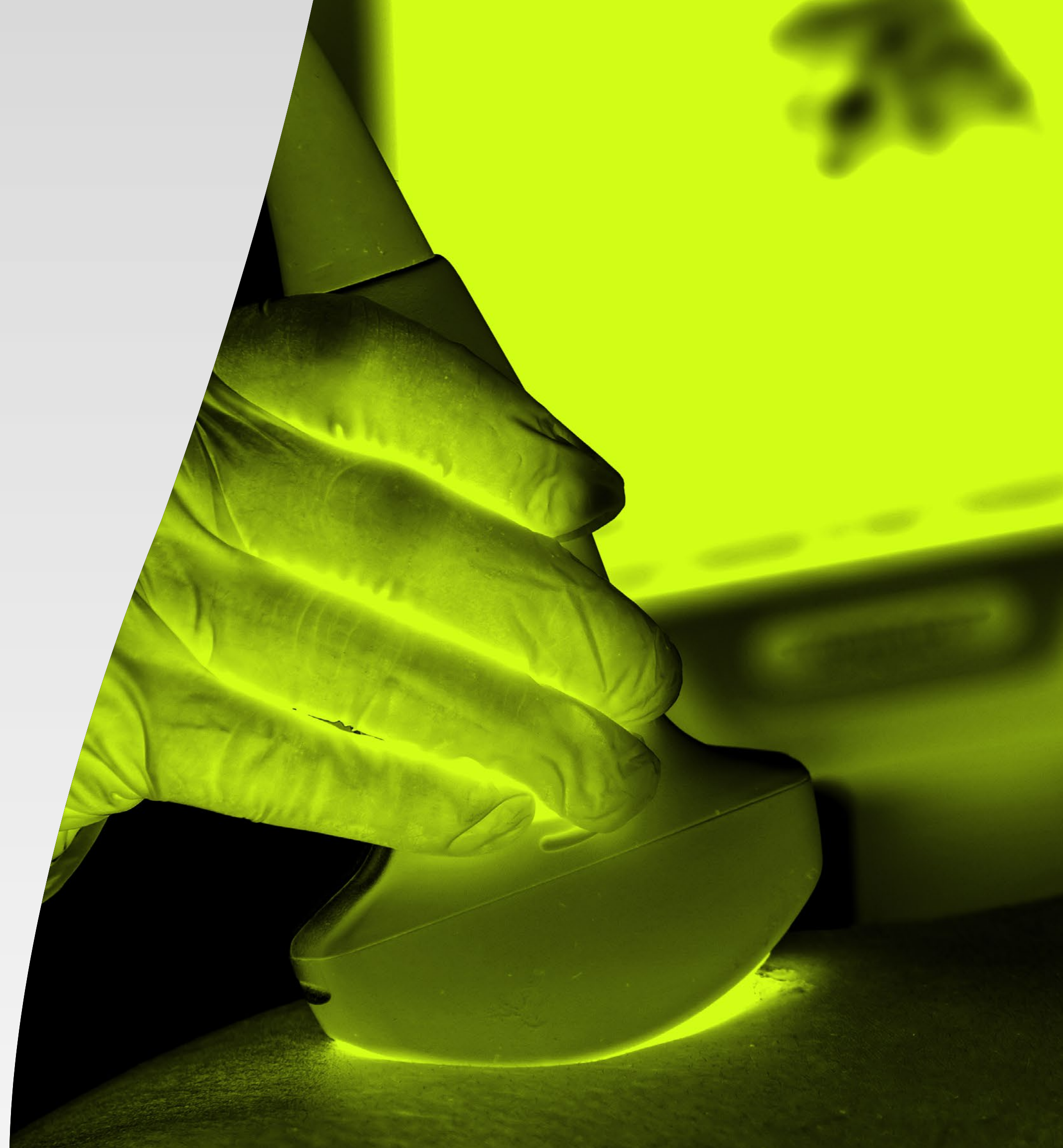
MODERN RADIOLOGY
eBook

Ultra-sound

ESR EUROPEAN SOCIETY OF RADIOLOGY



Preface

Modern Radiology is a free educational resource for radiology published online by the European Society of Radiology (ESR). The title of this second, rebranded version reflects the novel didactic concept of the *ESR eBook* with its unique blend of text, images, and schematics in the form of succinct pages, supplemented by clinical imaging cases, Q&A sections and hyperlinks allowing to switch quickly between the different sections of organ-based and more technical chapters, summaries and references.

Its chapters are based on the contributions of over 100 recognised European experts, referring to both general technical and organ-based clinical imaging topics. The new graphical look showing Asklepios with fashionable glasses, symbolises the combination of classical medical teaching with contemporary style education.

Although the initial version of the *ESR eBook* was created to provide basic knowledge for medical students and teachers of undergraduate courses, it has gradually expanded its scope to include more advanced knowledge for readers who wish to 'dig deeper'. As a result, *Modern Radiology* covers also topics of the postgraduate levels of the *European Training Curriculum for Radiology*, thus addressing postgraduate educational needs of residents. In addition, it reflects feedback from medical professionals worldwide who wish to update their knowledge in specific areas of medical imaging and who have already appreciated the depth and clarity of the *ESR eBook* across the basic and more advanced educational levels.

I would like to express my heartfelt thanks to all authors who contributed their time and expertise to this voluntary, non-profit endeavour as well as Carlo Catalano, Andrea Laghi and András Palkó, who had the initial idea to create an *ESR eBook*, and - finally - to the ESR Office for their technical and administrative support.

