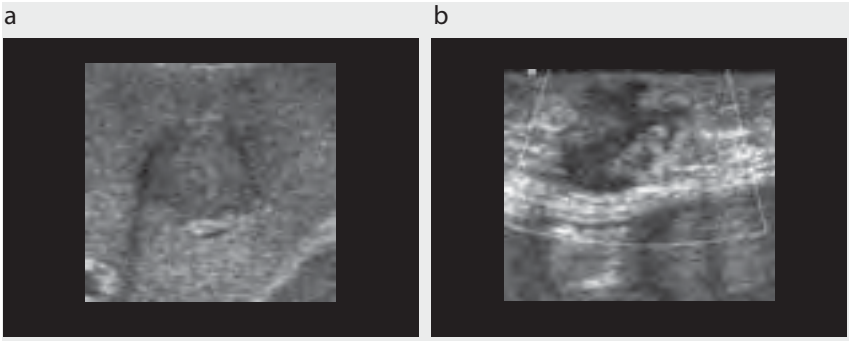
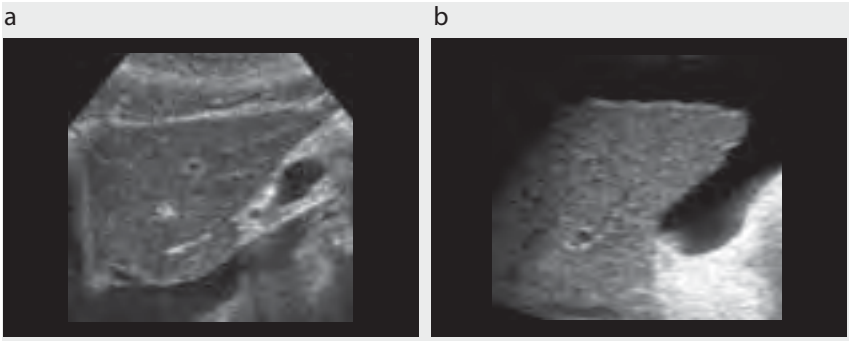


Fig. 2.11. Surface of the liver. (a) The normal healthy liver has a smooth surface. The echo structure of the normal liver is homogeneous and of normal brightness. (b) The cirrhotic liver has an irregular surface. (The echo pattern of the cirrhotic liver is slightly inhomogeneous (coarsened)



Echo free: no (real) echoes within a lesion, e.g. a cyst (Fig. 2.8, Fig. 2.13). This diagnosis requires the correct gain and the identification of artefacts (see section on Artifacts in Chapter 1). Furthermore, only fluid in the strict physical sense is really echo free. Other types of fluid (e.g. blood, abscesses or exudates) contain small particles (e.g. blood cells, fibrin) and cause weak echoes (Fig. 2.12).

Echo poor: an echo pattern consisting of only a few weak echoes (see Fig. 2.9).

An echo pattern appears to be **echo rich** if the tissue causes many weak echoes or a few strong echoes. In both situations, this region appears 'bright' on the screen. For the first type of echo-rich pattern, the term 'echo dense' is occasionally used. Generally, none of these types of echo-rich pattern is differentiated (Fig. 2.8, Fig. 2.9, Fig. 2.10, Fig. 2.11, Fig. 2.12, Fig. 2.13, Fig. 2.14).

WHO. "Manual of Diagnostic Ultrasound, Second Edition." WHO, 2011.

Fig. 2.12. Quality of echoes. The echoes in the upper part of the left lesion are weak, while those of the liver are average. In the right lesion, strong echoes caused by gas are seen. Both lesions (abscesses) show an inhomogeneous pattern; the one on the left is echo poor and the other partially echo rich. Behind the right-hand lesion, a tangential artefact is seen

