EUROPEAN SOCIETY OF RADIOLOGY

eBook for Undergraduate **Education in Radiology**

CHAPTER: Ultrasound

Preface

Undergraduate teaching of radiology in Europe is provided according to national schemes and may vary considerably from one academic institution to another. Sometimes, the field of radiology is considered as a "cross-cutting discipline" or taught within the context of other clinical disciplines, e.g., internal medicine or surgery.

This e-book has been created in order to serve medical students and academic teachers throughout Europe to understand and teach radiology as a whole coherent discipline, respectively. Its contents are based on the *Undergraduate Level of the ESR European Training Curriculum for Radiology* and summarize the so-called ***core elements*** that may be considered as the basics that every medical student should be familiar with. Although specific radiologic diagnostic skills for image interpretation cannot be acquired by all students and rather belong to the learning objectives of the *Postgraduate Levels of the ESR Training Curricula*, the present e-book also contains some ***further insights*** related to modern imaging in the form of examples of key pathologies, as seen by the different imaging modalities. These are intended to give the interested undergraduate student an understanding of modern radiology, reflecting its multidisciplinary character as an organ-based specialty.

We would like to extend our special thanks to the authors and members of the ESR Education Committee who have contributed to this eBook, to Carlo Catalano, Andrea Laghi and András Palkó who initiated this project, and to the ESR Office, in particular Bettina Leimberger and Danijel Lepir, for all their support in realising this project.

We hope that this e-book may fulfil its purpose as a useful tool for undergraduate academic radiology teaching.

Minerva Becker
ESR Education Committee Chair

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eBook for Undergraduate Education in Radiology

Based on the ESR Curriculum for Undergraduate Radiological Education

Chapter: **Ultrasound**

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Ultrasound Basics

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.

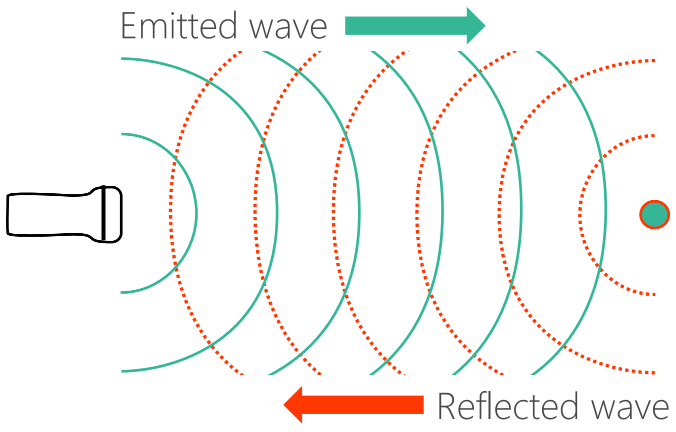

Fig. 1 – Schematic representation of the basic ultrasound (sonography or ultrasonography) principle.

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Ultrasound Basics

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

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.

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Ultrasound Basics

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.

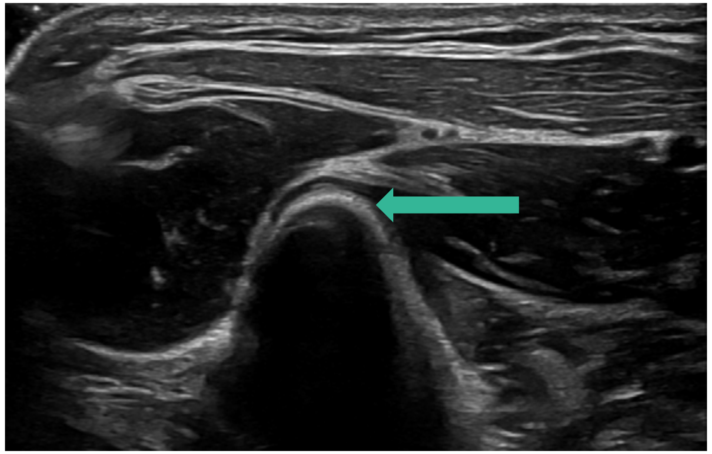

Fig. 2 – Cortical bone is strongly hyperechoic (green arrow) and casts an acoustic shadow (more on that later).