Modern Radiology embodies a collaborative spirit and unwavering commitment to this fascinating medical discipline which is indispensable for modern patient care. I hope that this *educational* tool may encourage curiosity and critical thinking, contributing to the appreciation of the art and science of radiology across Europe and beyond.

Minerva Becker, Editor
Professor of Radiology, University of Geneva, Switzerland

Ultrasound

CHAPTER OUTLINE:

Copyright and Terms of Use

How to cite this work:

European Society of Radiology,
Jonathan Cohen, Caroline Ewertsen (2024)
ESR Modern Radiology eBook:

- **Ultrasound.**
  DOI 10.26044/esr-modern-radiology-03

/ Signage

CORE KNOWLEDGE

FURTHER KNOWLEDGE

ATTENTION

COMPARE

QUESTIONS

HYPERLINKS

REFERENCES

CHAPTER OUTLINE:

MODERN RADIOLOGY eBook

Based on the ESR Curriculum for Radiological Education

Ultra-sound

CHAPTER OUTLINE:

AUTHORS

Jonathan Cohen | Caroline Ewertsen

AFFILIATION

Department of Radiology, Copenhagen University Hospital (Rigshospitalet), Copenhagen, Denmark

<↑> HYPERLINK

mailjonathancohen@gmail.com

caroline.ewertsen@dadlnet.dk

Chapter Outline

Ultrasound Basics

- Physics

Signal to Image

- Equipment
- Enhancing the Image

Artefacts

- Acoustic Shadowing
- Enhancement
- Anisotropy

The Doppler Effect

- Basic Physics
- Use in Medical Ultrasound

Contrast-Enhanced Ultrasound

- Indications and Contraindications

Strengths and Limitations

Take-Home Messages

References

Test Your Knowledge

Ultrasound Basics

Ultra-sound

CHAPTER OUTLINE:

/ Ultrasound Basics

CHAPTER OUTLINE:

Sonography is a non-invasive painless procedure, which uses **ultrasound waves** to produce images of organs, blood vessels or soft tissues for medical analysis. The terms **sonography and ultrasound** are often used **interchangeably.** A sonogram is an image generated by ultrasound.

Ultrasound waves have frequencies higher than the upper limit of human hearing. In medical ultrasound, frequencies typically fall in the 1 to 20 MHz range, while the upper limit of human hearing is around 20 kHz.

The basic ultrasound principle (Fig. 1):

- An ultrasound transducer emits an ultrasound signal.
- The transducer listens for the echo generated by the structures that the wave encounters.
- The echo is turned into an image based on characteristics of the echo, such as timing, amplitude and frequency.

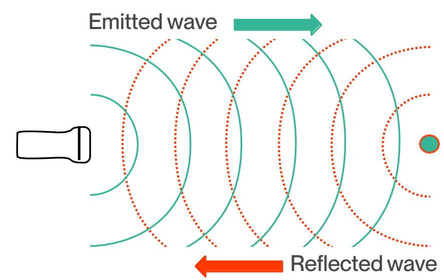


FIGURE 1

Schematic representation of the basic ultrasound (sonography or ultrasonography) principle

Ultrasound interacts with tissues in different ways:

- **Reflection** – waves are reflected back to the transducer.
- **Absorption** – waves are absorbed by the tissue and the energy is converted to heat.
- **Scattering** – waves are reflected in multiple different directions.
- **Refraction** – the direction of waves is changed.

FURTHER KNOWLEDGE

Each type of tissue has a particular **impedance – a resistance to the propagation of sound** which depends on the tissue density and the speed of sound in the tissue.

The amount of generated reflection depends on differences in impedance between tissues.

As an example, if the ultrasound wave travels from fat (low impedance) to bone (high impedance) a large difference in impedance is encountered, and a powerful echo will be generated.

CHAPTER OUTLINE:

Structures that elicit a powerful echo appear bright on our screen – we call them **hyperechoic** (Fig. 2).

Structures that elicit a weak echo appear dark on our screen – we call them **hypoechoic** (Fig. 3).

Structures that elicit an echo similar to their surrounding structures are called **isoechoic**.

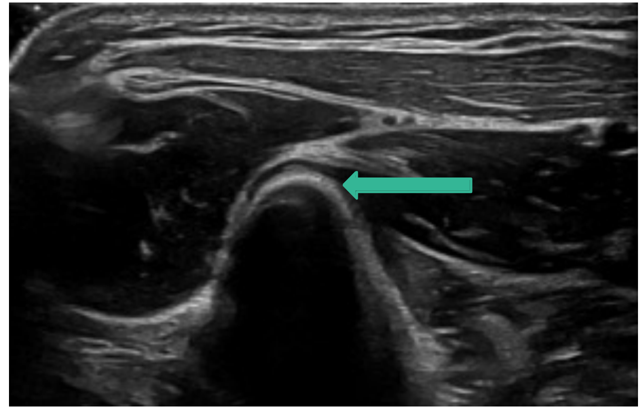


FIGURE 2

Cortical bone is strongly hyperechoic (**green arrow**) and casts an acoustic shadow (more on that later).