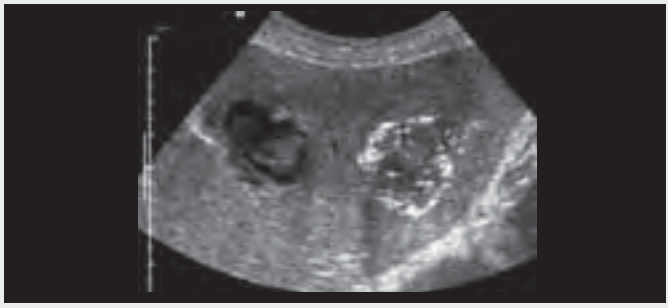
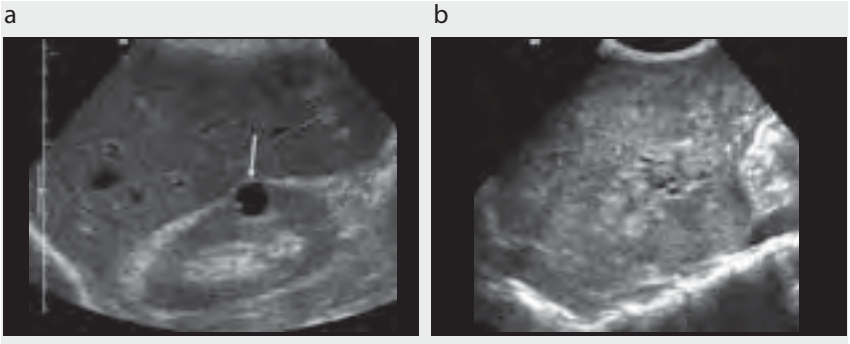


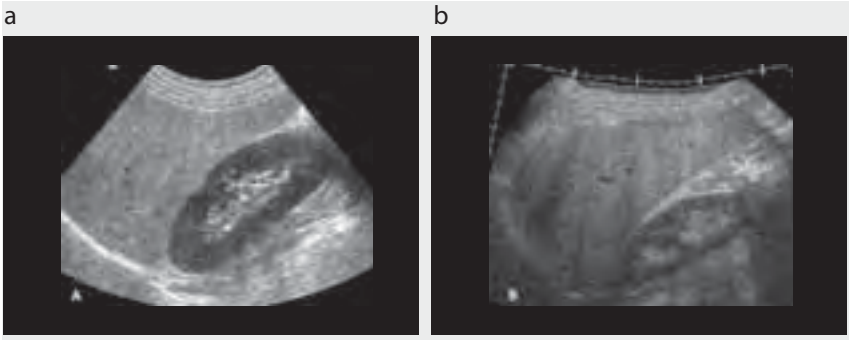
Fig. 2.13. Echo structure (echo pattern). (a) The ultrasonic structure of the liver and the parenchyma of the kidney are echo poor and homogeneous; the pattern in the centre of the kidney is echo rich. A small cyst (arrow) is echo free. (b) The liver shows an inhomogeneous echo-rich structure caused by echo-rich metastases



Increased **attenuation** of ultrasound in an organ may indicate pathological alterations, such as fibrosis; however, experience is needed to recognize this sonographic symptom, as no objective parameters exist (Fig. 2.14).

WHO. "Manual of Diagnostic Ultrasound, Second Edition." WHO, 2011.

Fig. 2.14. Attenuation. (a) The fatty liver shows a typical homogeneous echo-rich pattern. (b) The echo structure of the left liver is echo rich near the ventral surface, but the dorsal parts appear more echo poor. Provided the adjustment of the TGC is correct, this indicates higher than average attenuation of the ultrasound, as seen in fibrosis



Duplex technique

In interpreting Doppler information in an ultrasound image, account should be taken of the principal problems and limitations of the Doppler technique: angle dependency and aliasing.

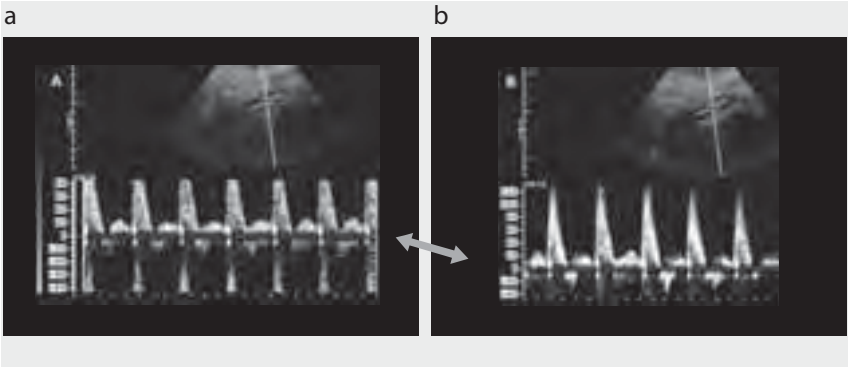
A suitable angle (< 60°) must be found for the ultrasound beam to reach the vessel of interest, especially if measurements (spectral Doppler) are to be made. The angle is less problematic for colour Doppler imaging, but colour pixels may be missed if the angle is close to 90° (see Fig. 1.32). Power Doppler images are not affected by this problem but give no information about the flow direction.

