Sonography

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In this chapter, you will learn how ultrasound waves are generated for use in sonography and how sonographic examinations can be technically controlled.

In addition, you will learn about the areas of application, possibilities and limitations of this procedure and in which cases it can be used as a radiation-free alternative examination in imaging diagnostics.

8.1 Physical Basics of Sonography

8.1.1 Ultrasonic Waves

Sonography uses ultrasound waves to produce cross-sectional images of the human body.

> Ultrasound is the term used to describe sound waves with frequencies above the range of human hearing.

The ultrasonic waves in sonography devices are generated via the so-called **reciprocal piezoelectric effect** on a quartz crystal. The solid body serves as the transmitter and receiver of the sound waves. The piezoelectric effect is created by the contraction and elongation—i.e. compression and expansion—of the crystal (Fig. 8.1a). An applied external electrical voltage causes the vibrations, i.e. the sound waves, to be emitted (= **sound wave emission**).

If the sound waves encounter an impedance jump (wave resistance) on their way, e.g. at the boundary between fatty tissue and water, they are reflected and received as an echo or resonance on the quartz crystal. The resulting sound pressure deforms the crystal and the electrical charge is shifted. This piezo effect (Fig. 8.1b) produces a measurable electrical voltage which is recorded by the connected electronics and displayed as an image.

Ultrasound waves are harmless to the human body. Only a slight increase in body temperature is conceivable during an intensive examination.

The speed of propagation of the sound waves depends on the medium through which they pass and its elasticity and molecular density (Table 8.1).

The ultrasound image is created by waves that are reflected, scattered and refracted at tissue junctions. This effect is caused by impedance jumps, e.g. at organ boundaries or vessel walls. Impedance (z) stands for the transition resistance, which is a product of the speed of sound (c) in the medium and the density (ρ) of the medium:

$$z = c \times \rho$$

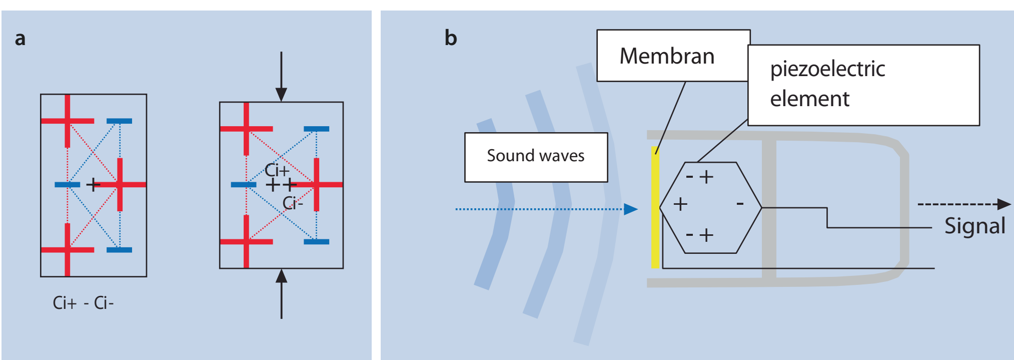


Fig. 8.1 In the resting state, the centers of the positive and negative charges lie on top of each other, the charges neutralize each other. When the crystal is compressed, the centers of the charges shift towards each other, a measurable electric voltage is produced **a**. Piezoelectric effect **b**. (From Hartmann et al. 2014)

Table 8.1 Speed of ultrasound waves as a function of the medium

Air	340 m/s
Water/grease	1450 m/s
Soft tissue	1540 m/s
Bones	2700–4100 m/s

No border crossings, no ultrasound!

What Happens to the Ultrasound Waves in the Body?

1. **Absorption**
   A large part of the ultrasound waves is absorbed, i.e. completely absorbed into a medium (lat. absorptio = absorption).

   The absorption increases exponentially with increasing image depth and increases linearly with the applied frequency.

   The absorbed energy is converted into heat. Therefore, there are different transducers that emit different frequencies. Typically, frequencies of 3.5 MHz are used for abdominal imaging; for superficial structures, high-frequency transducers of up to 20 MHz can be used, which can produce an image extending only a few cm into the depth (Table 8.2).
2. **Reflection and Scattering**
   If the boundary surfaces are considerably larger than the wavelength, reflection occurs.