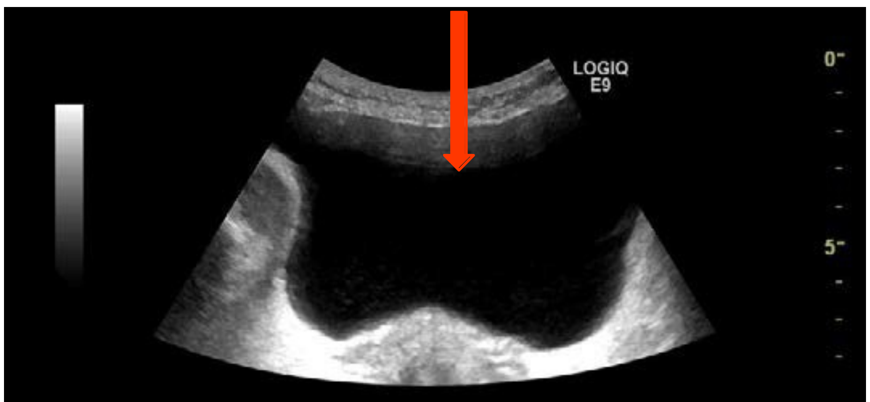


FIGURE 3

Urinary bladder filled with hypoechoic fluid (**red arrow**).

/ Ultra-sound

CHAPTER OUTLINE:

/ Signal to Image

/ Signal to Image

CHAPTER OUTLINE:

The ultrasound equipment generates an electrical signal (Fig. 4) which is sent through a cable to the **ultrasound transducer** (sometimes called an **ultrasound probe**). In the transducer, an array of **piezoelectric crystals** translate the signal to sound waves, which propagate from the probe outwards (Fig. 4). Piezoelectric crystals are crystals which have the ability to generate an electric charge when mechanical pressure is applied (e.g., quartz).

The same crystals convert the returning ultrasound echo into an electrical signal, which the ultrasound system then converts to an image.

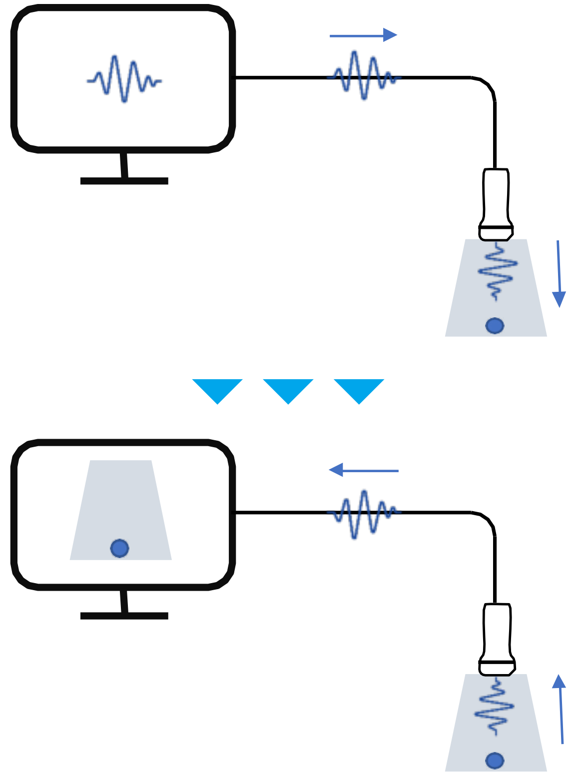


FIGURE 4

Schematic representation of the process by which an ultrasound image (sonogram or ultrasonogram) is generated.

Different ultrasound transducers (Fig. 5) have different strengths and limitations, and therefore different applications. Below is an overview of the most common transducer types and their typical applications.

Curved, 1-5 MHz

ADVANTAGES:

+ Good penetration, wide field of view.

DISADVANTAGES:

– Low resolution.

/ Abdominal, deep structures.

Linear, 3-12 MHz

ADVANTAGES:

+ High resolution.

DISADVANTAGES:

– Poor penetration.

/ Musculoskeletal, superficial structures, neck.

Phased array, 1-5 MHz

ADVANTAGES:

+ Wide field of view with small transducer surface.

DISADVANTAGES:

– Low resolution.

/ Echocardiography, intercostal views.

FIGURE 5

Advantages, disadvantages and main applications of different types of ultrasound transducers.

/ **Ultra-sound**

CHAPTER OUTLINE:

Modern ultrasound systems continually and automatically optimise the image while you scan.

Some parameters can be adjusted by the user to further optimise the image.

- **Gain:** high gain increases the overall brightness of the image, but also increases noise.
- **Frequency:** high frequency means better image quality, but poorer penetration. Most transducers have a set centre frequency, around which the frequency can be adjusted slightly.
- **Depth:** larger depth gives better overview, but details appear less visible.
- **Focus:** improves the appearance of the ultrasound image at the depth at which the focus is set.

/ Artefacts

/ Ultra-sound

CHAPTER OUTLINE:

/ Artefacts

CHAPTER OUTLINE:

Interactions between the ultrasound equipment and the body often cause **artefacts**. In ultrasound, some artefacts can be used to gain information about what you are scanning.

The following slides illustrate some of the most common artefacts encountered: **acoustic shadowing, enhancement** and **anisotropy**.

<!> ATTENTION

Knowledge of artefacts is imperative when performing ultrasound, as wrong interpretations of artefacts can lead to misdiagnosis!

Acoustic shadowing (Fig. 6) corresponds to low signal behind structures that strongly absorb or reflect ultrasound waves.