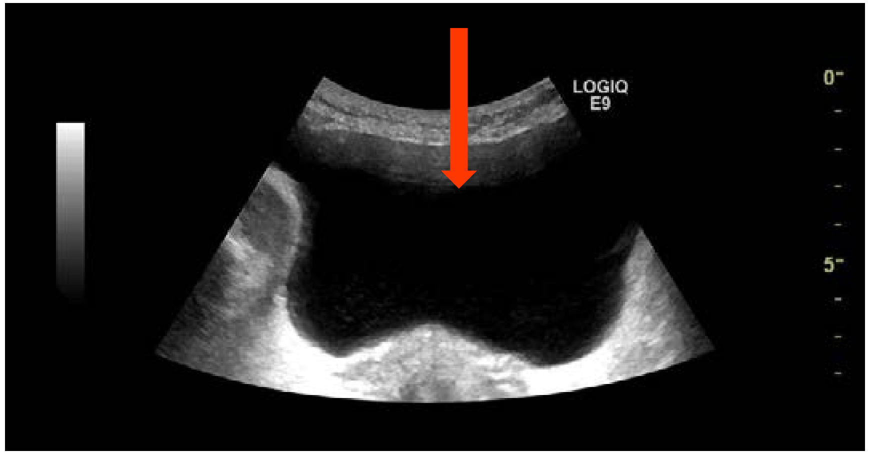

Fig. 3 – Urinary bladder filled with hypoechoic fluid (red arrow).

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Signal to Image

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.

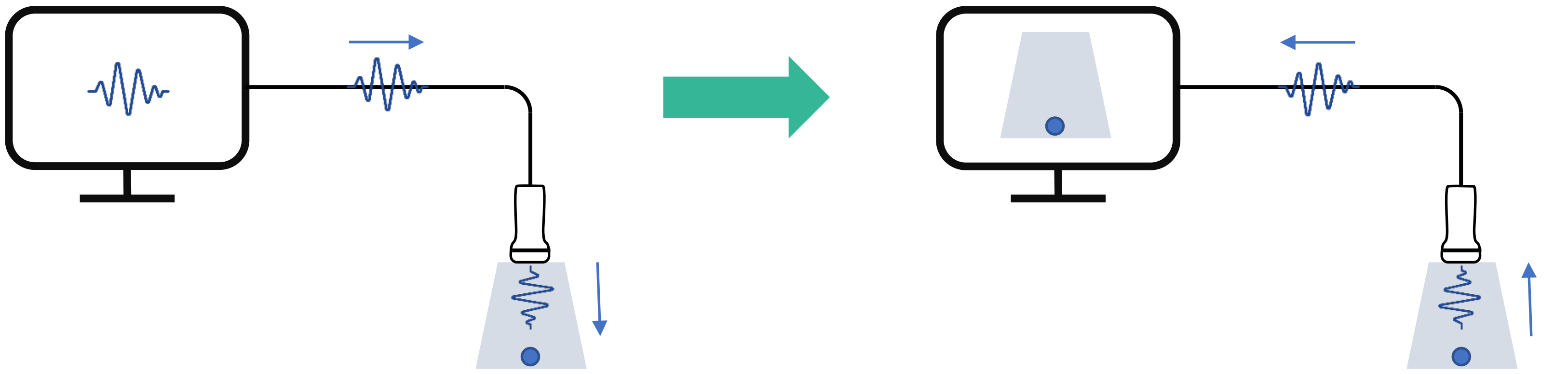

Fig. 4 – Schematic representation of the process by which an ultrasound image (sonogram or ultrasonogram) is generated.

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Signal to Image

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.

Fig. 5 – Advantages, disadvantages and main applications of different types of ultrasound transducers

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Signal to Image

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

Some **parameters** can be adjusted by the user to further optimize 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.

