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Editors: Jan Tuma, Radu Badea, Christoph F. Dietrich

Ultrasound of the liver

Christoph F. Dietrich[1], Jan Tuma[2], Radu Badea[3]

[1]Caritas-Krankenhaus Bad Mergentheim, Germany
[2]Uster, Switzerland
[3] University of Medicine & Pharmacy "Iuliu Hatieganu", Cluj Napoca, România

Corresponding author:
Prof. Dr. Christoph F. Dietrich
Medizinische Klinik 2
Caritas-Krankenhaus Bad Mergentheim
Uhlandstr. 7
97980 Bad Mergentheim
Tel.: (+) 49 - 7931 – 58 – 2201
Fax: (+) 49 - 7931 – 58 – 2290
Email: christoph.dietrich@ckbm.de

Content

Introduction

Ultrasound is the first and most important imaging method in suspected liver disease, both for proving (*e.g.* metastatic disease) and excluding pathology. It is the single best tool in the evaluation of focal liver lesions (FLL). It is unrivalled by any other imaging modality owing to its real-time, dynamic nature, high-resolution and good safety record. It is invaluable in the differential diagnosis of cholestasis and jaundice, in describing liver cirrhosis complications and in any form of ultrasound guided intervention. Ultrasound is an indispensable tool in clinical hepatology.

Topography

The liver is located inside the intraperitoneal cavity and under the right hemidiaphragm, but can also extend across the midline reach to the left hemidiaphragm and to the spleen in some patients [Figure 1].

Figure 1 Schematic representation of the liver into the abdominal cavity. Coronal plane. Close relations with the diaphragm and stomach are represented. FL: falciform ligament. LTH: Ligamentum teres hepatis. [Drawing kindly provided by Dr Þoþea Radu Alin].
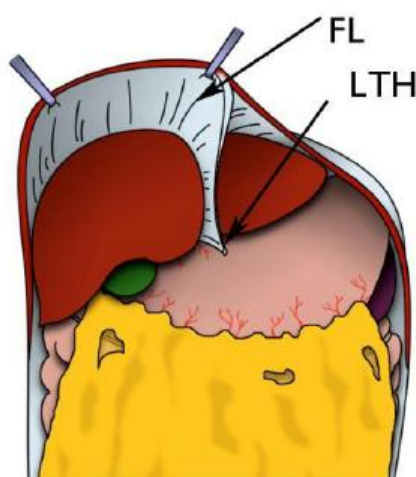
The liver is fixed to the diaphragm by the *pars affixa* and to the ventral abdominal wall by the ligamentum falciforme (falciform ligament) and its strong margin, the

ligamentum teres hepatis. The minor omentum consists of the ligamentum hepatogastricum and the ligamentum hepatoduodenale. The hepatoduodenal ligament carries three vessels – two containing blood (the portal vein and hepatic artery) and one carrying bile (common bile duct, CBD) [Figure 2].

Figure 2 Common bile duct (CBD), and therefore the liver hilum, is often best examined in a left lateral decubitus position using a sub-costal approach in slight inspiration [Images & video 5, http://www.efsumb-portal.org/ep/article.php?id=147]. In a typical view the CBD (in between markers (+)), portal vein (PV), hepatic artery (HA), inferior vena cava (IVC) and right renal artery (RRA) (sometimes the aorta (AO) can also be seen; the papilla region (PAP) is indicated.

The further course of these three vessels (known as **Glisson's** triad) is mainly parallel. The liver has three main hepatic veins – left, middle and right – that drain the liver blood to the inferior vena cava (IVC) located in the retroperitoneal space.

The IVC is variably surrounded by liver parenchyma. The organs and structures of the peritoneal cavity surround the liver, as well as pleural and pericardial structures. Neighbouring structures adjacent to the liver are numerous and include (clockwise) basal lung portions separated by the muscular layers of the right diaphragm (and more or less the left diaphragm as well), heart, stomach, intestine (*e.g.* upper duodenal loop and right colonic flexure), abdominal aorta, IVC, right adrenal gland and right kidney [Figure 3 and 4].

Figure 3 Neighbouring structures adjacent to the left liver lobe (LLL): left and cranial is heart. LV: left ventricle. RV: right ventricle. LA: left atrium. RA: right atrium. S: septum.

Figure 4 Neighbouring structures adjacent to the liver: right and caudal is gall bladder (GB) and right kidney.