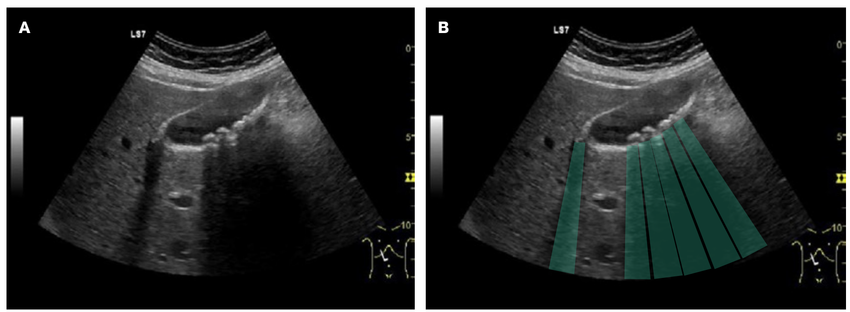


FIGURE 6

Gall bladder containing multiple gall stones which display acoustic shadowing (**A**). In image **B**, acoustic shadowing is rendered by green overlay.

Enhancement (Fig. 7) corresponds to increased signal below structures that transmit sound well (e.g., fluid).

>▪< FURTHER KNOWLEDGE

Ultrasound waves lose energy on their way through the body. Waves that are **reflected** from deeper structures lose more energy. To compensate for this, the ultrasound machine applies more **gain** to deeper echoes. If the deeper waves mainly travel through fluid, in which minimal energy is lost, the machine "overcompensates", and the resulting image appears "too bright".

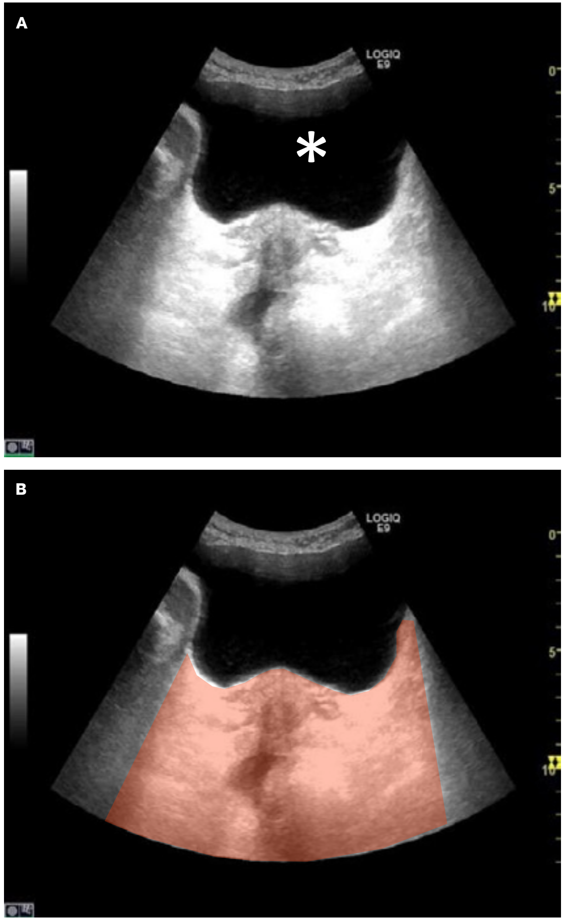


FIGURE 7

Enhancement artefact below the urinary bladder (**asterisk**) containing hypoechoic fluid (**A**). The enhancement artefact is rendered in red in **B**.

Anisotropy is an angle-generated artefact, which is mainly encountered in musculoskeletal ultrasound. Anisotropy refers to fibrillar structures such as a tendon or a ligament reflecting the ultrasound waves **away from the transducer.** (Fig. 8) The amount of echo is therefore reduced, and the structure seems hypoechoic.

>■< FURTHER KNOWLEDGE

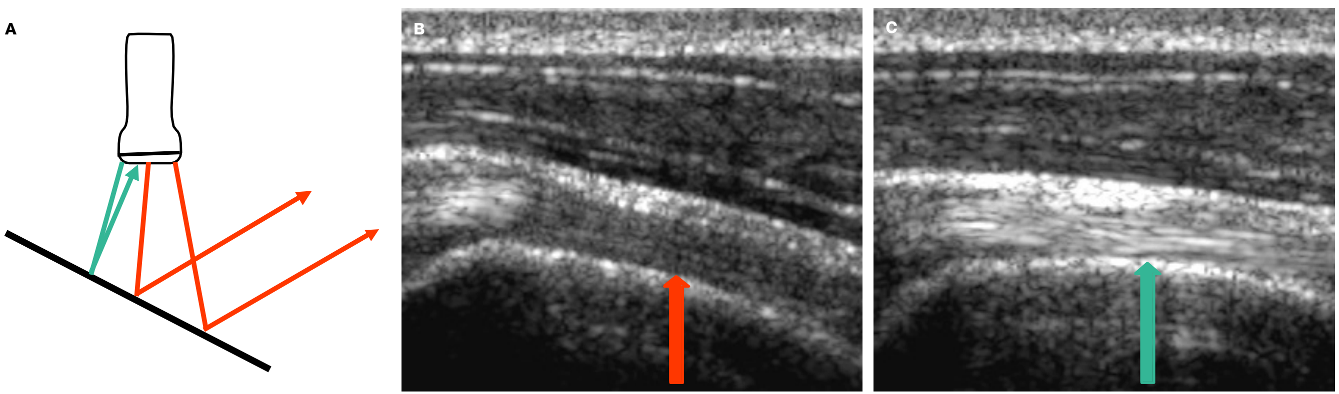
<!> ATTENTION

Anisotropy can lead to misinterpreting a tendon as hypoechoic and damaged, when it is in fact due to anisotropy. Anisotropy can be alleviated by changing the angle of the transducer relative to the subject.