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Artifacts

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

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

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

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Artifacts

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

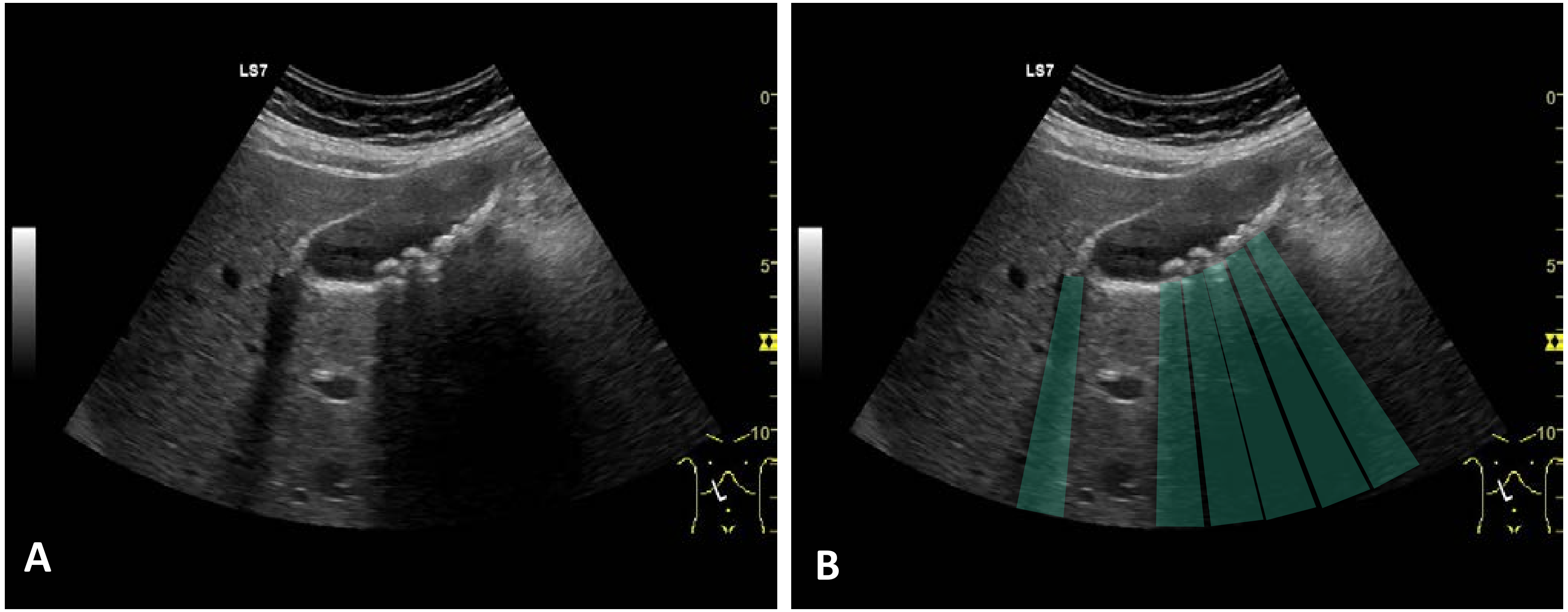

Fig. 6 – Gall bladder containing multiple gall stones which display acoustic shadowing (A). In image B, acoustic shadowing is rendered by green overlay.