The window for the Doppler examination should be as small as possible, as its width and length determine the time needed for the construction of one image and, therefore, the image frequency (Fig. 1.19, Fig. 1.20, Fig. 1.21). The distal border of the window, or the penetration depth for the Doppler ultrasound, limits the pulse repetition frequency because a second pulse can be emitted only if the echoes of the adjusted depth have reached the transducer. The pulse repetition frequency limits the flow velocity, which can be depicted without aliasing (see section on Doppler techniques in Chapter 1). Initially, it is useful to adjust the settings to a relatively low velocity (17–24 cm/s) to depict the slow flow velocities in the veins. For the same reason, the filter should be low to avoid suppressing slow flow signals with those caused by the movement of the wall. For the examination of veins and arteries, the wall filter should be adjusted to 50–100 Hz and 200 Hz, respectively. If aliasing (see section on Doppler techniques in Chapter 1) occurs in the arteries, the pulse repetition frequency can gradually be adapted to higher velocities. The baseline can also be shifted to avoid aliasing in the arteries (Fig. 2.15) because the velocity in the veins in the opposite direction is slow.

The gain of the Doppler signals should be high so that single colour pixels are seen in the tissue, especially if thrombosis is suspected. If no colour-coded signals are seen in a vessel, the angle and adjustment, particularly of the pulse repetition frequency, should be checked. If they are correct, spectral Doppler should also be used to obtain a definite diagnosis.

WHO. "Manual of Diagnostic Ultrasound, Second Edition." WHO, 2011.

Fig. 2.15. Aliasing. (a) The spectral Doppler depiction (duplex technique) of the flow in the aorta shows aliasing. The peak velocity signals, 80–120 cm/s, are shown below the baseline (arrow). (b) Correct depiction as a result of shifting the baseline (arrow)



In an artery, the colour Doppler technique will yield high systolic flow and give a good signal. In diastole, however, the flow may become very slow or even reverse (high-resistance flow), resulting in a weak signal and an unsatisfactory image of the vessel. With persistence, it is possible to extend the peak flow to get a better colour Doppler image (Fig. 2.16).

B-scan provides information about the anatomy of vessels, including diagnoses of dilatation, aneurysms and alterations of the wall and stenosis. Thrombosis in a vessel can also be demonstrated.

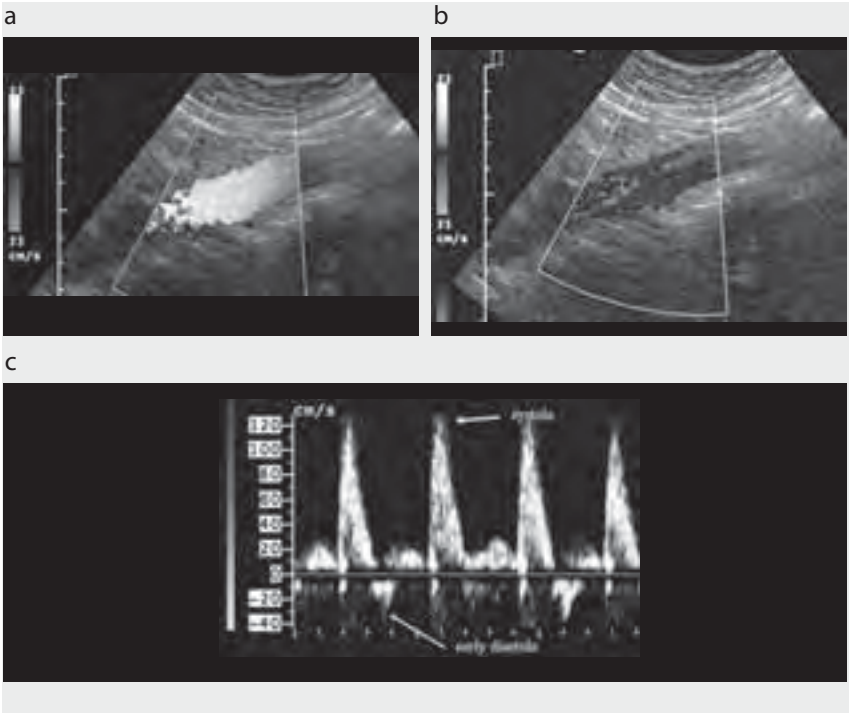
The colour Doppler technique permits detection of small vessels and gives information about flow and direction. Power Doppler is more sensitive for examining small vessels and slow flow but does not provide information about the direction of flow. In particular, it is used to estimate the vascularity of a structure or a mass.