   Reflection means that the angle of incidence and the angle of reflection are equal.

   The sound waves are therefore reflected back, like the billiard balls on the rail. With small structures, the sound waves are increasingly scattered. Scattering is non-directional, comparable to sugar falling on the kitchen table.

Table 8.2 Frequency-dependent penetration depth of sound waves into tissue

Frequency	Resolution axial/lateral	Depth of field
3.5	1 mm/2 mm	160 mm
5	0.6 mm/1.2 mm	100 mm
7.5	0.4 mm/0.8 mm	50 mm

3. **Refraction (Refraction)**
   Refraction **deflects ultra**sound waves as they enter another medium. The effect is amplified by a more acute angle and by a higher resistance between the two media. The same effect refracts sunlight in rain and creates the rainbow.
4. **Diffraction (Diffraction)**

   Diffraction describes the deflection of waves at an obstacle, which leads to the creation of new waves at the obstacle and their interference (superposition).

8.1.2 Procedure

A-Mode

The A-mode is the oldest method. "A" stands for amplitude modulation. Today, the method is still used for distance determination in ENT, ophthalmology and neurology. In the early days, before the development of computer tomography, this method could be used, for example, to detect a midline shift in a brain tumor.

M-Mode

The M-mode (from "motion") can be used to map the temporal behavior of a tissue. It is used in particular in cardiology (Fig. 8.2). A typical example is the imaging of the movement of a heart valve or the myocardium.

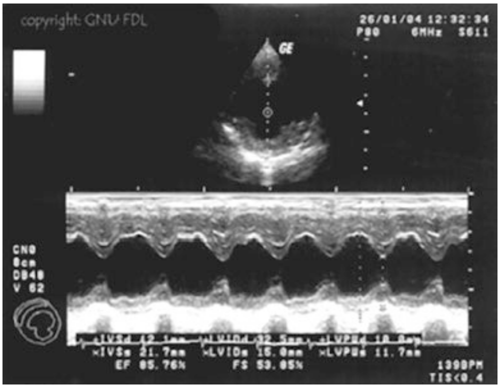


Fig. 8.2 Examination of a heart valve. (From Hartmann et al. 2014)

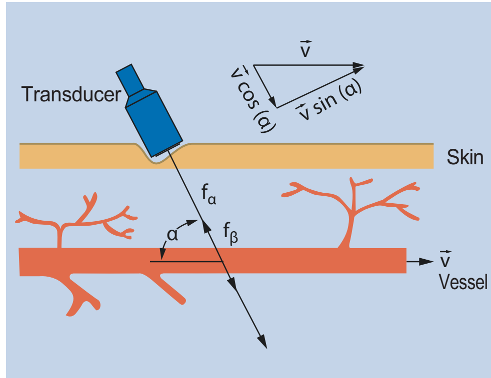


Fig. 8.3 Angular ratios in the determination of the Doppler shift. (From Hartmann et al. 2014)

B-Mode

The B-mode (for "brightness") is the most frequently used method. In the 2D image, the different pixels are detected with different brightness grey dots, depending on the strength of the reflected signal.

A further development of the method is 3D ultrasound, which generates spatial still images. For this purpose, in addition to the scan in one plane, the angle of the sound is swiveled in order to obtain image information in the 3rd plane. If not only a still image is generated, but the examination is performed in real time, a 4D ultrasound is created with time as the 4th dimension.

Sonography Doppler

In 1842, the physicist Christian Johann Doppler described the **Doppler effect** named after him. When the sound source and reflector move towards each other, the sound waves are bundled and reach the receiver at a higher frequency. You already know the principle: you can hear whether the sirens of an ambulance are coming towards you or moving away! This effect is used for Doppler sonography.

The effect is strongly angle-dependent (Fig. 8.3). If the angle between the sound source and the reflector is 90°, no signal can be obtained. The smaller the angle between sound source and reflector, the smaller the error!