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Artifacts

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

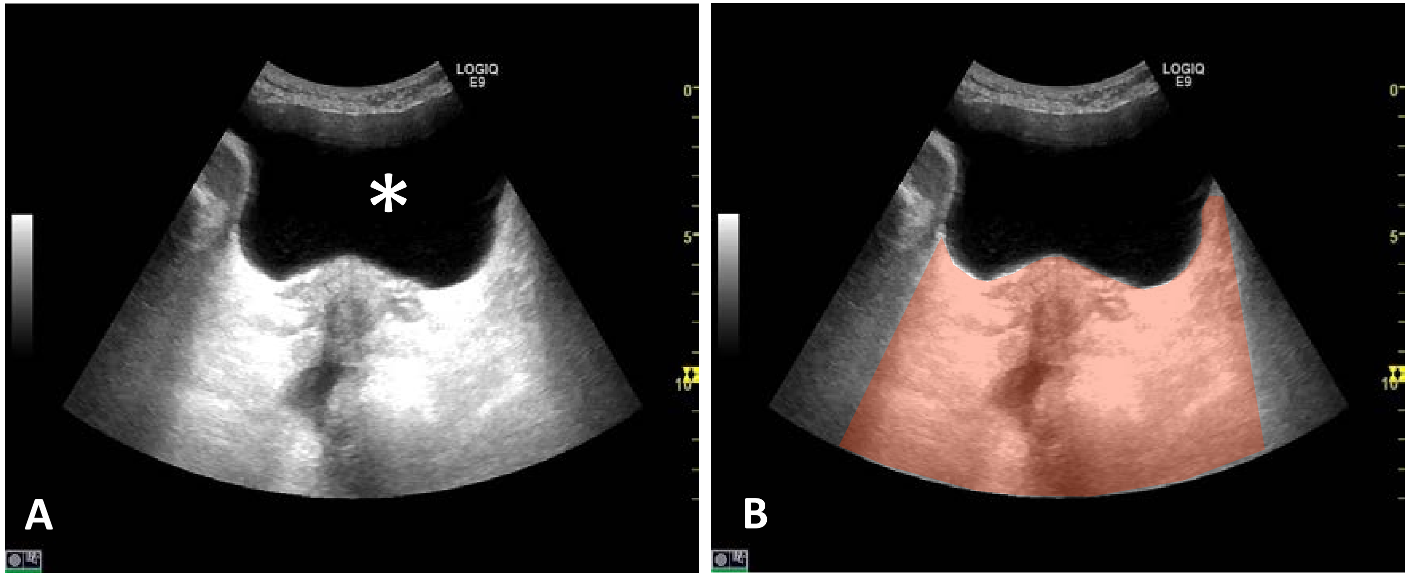

Fig. 7 – Enhancement artifact below the urinary bladder (asterisk) containing hypoechoic fluid (A). The enhancement artifact is rendered in red in B.

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".

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Artifacts

Anisotropy is an angle-generated artifact, 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.

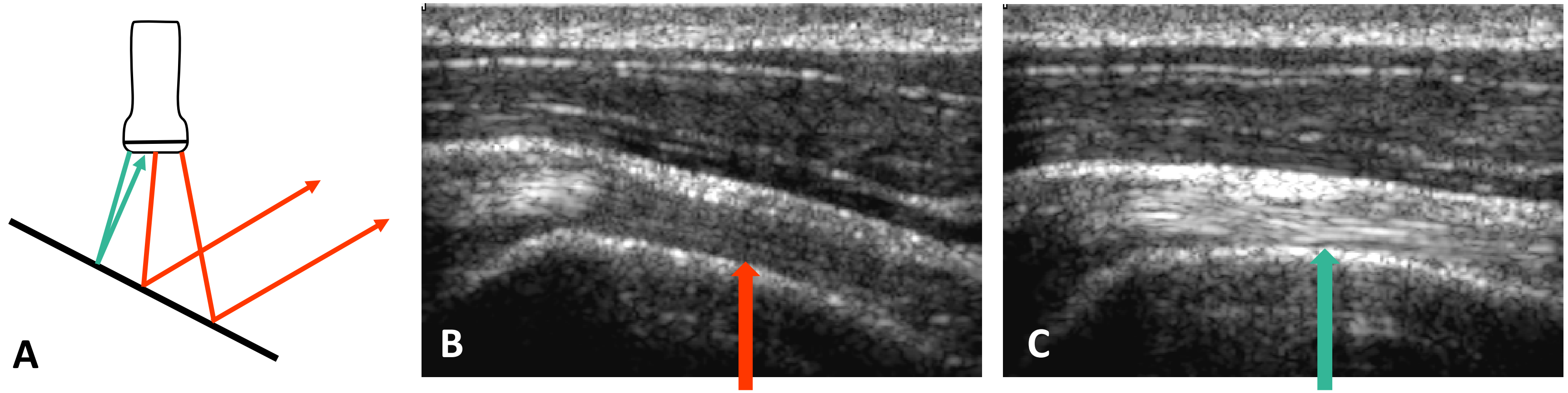

Fig. 8 – A. Schematic drawing illustrating the formation of this angle-generated artifact. B and C. two pictures of the same tendon taken moments apart. Notice the change of echogenicity from hypoechoic (A) to hyperechoic B). The only difference is the angle of the transducer relative to the tendon.

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.

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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.

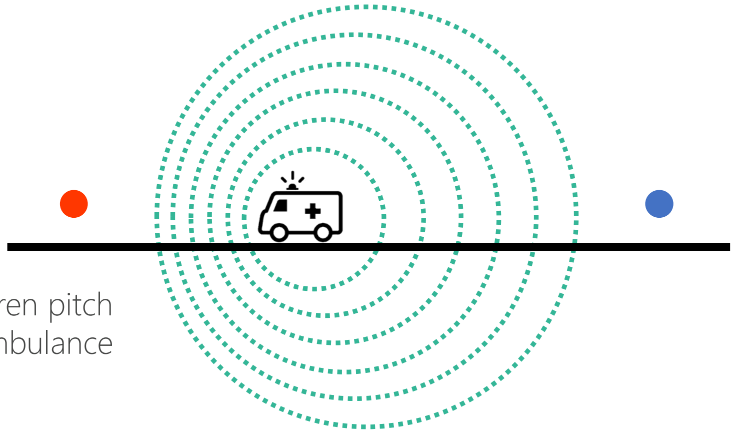

Fig. 9 - The bystanders (dots) perceive the siren pitch differently depending on whether the ambulance moves towards them or away from them.