Estimation of flow velocity from the brightness of colour pixels is rather approximate. Even turbulent flow, caused by stenosis, is not reliable.

Use of spectral Doppler (triplex technique) is needed for a more accurate analysis of the flow, e.g. direction, velocity and dynamic course. A condition required for an exact analysis is a Doppler angle of < 60° (best, ~30°), which may be difficult to achieve in the abdomen. Each measurement should be made a least three times, and the average finding should be used. Attention should be paid to specific conditions, such as a change in flow, which depend on the activity of the region or tissues it supplies.

WHO. "Manual of Diagnostic Ultrasound, Second Edition." WHO, 2011.

Fig. 2.16. Colour Doppler and spectral Doppler of the abdominal aorta. (a) The colour Doppler image shows red (here bright) signals, because it is made in systole, whereas the image in (b) shows blue signals (here dark), indicating reverse flow in early diastole. Both phases are indicated in the spectral Doppler (c)



WHO. "Manual of Diagnostic Ultrasound, Second Edition." WHO, 2011.

2. Diagrams and Schematics of Medical Ultrasound

Featured in this Section:

Bruce Blaus. "Fetal Ultrasound." *Wikipedia Commons*, November 9, 2015. Retrieved from: https://commons.wikimedia.org/wiki/File:Fetal_Ultrasound.png

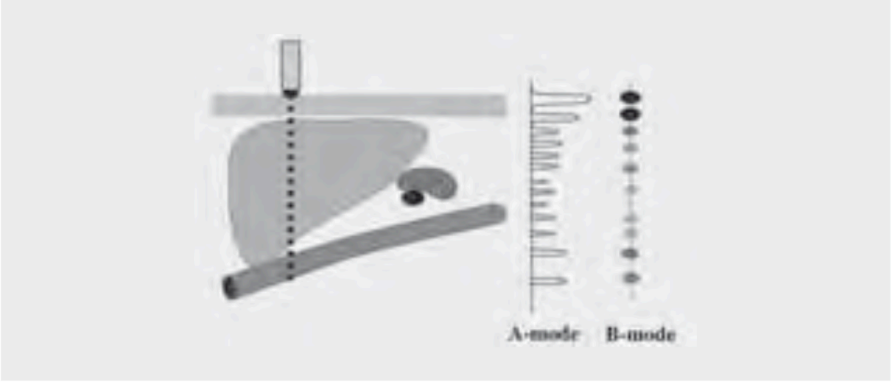
WHO. "Manual of Diagnostic Ultrasound, Second Edition." *WHO*, 2011. Retrieved from: http://apps.who.int/medicinedocs/documents/s21383en/s21383en.pdf

Figure 1: B-Mode Ultrasound

B-mode

B-mode (brightness modulation) is a similar technique, but the echoes are displayed as points of different grey-scale brightness corresponding to the intensity (amplitude) of each signal (Fig. 1.12).

Fig. 1.12. A-mode and one-dimensional B-mode. The peak heights in A-mode and the intensity of the spots in B-mode are proportional to the strength of the echo at the relevant distance



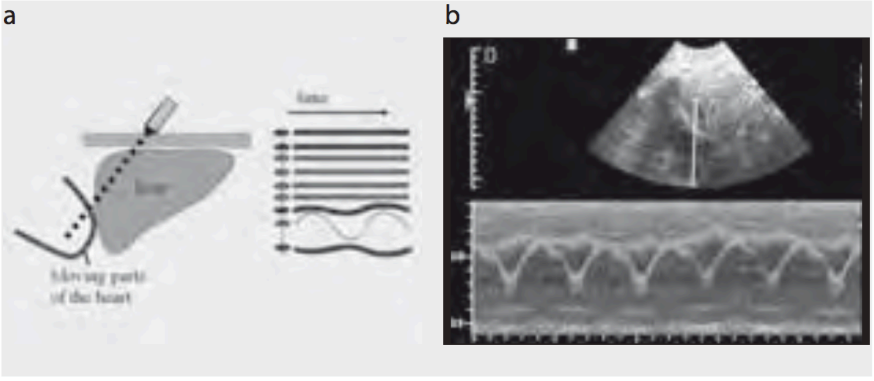
WHO. "Manual of Diagnostic Ultrasound, Second Edition." WHO, 2011, p. 12.