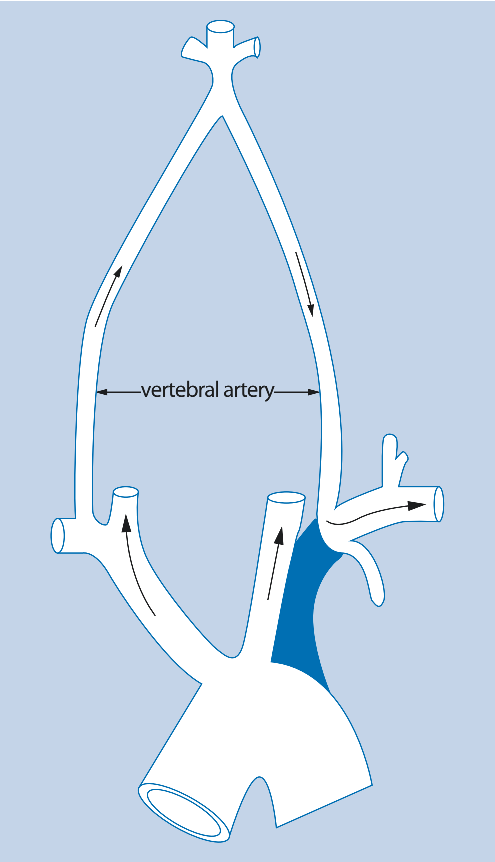
Doppler sonography is used to determine flow velocities. From these, stenoses of vessels can be quantified. The classic field of application is the examination of the carotid arteries.

Sonography Color Doppler and Power Doppler

Color Doppler (synonyms: color-coded Doppler sonography; color-coded duplex sonography; FKDS) is a further development of Doppler sonography. The image is color-coded with the measured flow velocities and flow directions. The following applies by definition:

> Blood flow toward the transducer is coded red; blood flowing away from the transducer is coded blue. Faster blood flow is shown lighter than slower flow. In the image on the right, a corresponding coding is shown with an indication of the measured flow velocity.

For example, it is important to detect the direction of flow in subclavian-steel syndrome, in which flow reversal of the associated vertebral artery occurs due to stenosis of the subclavian artery (Fig. 8.4). Clinically, affected patients usually have dizziness, especially during physical exertion and strain of the corresponding arm.



■ **Fig. 8.4** Flow reversal in subclavian steal syndrome. (From Hartmann et al. 2014)

Power Doppler is an amplitude-coded Doppler method. In contrast to FKDS, it does not detect flow velocities, but the quantity of moving particles. The power Doppler can therefore also detect much slower flows.

The use of ultrasound contrast agents can enhance the visualization of blood flow. The field of application of contrast-enhanced sonography is primarily the dignity assessment of space-occupying lesions, in particular of the liver, or during cardiac ultrasound for the detection of an open foramen ovale, i.e. a pathological connection between the right and left atrium.

8.2 Design and Operation of a Sonography Device

A modern ultrasound scanner (■ Fig. 8.5) consists of the following components:

- Control computer
- Monitor
- Keyboard
- Transducers
- Printer or connection to the PACS for image documentation

The most important elements are the various transducers, which are sensitive and should therefore not be dropped or handled with aggressive cleaning agents. Depending on the device class, the prices for such transducers can correspond to a small car. Therefore, in case of doubt, it is also worth taking a look at the operating instructions.

■ **Fig. 8.5** Ultrasound device. (From Hartmann et al. 2014)

Fig. 8.6 Transducer variants. (From Hartmann et al. 2014)

Fig. 8.7 Reverberation

8.2.1 Transducers

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The transducers (Fig. 8.6) are subdivided according to the propagation of the sound waves into

- **Linear transducers**: The sound waves propagate in parallel, which has the advantage of geometrically accurate imaging.
- **Convex transducers** (curved array): The sound waves spread out like a fan. A larger area can be imaged.
- **Sector transducers**: The sound wave propagation is fan-shaped and radial. Typical application is cardiac ultrasound with a transcostal access path between the ribs.

Sonography Pocket Doppler

A special form is the so-called pocket Doppler, in which the ultrasound probe looks like a thick pen. It is mainly used in vascular diagnostics to measure occlusion pressure. Here, for example, the blood flow over the dorsalis pedis artery is derived from the foot and at the same time a blood pressure cuff is inflated on the lower leg. As soon as the sound of pulsating blood disappears, the blood pressure cuff is slowly released again. The blood pressure reading at which the sound reappears is the occlusion pressure. The value is lowered in the event of stenosis or occlusion of the leg arteries.