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The Doppler Effect

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.

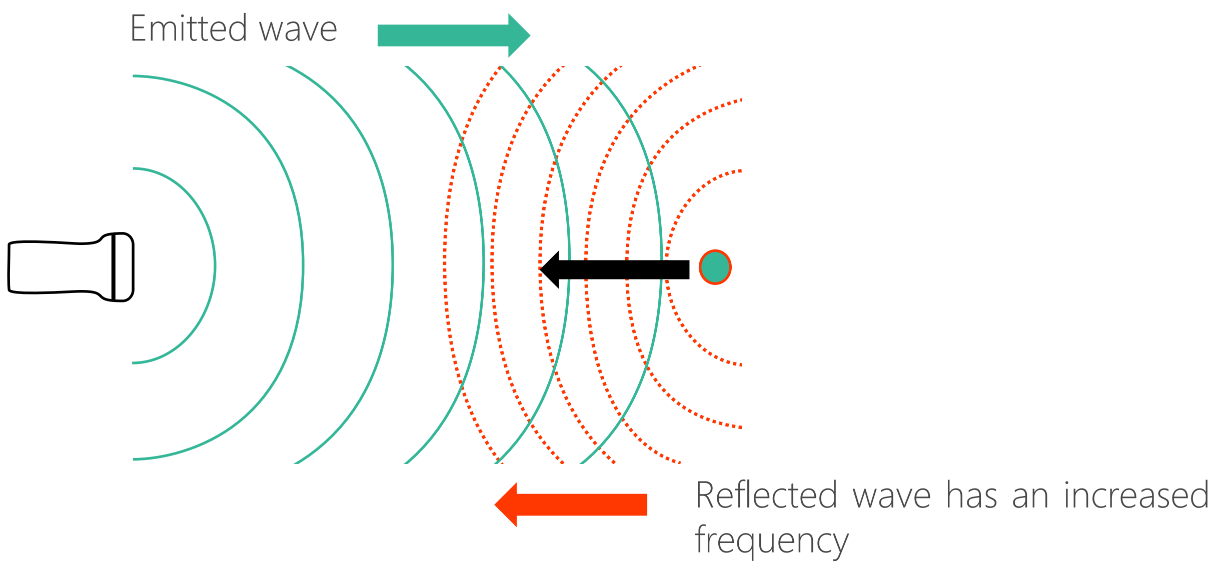

Fig. 10 – The Doppler effect in medical ultrasound. The reflecting tissue here (green dot) is moving towards the transducer.

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The Doppler Effect

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.

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

Positive Doppler shift => positive velocity (red)

Negative Doppler shift => negative velocity (blue)

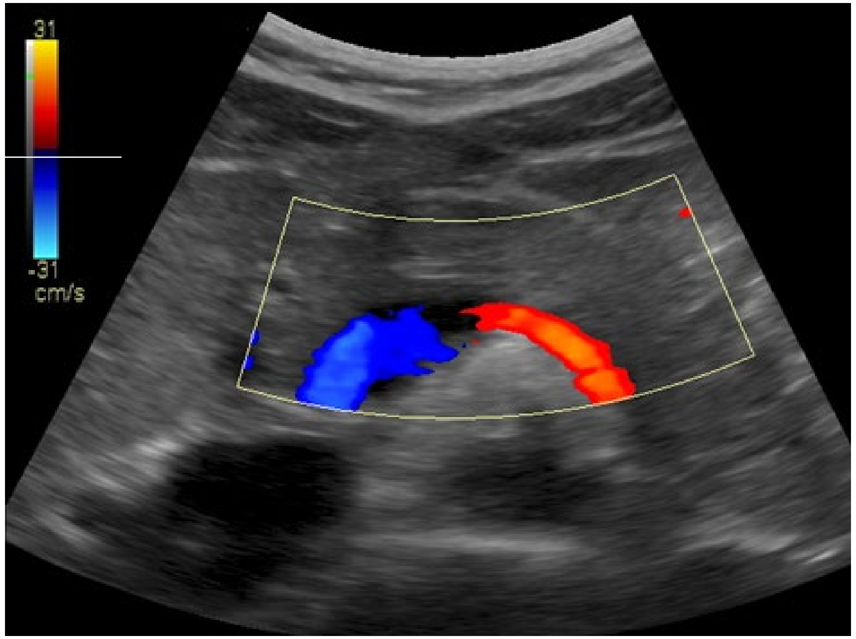

Fig. 11 – Splenic vein with colour Doppler overlay. The flow velocity (in cm/s) and flow direction are indicated in the scale on the left side of the ultrasound image.