Figure 2: M or TM-Mode Ultrasound

M-mode or TM-mode

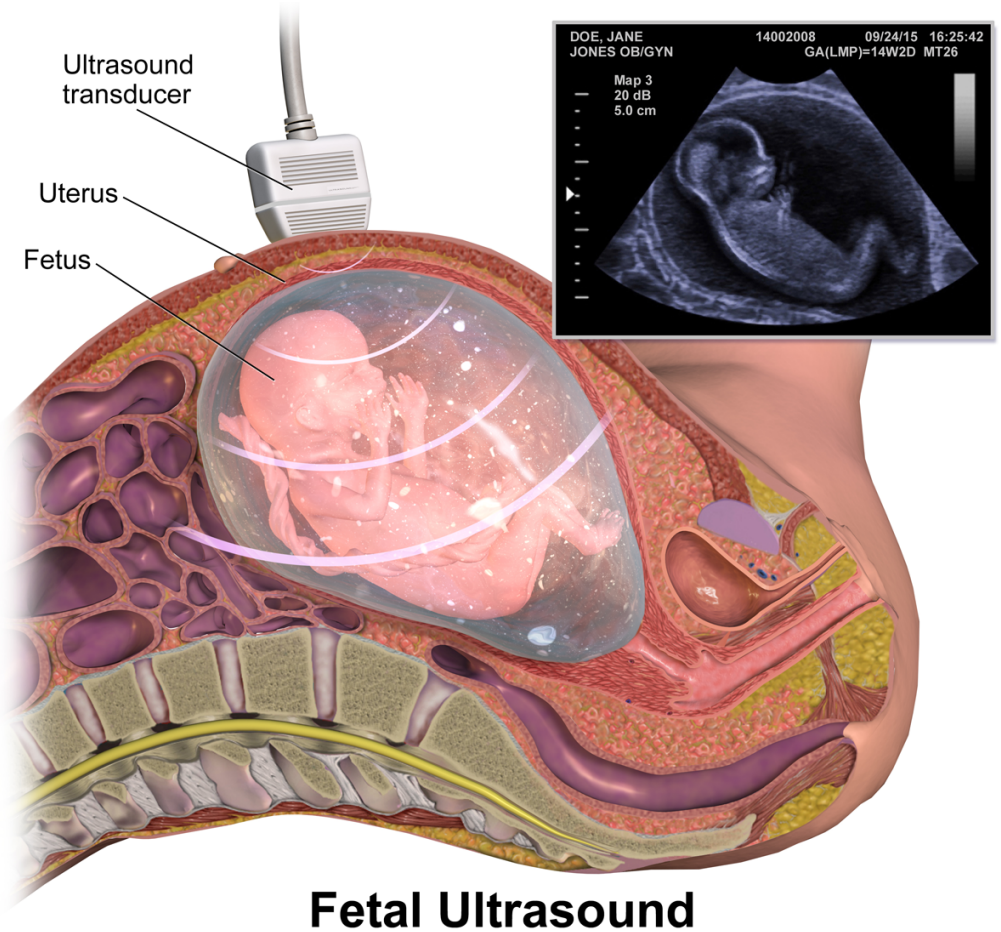
M-mode or TM-mode (time motion) is used to analyse moving structures, such as heart valves. The echoes generated by a stationary transducer (one-dimensional B-mode) are recorded continuously over time (Fig. 1.13).

Fig. 1.13. TM-mode. (a) The echoes generated by a stationary transducer when plotted over time form lines from stationary structures or curves from moving parts. (b) Original TM-mode image (lower image) corresponding to the marked region in the B-scan in the upper image (liver and parts of the heart)



WHO. "Manual of Diagnostic Ultrasound, Second Edition." WHO, 2013. p. 12.

Figure 3: Fetal Ultrasound



Fetal Ultrasound

Bruce Blaus. "Fetal Ultrasound." Wikipedia Commons, November 9, 2015. Retrieved from: https://commons.wikimedia.org/wiki/File:Fetal_Ultrasound.png

3. Preventative Maintenance of Medical Ultrasound

Featured in this Section:

Cooper, Justin and Alex Dahinten for EWH. “Ultrasound Preventative Maintenance.” From the publication: *Medical Equipment Troubleshooting Flowchart Handbook*. Durham, NC: Engineering World Health, 2013.