Good coupling between the transducer and the skin is important for ultrasound examinations. An insufficient coupling leads to artefacts, the so-called reverberations and an insufficient image quality. For this reason, ultrasound gel is applied to the transducer and also the patient's skin, which improves the connection between the transducer and the skin.

By the way: Reverberations (Fig. 8.7) also occur with intestinal air or with pathological air accumulations intraabdominal.

If the ultrasound is used in a sterile environment, e.g. during an operation, gel must also be filled into the sterile cover used for the transducer (in the case of pocket Doppler, sometimes also a sterile glove). In these cases, the sterile tube is coupled to the patient using saline solution or skin disinfectant spray, for example.

For **endosonography,** there are other special transducers that are designed for the corresponding application. These include endosonography of the pancreas, the heart, the prostate and the internal female genitals.

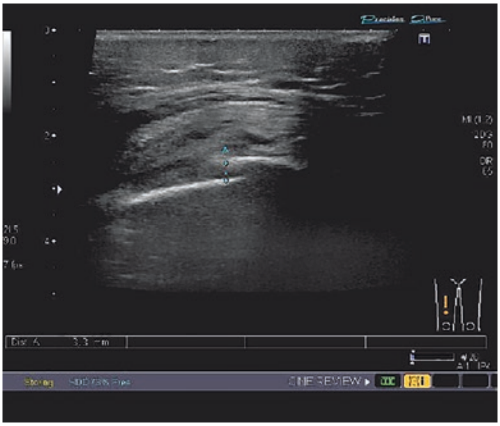
8.2.2 Where to Press…

Each sonography device is designed slightly differently depending on the manufacturer. Nevertheless, we would like to introduce you to the most important operating elements, which are actually always present:

- Before starting the examination: Enter the **patient's name**, usually on the top right of the keyboard, often marked with "ID". In radiology, the devices are usually linked to the RIS, so in these cases you select the patient's name from a work list.
- The selection keys for the **various organ programs are** usually located in the upper row of the keyboard and are marked **"Preset"**.
- If multiple transducers are available, they can be changed by pressing a button, often labeled **"Probe"**.
- A button shows the **outline of a body**. This displays the so-called **body marker** in the image, which is used to document the section plane in the image.
- The often somewhat larger **"Freeze"** or **"FRZ"** button (usually on the bottom right of the device) is used to freeze the image for saving.
- In the lower part of the keyboard there is usually a knob labeled **"Gain"** or **"Depth"** which is used to adjust the overall gain.
- The **depth compensation** has a similar function, but it controls the gain for the different image depths separately. The depth control is a slider that is placed in several rows, usually in the upper right corner.
- Often the **focus** can be shifted with a **toggle switch.** This achieves an optimal image at a certain depth.
- The **trackball is** used to move markers or measuring points. You can find these via buttons, which are usually marked with crosses or dots.
- Devices with color duplex function have a (rotary) knob, usually marked with colored dots, or a **"Color"** or **"CDI"** button, which can be used to set the color duplex or to amplify it by rotation.
- The **power mode** is often marked with **"PW"** and is also designed as a rotary knob.
- New and especially larger devices often also have a **touchscreen** for operation.

8.3 Possibilities and Limits of Ultrasound Diagnostics

Ultrasound diagnostics is the primary diagnostic imaging method for abdominal complaints, vascular diseases and for diagnosing cardiac function. Exceptions are highly acute diseases, e.g. polytrauma patients. In these cases, a computer tomography can provide an accurate diagnosis in a very short time, while sonographic clarification requires sufficient time, depending on the experience of the examiner. For an ultrasound diagnosis of the entire abdomen without significant peculiarities, even the experienced examiner needs 10–15 min. In principle, one can examine almost everything with ultrasound, especially when it comes to children. Thus, fractures can also be detected with sonography (◘ Fig. 8.8).



◘ **Fig. 8.8** Fracture in the child on sonography

However, the result is more dependent on what the examiner sees and documents as an image than with any other procedure.

Practice Questions

1. What is the piezoelectric effect?
2. Please briefly explain the meaning of A-, M- and B-mode.
3. What is the meaning of the red and blue coding in color Doppler or a lighter or darker display?
4. What is the pocket Doppler and where is it used?
5. In which clinical situations is sonography mainly used?

Solutions ► Chap. 27