Conventional real-time ultrasound produces images of thin slices of the liver on screen, therefore it is essential that the operator always scans the entire organ systematically in at least two anatomical planes to ensure the entire volume of the liver tissue and structures have been imaged. The operator must then use this two-dimensional information to visualise a three-dimensional map of the individual patient's liver anatomy and pathology. This requires good hand-eye-brain coordination.

The interposition of the colon between the liver and the anterior abdominal wall can prevent sonographic approach to the right liver lobe in cases of Chilaiditi's syndrome. Finally, in the case of complete or incomplete situs inversus, topographic relations are inverted.

Anatomy

Anatomical orientation

Liver anatomy is defined by ligaments and fissures as well as by vascular architecture *i.e.* the branches of the hepatic artery, portal vein and bile ducts define the centers of liver segment anatomy by their parallel course.

The functional component of the liver is the lobule, which has a pyramidal shape and a diameter of around 1 mm or less.

The composition of the lobule in cells (situated in the middle) and fibrotic tissue (in the periphery) is responsible for a typical ultrasound picture as a small hypoechoic structure surrounded by echogenic linear structures. The sum of the lobules is giving us the so called "liver echo structure" which is in fact the most typical parenchymal pattern in the human body [Figure 5].

Figure 5 One slice through a true liver (b - right picture) and an ultrasound slice (a - left picture). The information between the two is very similar. Ultrasonography can be considered a sectional procedure with a very good resolution, close to the dimension of the liver lobule.
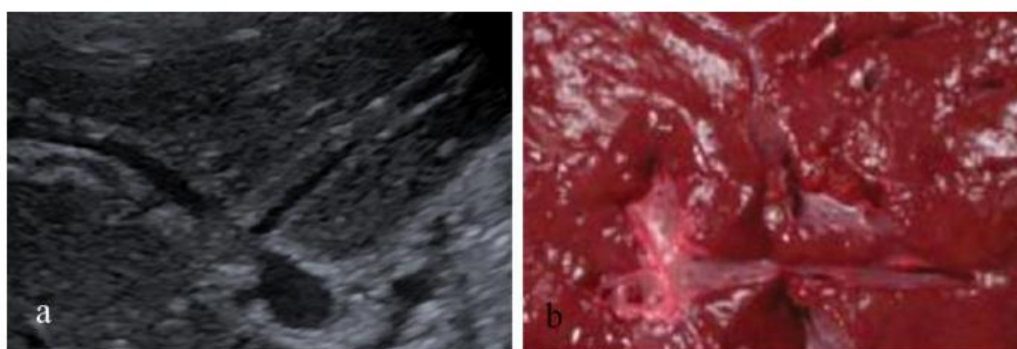
The liver is surrounded by a fibrous capsule ("Glisson's capsule"), which is penetrating between the right and left lobe from the surface to the round ligament (ligamentum teres).The falciforme ligament runs between the ventral abdominal wall and the liver, ending with its free caudal margin as the ligamentum teres containing the obliterated umbilical vein. It can be identified at the left lateral border of segment IVb (in the quadrate lobe), and it is often mistaken to form the anatomical border between the left and right liver lobe, which is not the case. This border follows a plane along the middle hepatic vein between the IVC and the longitudinal gallbladder axis. In anatomy, the round ligament of the liver (also commonly known by its Latin name, ligamentum teres - or more specifically ligamentum teres hepatis as the human body has seven round ligaments in total), is a degenerative string of tissue that exists in the free edge of the falciform ligament of the liver. Anatomically, the round ligament divides the left part of the liver into medial and lateral sections. The round ligament represents the remnant of the fetal umbilical vein. The round ligament therefore only exists in mammals. Prenatally and for a month or two after birth, the umbilical vein is patent, subsequently degenerating to fibrous tissue, the round ligament. However, in case of cirrhosis, the umbilical vein in the round ligament may be recanalized [Figure 6].

Architecture

Figure 6   Here is a case of cirrhosis. The umbilical vein (UV) in the round ligament (LTH, ligamentum teres hepatis) is recanalized.

The macroscopic anatomy of the liver is defined by ligaments and fissures as well as by vascular architecture i.e. the branches of the hepatic artery, portal vein and bile ducts define the central portions of liver segment anatomy by their parallel course [Figure 7].