Strengthening Specialised Clinical Services in the Pacific. *User Care of Medical Equipment: A first line maintenance guide for end users*. (2015).

Ultrasound Preventative Maintenance

Preventive Maintenance

- After every use, clean the probe and cable with a damp cloth to ensure that it
- is free of gel.
- Replace the internal battery to protect internal memory if necessary
    - when replacing
- read the manual to tell you what to do
- Clean the controls by wiping them with a damp cloth or tissue after every
- working day.
- Change the dust filter every 3 to 6 months.
- Ultrasound Proper Usage
    - Ensure proper mains voltage range.
    - When changing the dust filter, if the original filter paper cannot be found, a
- piece of double gauze may be used.
    - Ensure there is no air between the probe and the patient by having enough
- ultrasonic gel to ensure a quality image.
    - Do not soak the cable with gel.
    - Do not turn off and on the machine quickly. Leave two minutes between each
- to retain internal memory of the device. Also, leave the machine running for
- at least 15 minutes every time.
    - To adjust the greyscale during a session, use dynamic controls on the
- machine not those controls on the monitor. Otherwise use the grey wedge on
- the monitor.
    - The ultrasound may freeze if the information is typed in too quickly. If the
- machine freezes, turn the machine off and wait two minutes before
- restarting.
    - Do not spill liquids on the machine.
    - Do not hang anything for the controls of the machine.
- 10.If the mains voltage varies more than the tolerance of the machine specified
- by the manufacturer (usually around + 10%), a voltage stabilizer is required.
- 11.Ventilation holes of the ultrasound must not be covered by papers, forms, or
- tissue
- 12.When troubleshooting the electronics of the device, start replacing fuses if
- necessary and checking the highly stressed circuit that powers the pulse
- generator.

Cooper, Justin and Alex Dahinten for EWH. "Ultrasound Preventative Maintenance." From the publication: Medical Equipment Troubleshooting Flowchart Handbook. Durham, NC: Engineering World Health, 2013.

Ultrasound Preventative Maintenance Checklist

User Care of Medical Equipment – First line maintenance for end users

User Care Checklist – Ultrasound machines

Daily	
Cleaning	✓ Wipe dust off exterior and cover equipment after checks ✓ Remove any tape, paper or foreign body from equipment ✓ Wipe probe with alcohol-free tissue or cloth
Visual checks	✓ Check all fittings and accessories are mounted correctly ✓ Check cables are not twisted and probe is safely stored
Function checks	✓ If in use that day, run a brief function check before clinic

Weekly	
Cleaning	✓ Unplug, clean outside / wheels / rear with damp cloth, dry off ✓ Remove, clean and dry external filter if present
Visual checks	✓ Check mains plug screws are tight ✓ Check mains cable has no bare wire and is not damaged
Function checks	✓ If machine has not been in use, run and test briefly

Every six months
Biomedical Technician check required

4. Troubleshooting and Repair of Medical Ultrasound

Featured in this Section:

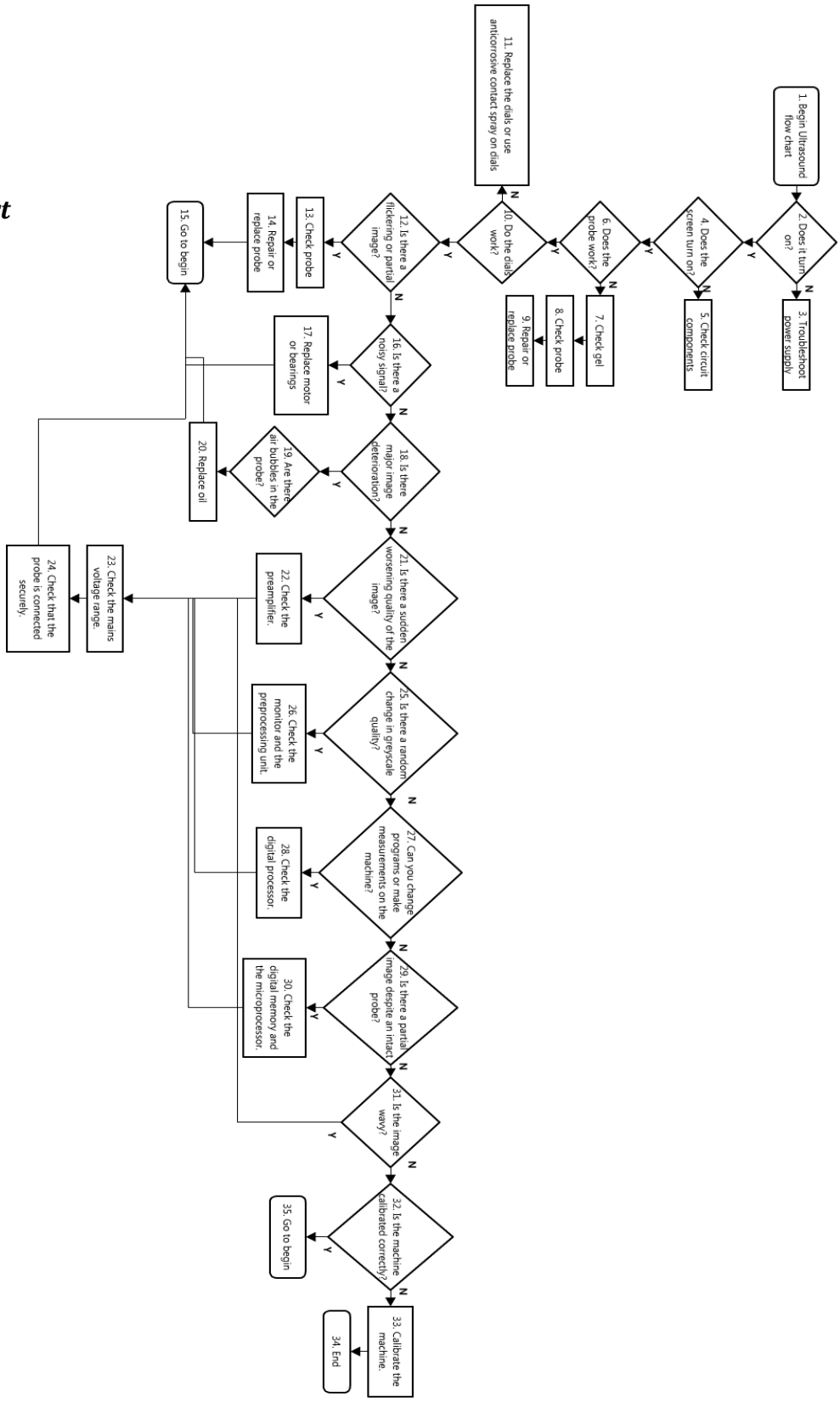
Cooper, Justin and Alex Dahinten for EWH. “Ultrasound Troubleshooting Flowchart.” From the publication: *Medical Equipment Troubleshooting Flowchart Handbook*. Durham, NC: Engineering World Health, 2013.

Strengthening Specialised Clinical Services in the Pacific. *User Care of Medical Equipment: A first line maintenance guide for end users*. (2015).

Ultrasound Troubleshooting Flowchart

Ultrasound Repair and Troubleshooting

Flowchart



Cooper, Justin and Alex Dahinten for EWH. "Ultrasound Troubleshooting Flowchart." From the publication: Medical Equipment Troubleshooting Flowchart Handbook. Durham, NC: Engineering World Health, 2013.

Description

1. Begin Ultrasound Flow Chart	Begin Ultrasound Flow Chart
2. Does it turn on?	Does it turn on?
3. Troubleshoot Power Supply	See power supply flowchart
4. Does the screen turn on?	Does the screen turn on?
5. Check circuit components	Troubleshoot the circuit (see troubleshooting guide)
6. Does the probe work?	Does the machine show an image?
7. Check gel.	Is there enough of the proper gel.
8. Check probe.	Ensure that the probe is properly connected and undamaged.
9. Repair or replace probe.	Solder the broken connections or replace the probe.
10. Do the dials work?	Do the dials properly control the machine?
11. Replace dials or use anticorrosive contact spray on dials.	Replace or use anticorrosive contact spray on dials.
12. Is there a flickery or partial image	Does the image on the screen have missing sections? Does the screen flicker?
13. Check probe.	Gently pull on the cable at different points to see when the image flickers. This is where the cable is broken. For composite probes wave a pencil across the transducer. If not seen, this is where the transducer is not