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The Doppler Effect

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?

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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 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:

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

=> see also e book chapter on contrast agents

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Contrast Enhanced Ultrasound (CEUS)

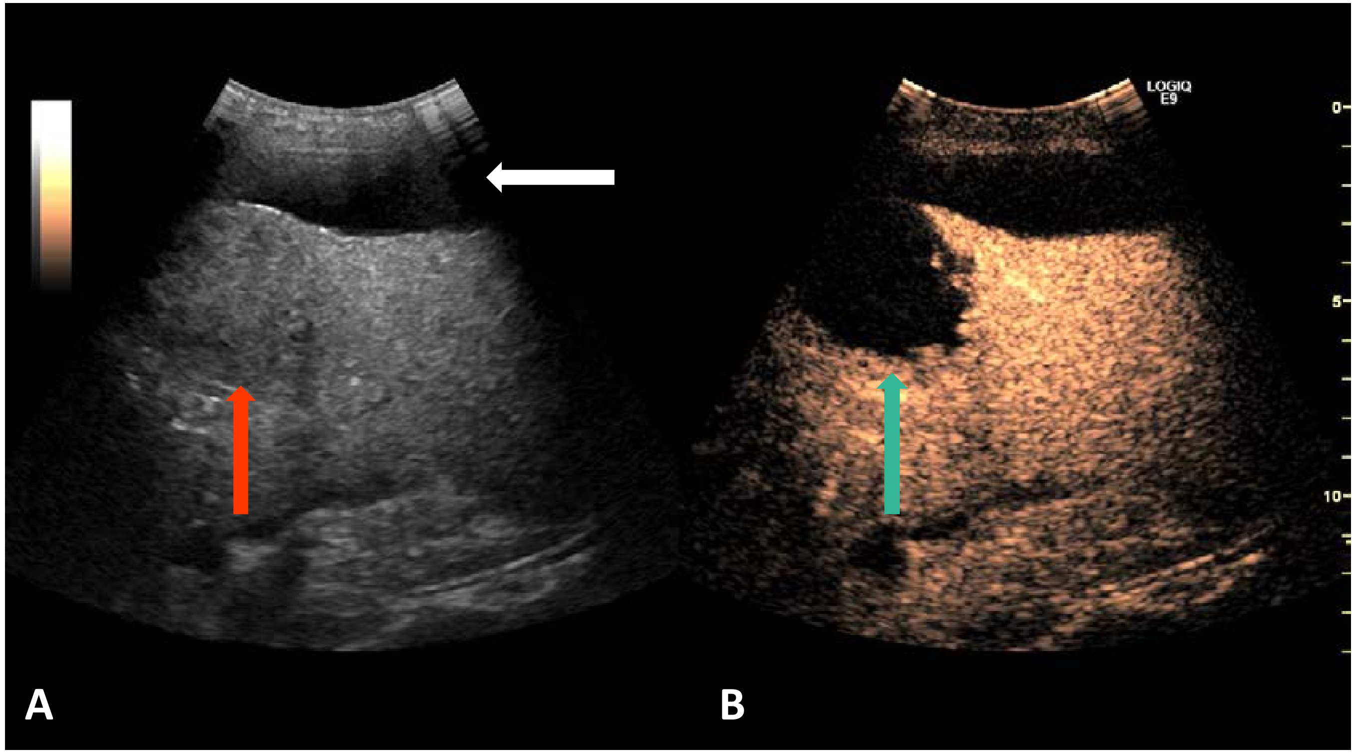

Fig. 12 – Regular US image (A) showing a slightly hypoechoic and heterogenous liver mass (red arrow) surrounded by normal liver parenchyma. CEUS (B) in portal venous phase reveals the mass (green arrow) to have distinct washout of contrast, strongly suggesting malignancy – this turned out to be a metastasis. Notice the hypoechoic area above the liver (white arrow in A) – this is ascites.

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Contrast Enhanced Ultrasound (CEUS)

CEUS is generally considered very safe.