Figure 7   Schematic representation of liver segmental anatomy. [Drawing kindly provided by Dr Þoþea Radu Alin].
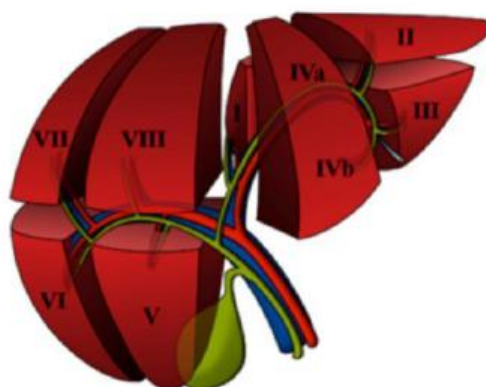
Liver segment anatomy

A simplified anatomy divides the liver into lobes and segments. The larger lobe is the right one (including segments V, VI, VII and VIII); the left lobe with its medial (IV a, b) and lateral segments (II, III); and the caudate lobe (I).

In a clockwise fashion starting with the caudate lobe as segment I [Images & video 1, http://www.efsumb-portal.org/ep/article.php?id=147], the left posterolateral segment is number II, followed by the left anterolateral, segment III [Images & video 2, http://www.efsumb-portal.org/ep/article.php?id=147]; left superomedial, segment IVa;

left inferomedial, segment IVb [Images & video 3, http://www.efsumb-portal.org/ep/article.php?id=147]; right anteroinferior, segment V; right posteroinferior, segment VI; right posterosuperior, segment VII; and right anterosuperior, segment VIII.

Couinaud classification

The widely accepted Couinaud system describes liver segment anatomy. This classification, modified by Bismuth (segment IVa, b), is based on eight segments, each of which has its own arterial and portal venous vessel architecture (**Glisson's** triad) for vascular inflow, outflow and biliary drainage. As a result of this division into self-contained units, each can be resected (alone or in groups) without damaging the remaining segments because the vascular inflow, outflow and biliary drainage are preserved. Depending on the three-dimensional volume orientation of the liver (longitudinal or oblique), the interpretation of the Couinaud classification can be inconsistent in the literature. While the portal vein plane has often been described as transverse, it may also be oblique because the left branch runs superiorly and the right runs inferiorly. In addition to forming an oblique transverse plane between segments, the left and right portal veins branch superiorly and inferiorly to project into the centre of each segment.

The most unique of the Couinaud segments is segment I, which is part of the caudate lobe (sometimes called the Spiegel lobe). This segment is located posteriorly and adjacent to segment IV. Its medial and lateral boundaries are defined by the IVC and ligamentum venosum (remnant of duct of Arantii in the foetus), respectively, which runs caudally to the hepatic artery and can be identified in this way. The caudate lobe has a variable vessel anatomy that differs from the rest of the liver; its portal inflow is derived from both the left and right branches of the portal vein, and it has its own short (and usually small) hepatic veins that connect directly to the IVC. Owing to the variable and extensive crossing of vessels, and its position relative to the liver hilum and IVC, segment I is frequently not resected, unless absolutely necessary. A more detailed description can be found in the EFSUMB Course Book on Ultrasound.

Surgical resections proceed along the vessels that define the peripheries of the segments. In general, this means resection lines are parallel to the hepatic veins to preserve the hepatic arteries, portal veins and bile ducts that provide vascular inflow and biliary drainage through the centre of the segment.

Examination technique

Patient preparation

In general, there are no specific preconditions to do an ultrasound evaluation of the liver. However, it is recommended that patients undergo a period of fasting prior to upper abdominal imaging in order to maximise the distension of the gall bladder and reduce food residue and gas in the upper gastrointestinal tract, which may reduce image quality or preclude liver imaging. This is essential for complete imaging of the liver and related biliary tree, but may not be required in an acute situation such as trauma, where immediate imaging of the gall bladder is not essential.

Patient positioning and systematic liver examination

The patient should be examined first in the supine position. Sagittal and subcostal transducer positions allow representation of segments I-VI and intercostal transducer positions are complemented with an optimal representation of segments VI, VII and VIII. For the last mentioned, the transducer position is used slightly oblique to the **patient's** position with the right arm above the head and the right leg stretched. The consistency (elasticity) of the liver is assessed using the sonographic palpation. Examination in the standing position is also helpful owing to the liver moving caudally with gravity [ECBv Ch 02 Liver 8 RLL standing.avi www.efsumb.org]. Scanning from the sub- or intercostal probe positions (depending on the individual anatomy) avoids interposed lung, which can occur in the right posterolateral (superficial) parts of the liver when using the intercostal approach [Video 05.09 Images & video 8, http://www.efsumb-portal.org/ep/article.php?id=147].