	connected.
14. Repair or replace probe.	Solder the broken connections or replace the probe.
15. Go to begin.	Go to begin.
16. Is there a noisy signal?	Is there distortion in the produced image?
17. Replace motor or bearings	Replace the motor or bearings if they are broken or damaged.
18. Is there major image deterioration?	Is the image severely deteriorated?
19. Are there air bubbles in the probe?	Does the oil in the probe have air bubbles in it?
20. Replace oil.	Replace oil.
21. Is there a sudden worsening quality of the image?	Does the image have sudden changes in quality?
22. Check the preamplifier.	Check the preamplifier.
23. Check the mains voltage range.	Check the outlet voltage range.
24. Check that the probe is connected securely.	Check that the probe is connected securely.
25. Is there a random change in greyscale quality?	Is there a random change in greyscale quality?
26. Check the monitor and the preprocessing unit.	Check the monitor and the preprocessing unit.
27. Can you change programs or make measurements on the machine?	Can you change programs or make measurements on the machine?

28. Check the digital processor.	Check the digital processor.
29. Is there a partial image despite an intact probe?	Is there a partial image despite an intact probe?
30. Check the digital memory and the microprocessor.	Check the digital memory and the microprocessor.
31. Is the image wavy?	Is the image wavy?
32. Is the machine calibrated correctly?	Is the machine calibrated correctly?
33. Go to begin.	Got to begin.
34. Calibrate the machine.	Calibrate the machine.
35. End	End

Ultrasound Troubleshooting Table

Troubleshooting – Ultrasound Machines

	Fault	Possible Cause	Solution
1.	Equipment is not running	No power from mains socket	Check power switch is on. Replace fuse with correct voltage and current if blown. Check mains power is present at socket using equipment known to be working. Contact electrician for rewiring if power not present.
		Electrical cable fault	Try cable on another piece of equipment. Contact electrician for repair if required.
2.	Fuse keeps blowing	Power supply or cable fault	Refer to electrician
3.	Probe head damaged or noisy	Possible internal fault	Exchange probe Send for testing and repair
4.	Image quality poor	Gel insufficient	Use more ultrasound gel
		Controls set incorrectly	Check controls for correct positioning and operation (refer to user manual)
		Mains voltage is too low	Use voltage stabiliser
		Probe / display problem	Refer to biomedical technician
5.	Display / computer error	Software fault	Turn machine off and restart. If problem persists, refer to biomedical technician
6.	Electrical shocks	Wiring fault	Refer to electrician

5. Resources for More Information about Medical Ultrasound

Featured in this Section:

WHO. "Manual of Diagnostic Ultrasound, Second Edition." *WHO*, 2011. Retrieved from: http://apps.who.int/medicinedocs/documents/s21383en/s21383en.pdf

WHO. "Manual of Diagnostic Ultrasound, Volume 2." *WHO*, 2013. Retrieved from: http://apps.who.int/medicinedocs/en/m/abstract/Js21384en/

WHO. "Ultrasound Equipment: Basic Principles." *Maintenance and Repair of Laboratory, Diagnostic Imaging, and Hospital Equipment* (WHO: 1996).

Resources for More Information:

Internal Resources at library.ewh.org: For more information about medical ultrasound, please see this resource in the BMET Library!

1. WHO. "Ultrasound Equipment: Basic Principles." *Maintenance and Repair of Laboratory, Diagnostic Imaging, and Hospital Equipment* (WHO: 1996).

External Resources:

2. This 2-part WHO manual covers the basic types of ultrasound equipment, operation and use of ultrasound, and applications of ultrasound. Volume 1 discusses the basics of ultrasound and topics such as ultrasound use on the neck, abdomen, and kidneys. Volume 2 covers the use of ultrasound in obstetrics and gynecology.

    a. **Volume 1:** WHO. "Manual of Diagnostic Ultrasound, Volume 1." *WHO*, 2011. Retrieved from: http://apps.who.int/medicinedocs/documents/s21383en/s21383en.pdf

    b. **Volume 2:** WHO. "Manual of Diagnostic Ultrasound, Volume 2." *WHO*, 2013. Retrieved from: http://apps.who.int/medicinedocs/en/m/abstract/Js21384en/

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Cooper, Justin and Alex Dahinten for EWH. "Ultrasound Repair and Troubleshooting." From the publication: *Medical Equipment Troubleshooting Flowchart Handbook*. Durham, NC: Engineering World Health, 2013.

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Wikipedia. " Medical Ultrasound." *Wikipedia*, pgs 1-15. Retrieved from: https://en.wikipedia.org/wiki/Medical_ultrasound