CHAPTER OUTLINE:

FIGURE 8

A. Schematic drawing illustrating the formation of this angle-generated artefact. **B** and **C**. two pictures of the same tendon taken moments apart. Notice the change of echogenicity from hypoechoic (**A**) to hyperechoic (**B**). The only difference is the angle of the transducer relative to the tendon.



/ The Doppler Effect

CHAPTER OUTLINE:

/ The Doppler Effect

The Doppler effect is used extensively in ultrasound to detect and measure movement within the subject, especially blood flow within vessels.

The Doppler effect causes a **shift in the frequency of sound waves** when the emitting object is moving in relation to the observer (Fig. 9).

The perceived frequency of the sound **increases** when the emitter is moving **towards** the observer, and the frequency **lowers** when the emitter is moving **away** from the observer.

The classic example is that of an ambulance sounding its siren while passing by a bystander.

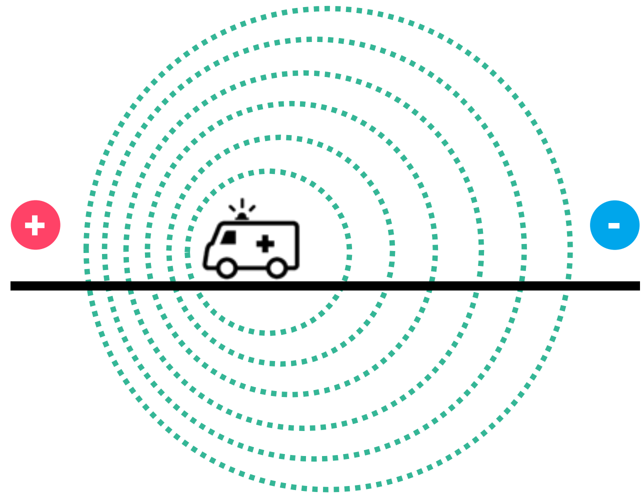


FIGURE 9

The bystanders (dots) perceive the siren pitch differently depending on whether the ambulance moves towards them or away from them.

In medical ultrasound, the frequency of the echo shifts when the reflecting tissue is moving relative to the transducer (Fig. 10).

The frequency of the echo **increases** when the reflecting tissue is moving **towards** the transducer, and the frequency **lowers** when the reflecting tissue is moving **away** from the transducer.

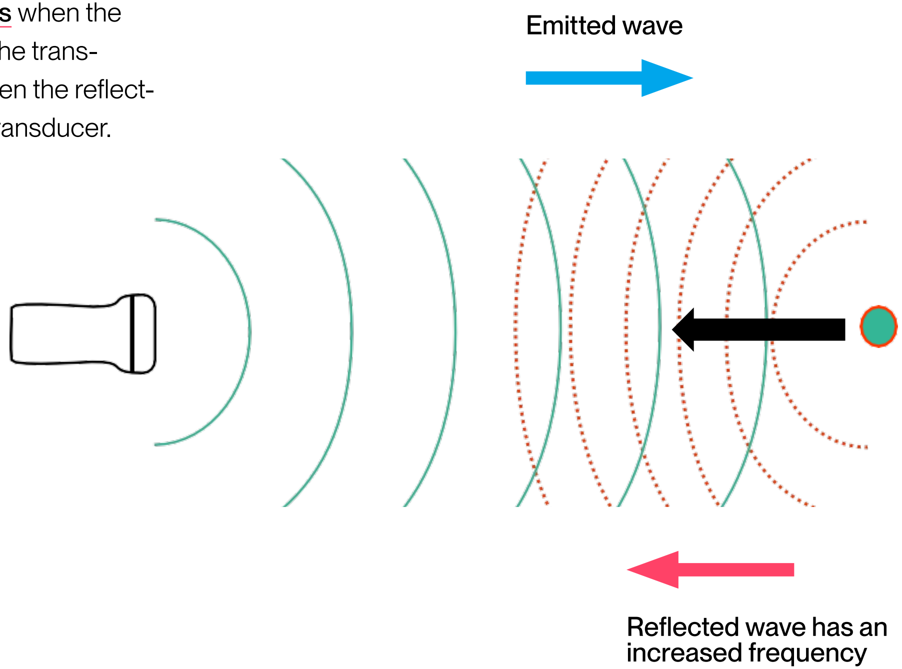


FIGURE 10

The Doppler effect in medical ultrasound. The reflecting tissue here (**green dot**) is moving towards the transducer.

This is an example of using colour Doppler overlay (Fig. 11). This ultrasound system colours objects, in this case blood, moving **towards** the transducer (positive Doppler shift) in **red**, and objects moving **away** from the transducer (negative Doppler shift) are coloured in **blue**.

ATTENTION

The colours assigned can differ from machine to machine, so be careful!