Contraindications vary for different formulations. Below are a summarization 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).

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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

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

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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 artifacts are important to be aware of, as they may influence your diagnosis.
- The Doppler effect is used extensively to visualize movement and in particular blood flow.
- CEUS is generally a safe way to characterize liver lesions and has also other applications.
- Ultrasound has strengths and limitations that one needs to consider before performing an examination.

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Test Your Knowledge

1 – Medical ultrasound typically uses which frequency range?

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

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Test Your Knowledge

1 – Medical ultrasound typically uses which frequency range?

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

- Reflection
- Polarisation
- Refraction
- Scattering
- Absorption

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

- Hypoechoic
- Isoechoic
- Hyperechoic

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4 – Which of the follow 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

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4 – Which of the follow 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

Linear, 3-12 MHz
Advantages: High resolution.
Disadvantages: Poor penetration.
Musculoskeletal, superficial structures.

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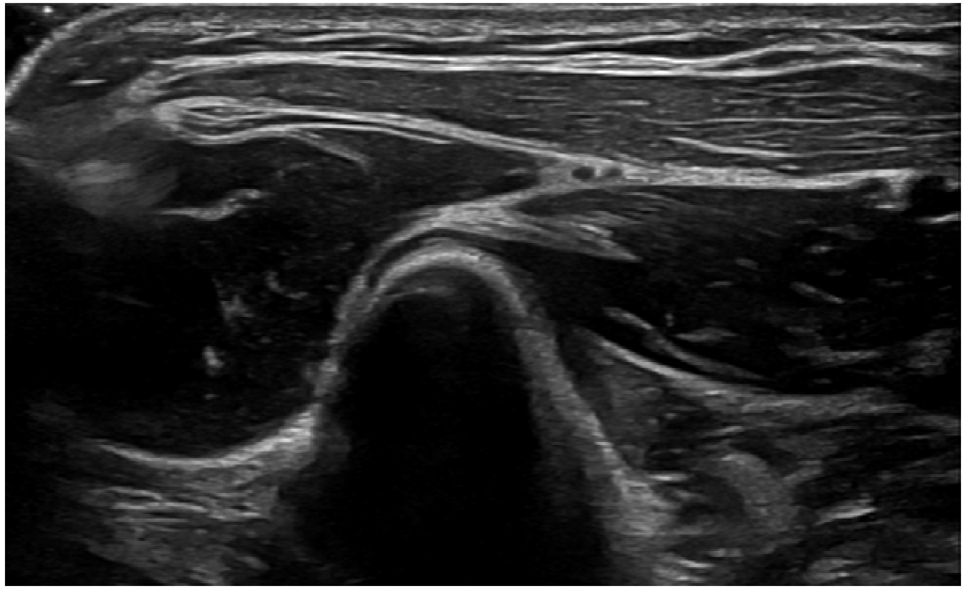
5 – Which common ultrasound artifact is seen here?

- Acoustic shadowing
- Enhancement
- Anisotropy



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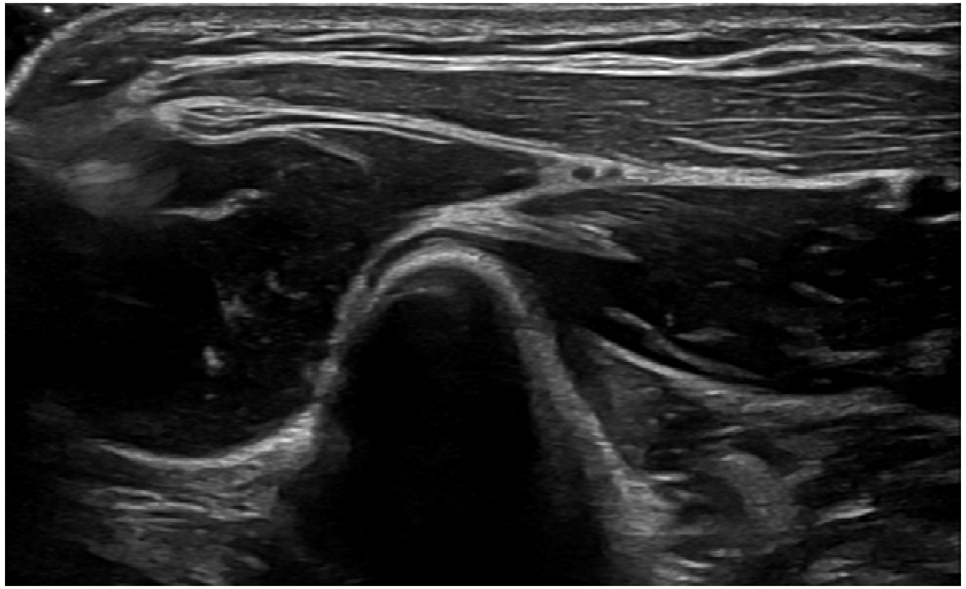