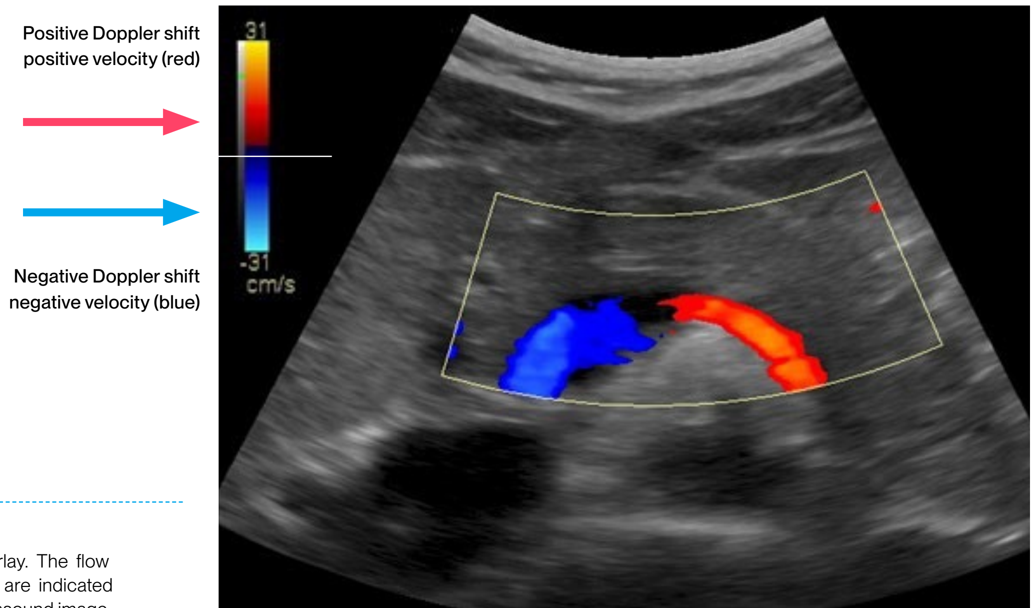


FIGURE 11

Splenic vein with colour Doppler overlay. The flow velocity (in cm/s) and flow direction are indicated in the scale on the left side of the ultrasound image.

/ Ultra-sound

CHAPTER OUTLINE:

This is used to answer both qualitative and quantitative questions. Here are some questions that can be answered with use of the Doppler effect:

Qualitative:

/ Is there increased blood flow in the gallbladder wall as a sign of inflammation?

/ Is there reduced blood flow in the testis as a sign of possible testicular torsion?

Quantitative:

/ What is the flow rate through the patient's heart valve?

/ What is the flow rate through the patient's carotid artery? Does the rate indicate stenosis?

CHAPTER OUTLINE:

Contrast-Enhanced Ultrasound

CHAPTER OUTLINE:

/ Contrast-Enhanced Ultrasound (CEUS)

CEUS uses a different contrast agent than CT or MRI.

Different contrast agent formulations exist, but they are all solutions of gas containing microbubbles. The bubbles diffuse into the tissues in much the same way as other contrast agents, but they are strictly intravascular as opposed to other contrast agents.

Half life in the blood stream is around 5-15 minutes, and side effects are extremely rare.

Common indications for CEUS are:

- Characterisation of liver masses (Fig. 12)
- Perioperative visualisation of targets in ablation procedures
- Characterisation of masses in other organs

<∞> REFERENCE

> see also eBook chapter on contrast agents

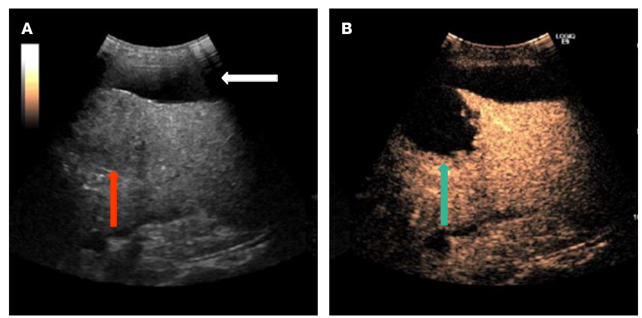


FIGURE 12

Regular US image (**A**) showing a slightly hypoechoic and heterogenous liver mass (**red arrow**) surrounded by normal liver parenchyma. CEUS (**B**) in portal venous phase reveals the mass (**green arrow**) to have distinct washout of contrast, strongly suggesting malignancy – this turned out to be a metastasis. Notice the hypoechoic area above the liver (**white arrow** in A) – this is ascites.

CHAPTER OUTLINE:

CEUS is generally considered very safe.

Contraindications vary for different formulations. Below are a summarisation of contraindications that need to be considered when performing CEUS:

- Hypersensitivity to the active substances
- Known right-to-left cardiac shunt
- Severe pulmonary hypertension or uncontrolled systemic hypertension
- Acute respiratory distress syndrome
- Known egg allergy (only some formulations)

CHAPTER OUTLINE:

Strengths and Limitations

CHAPTER OUTLINE:

/ Strengths and Limitations

Strengths and limitations of ultrasound vary greatly with different applications.

Below is an outline of general strengths and limitations of ultrasound as opposed to other imaging modalities, such as CT and MRI, that one needs to consider when choosing between modalities.

STRENGTHS:

+ Low cost
+ High availability
+ High portability
+ Safe and non-invasive
+ Fast
+ Dynamic

LIMITATIONS:

– Highly operator dependant
– Highly patient dependant
– Difficult to reproduce
– Poor penetration in air and bone

<∞> REFERENCE

> see for specific applications also eBook chapters on bile ducts, small bowel, musculoskeletal, cardiac and paediatric imaging

/ Take-Home Messages

- Ultrasound waves are sound waves with a high frequency.
- We analyse the echoes to gain information about the subject matter and depict them as images on a screen.
- Different transducers are used for different applications.
- Ultrasound artefacts are important to be aware of, as they may influence your diagnosis.
- The Doppler effect is used extensively to visualise movement and in particular blood flow.
- CEUS is generally a safe way to characterise liver lesions and has also other applications.
- Ultrasound has strengths and limitations that one needs to consider before performing an examination.

/ References and Further Reading

/ Rumack, C.M.; Wilson, S.R.; Charboneau, J.W. Diagnostic ultrasound. 2005, 3rd edition

/ Postema, M.; Kotopoulis, S.; Jenderka, K.-V. Physical Principles of Medical Ultrasound. EFSUMB Courseb. Ultrasound 2020, 1–23.

/ WFUMB ULTRASOUND BOOK Available online: http://wfumb.info/wfumb-ultrasound-book/additional- pages/html5_output/index.html (accessed on Aug 14, 2022).

/ Nolsøe, C.P.; Lorentzen, T. International guidelines for contrast-enhanced ultrasonography: ultrasound imaging in the new millennium. Ultrasonography 2016, 35, 89.

/ Appis, A.W.; Tracy, M.J.; Feinstein, S.B. Update on the safety and efficacy of commercial ultrasound contrast agents in cardiac applications. Echo Res. Pract. 2015, 2, R55.

CHAPTER OUTLINE:

Test Your Knowledge

/ Test Your Knowledge

<?> QUESTION

1

Medical ultrasound typically uses which frequency range?

- ☐ The kHz range
- ☐ The MHz range
- ☐ The Hz range

CHAPTER OUTLINE:

/ Test Your Knowledge

<?> ANSWER

1 Medical ultrasound typically uses which frequency range?

- ☐ The kHz range
- ■ The MHz range
- ☐ The Hz range

/ Test Your Knowledge

<?> QUESTION

2 Which of the following is not a way that ultrasound waves interact with the tissues within the body?

- ☐ Reflection
- ☐ Polarisation
- ☐ Refraction
- ☐ Scattering
- ☐ Absorption

/ Test Your Knowledge

<?> ANSWER

2 Which of the following is not a way that ultrasound waves interact with the tissues within the body?

- [ ] Reflection
- [x] Polarisation
- [ ] Refraction
- [ ] Scattering
- [ ] Absorption

/ Test Your Knowledge

<?> QUESTION

3 Objects that appear bright on the ultrasound screen are referred to as what?

- ☐ Hypoechoic
- ☐ Isoechoic
- ☐ Hyperechoic

/ Test Your Knowledge

<?> ANSWER

3 Objects that appear bright on the ultrasound screen are referred to as what?

- [ ] Hypoechoic
- [ ] Isoechoic
- [x] Hyperechoic

/ Test Your Knowledge

<?> QUESTION

4 Which of the following common types of transducer yields images with a high resolution?

- ☐ Curved probe, 1-5 MHz
- ☐ Phased array transducer, 1-5 MHz
- ☐ Linear transducer, 3-12 MHz

/ Test Your Knowledge

<?> ANSWER

Linear, 3-12 MHz

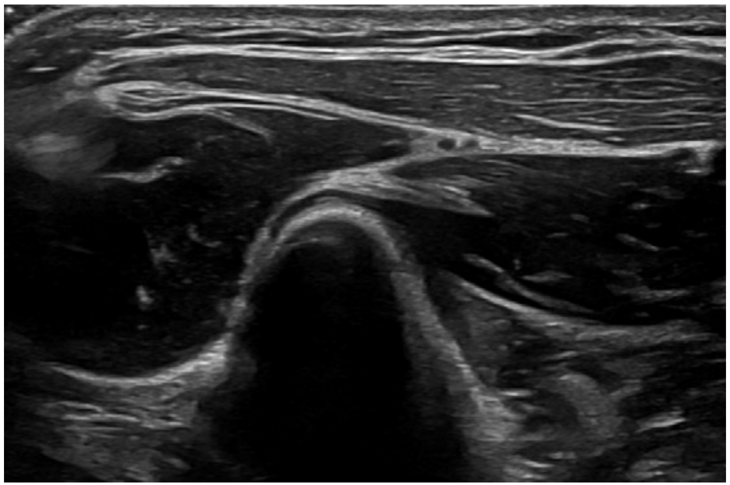
4 Which of the following common types of transducer yields images with a high resolution?