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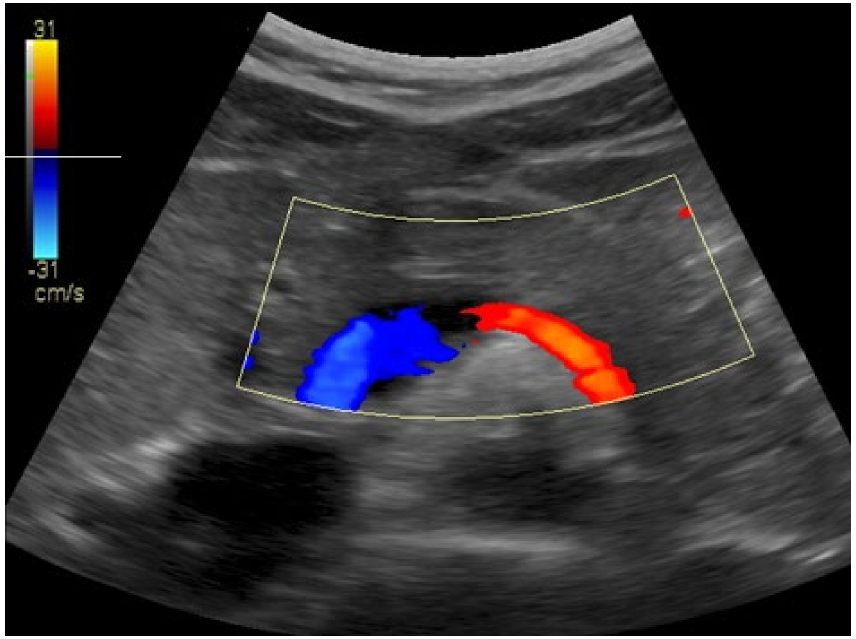
6 – In which direction does the blood flow through this vein?

- Left to right
- Right to left

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



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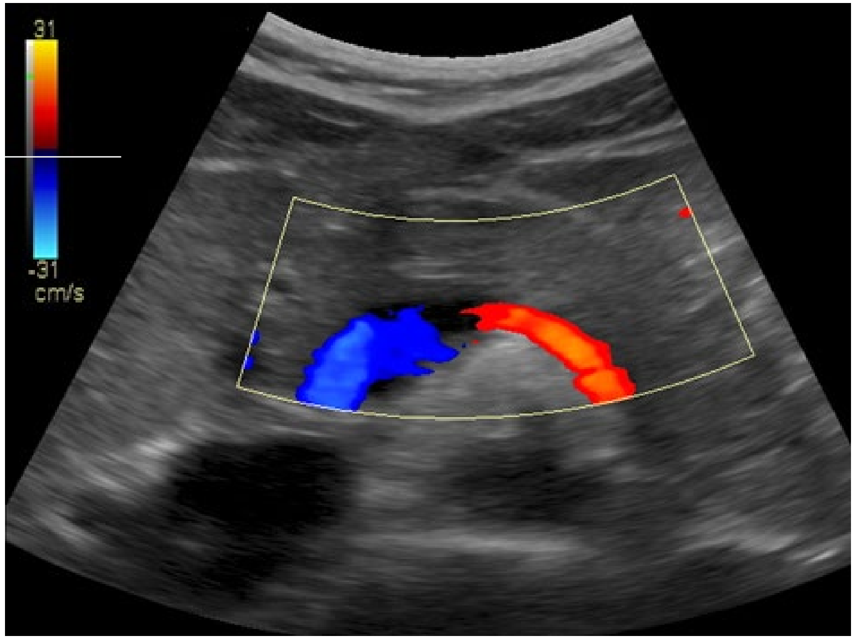

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7 – Which of the following is not a contraindication for CEUS?

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

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Test Your Knowledge

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- Acute respiratory distress syndrome.
- ✓ Hepatic tumour of unknown type

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

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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

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