- ☐ Curved probe, 1-5 MHz
- ☐ Phased array transducer, 1-5 MHz
- ■ Linear transducer, 3-12 MHz

/ Test Your Knowledge

<?> QUESTION

5 Which common ultrasound artefact is seen here?

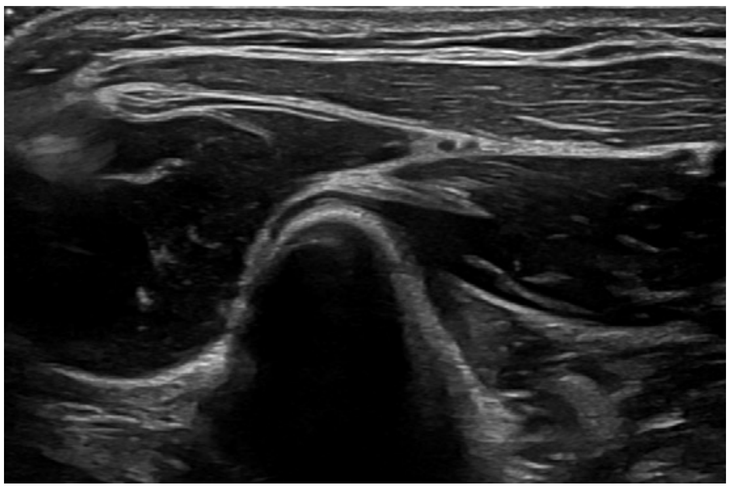


- ☐ Acoustic shadowing
- ☐ Enhancement
- ☐ Anisotropy

/ Test Your Knowledge

<?> ANSWER

5 Which common ultrasound artefact is seen here?

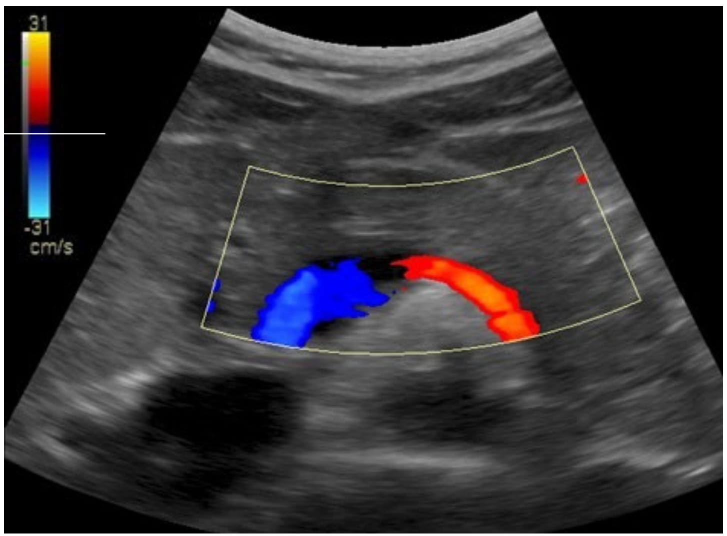


- [x] Acoustic shadowing
- [ ] Enhancement
- [ ] Anisotropy

/ Test Your Knowledge

<?> QUESTION

6 In which direction does the blood flow through this vein?



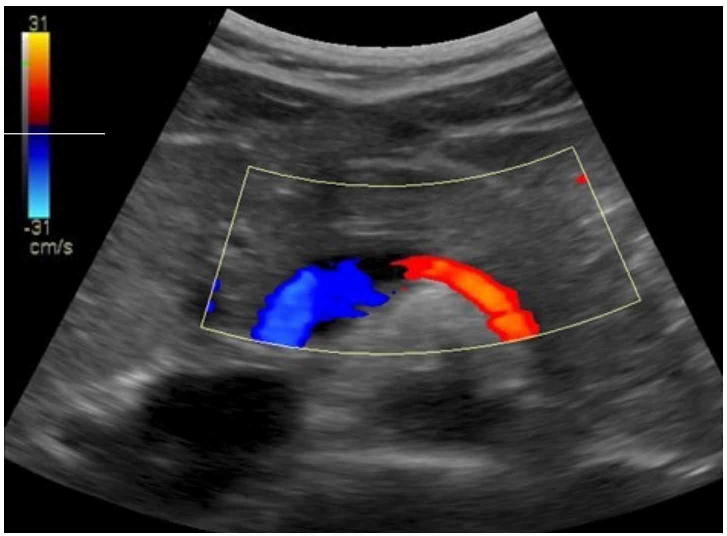
- ☐ Left to right
- ☐ Right to left

(note: colouring conventions used are as explained on slide no. 19.)

/ Test Your Knowledge

<?> ANSWER

6 In which direction does the blood flow through this vein?



- ☐ Left to right
- ■ Right to left

(note: colouring conventions used are as explained on page no. 19.)

/ Test Your Knowledge

<?> QUESTION

7 Which of the following is **not** a contraindication for CEUS?

- ☐ Known right-to-left cardiac shunt
- ☐ Severe pulmonary hypertension or uncontrolled systemic hypertension
- ☐ Acute respiratory distress syndrome
- ☐ Hepatic tumour of unknown type

/ Test Your Knowledge

<?> ANSWER

7 Which of the following is **not** a contraindication for CEUS?

- ☐ Known right-to-left cardiac shunt.
- ☐ Severe pulmonary hypertension or uncontrolled systemic hypertension
- ☐ Acute respiratory distress syndrome
- ■ Hepatic tumour of unknown type

/ Test Your Knowledge

<?> QUESTION

8 Name three general strengths and three general limitations of medical ultrasound.

/ Test Your Knowledge

<?> ANSWER

8 Name three general strengths and three general limitations of medical ultrasound.

STRENGTHS:

- Low cost
- High availability
- High portability
- Safe and non-invasive
- Fast
- Dynamic

LIMITATIONS:

- Highly operator dependant
- Highly patient dependant
- Difficult to reproduce
- Poor penetration in air and bone

EUROPEAN SOCIETY
OF RADIOLOGY