Transducer selection

The transducer recommended for the examination of the liver is the convex one, with 1 – 8 MHz. For obese patients and very large persons we use lowest possible frequencies, for slim persons or children higher frequencies [Figure 8].For very difficult cases sector transducers could be used. For imaging of the near filed (surface) in patients with suspected liver cirrhosis and superficially located liver nodules, high frequency transducers are recommended.

Figure 8   Ultrasound probes for optimal liver investigation: Convex probe (C5-1) is commonly used. Sector probe (S5-1) may be beneficial in obese patients. Linear probe (L12-5) is used to assess the liver surface.

Figure 9 Application of the sector probe: the maximum distance of diaphragmatic dome to the lower edge of the liver in the midclavicular line (MCL) is 19.5 cm (normal < 18 cm).

Examination technique of the liver

For orientation, the central portion of the liver can be differentiated into three levels [Figures 10 - 12]:

- Level of the confluences of the hepatic veins [Figure 10].
- Level of the pars umbilicalis of the (left) portal vein branch [Figure 11].
- Level of the gall bladder [Figure 12].

Figure 10   Confluences of the hepatic veins. This "junction" level is the first in ultrasound examination of the right liver lobe by sub-costal scanning sections steeply "looking" upwards, preferably in deep inspiration [Images & video 4, http://www.efsumb/portal.org/ep/article.php?id=147]. VCI: inferior vena cava. LLV: left liver vein. MLV: middle liver vein. C: confluens of the LLV and MLV. RLV: right liver vein. The RLV often separately joins the inferior vena cava, whereas the LLV and MLV often reveal a common trunk. The segments are indicated.

Figure 11 Pars umbilicalis of the portal vein. Scanning planes display the left and right liver lobes in a more downwards orientated view into the right liver lobe as compared with the level of the confluens of the hepatic veins [Images & video 4, http://www.efsumb-portal.org/ep/article.php?id=147]. PA, portal vein; PU, pars umbilicalis of the portal vein; VCI, inferior vena cava.

Figure 12 Gall bladder level as the most caudate scanning plane [Images & video 4, http://www.efsumb-portal.org/ep/article.php?id=147]. GB, gall bladder; LTH, ligamentum teres hepatis; S4, segment IV of the liver (quadrate lobe).

The examination technique is explained in more detail by videos [see http://www.efsumb-portal.org/ep/article.php?id=147].

The interposition of the colon between the liver and the anterior abdominal wall can prevent sonographic approach to the right liver lobe in cases of Chilaiditi's syndrome.

Finally, in the case of complete or incomplete situs inversus, topographic relations are inverted.

Ultrasound assessment criteria of normal findings and its variants

Knowledge of the normal US features is highly important for a better understanding of the main spectrum of pathologies in which the method is valuable (called clinical applications). It must be understood that "US anatomy" is only partially superimposed upon "classical anatomy". Ultrasound can only visualize some anatomical structures; the method is actually a simplified representation of the reality. For example a number of structures such as the lymph plexuses, nervous plexuses or structures of the microvasculature are not accessible to ultrasound. Echography can visualize vascular and tubular structures only from the level of large and medium divisions, leaving apart those with a small caliber. The confidence when expressing deep located structures is less than that of ones more superficial. The **examiner's** mind must build a virtual, tridimensional "projection" when represents anatomical structures seen on sonographic sections. Liver anatomy, in spite of its complexity, can be "simplified" by using a minimal number of sections that have to be known and can be considered ,"**fundamental**" sections. Once these sections are obtained, achievement of intermediary sections, parallel to orthogonal sections together with sections taken under different angles, will lead to an exact understanding of what is, in the end, the sonographic expression of the liver. It is of high importance that the "continuity" of the identified structures is permanently demonstrated. It is obvious that the process is based on a large number of conducted investigations, accumulated personal experience thus being of critical importance. Therefore, it is easier to use in systematic liver examination following evaluation criteria: position, size, shape and contour, surface (outline), texture and echogenicity (echopattern), architecture, consistency (elasticity)and vascularity.

Standardised scanning in a systematic sequence of probe- and patient positions, and of scanning planes is mandatory to cover all segments and the complete liver surface [see videos examination technique [http://www.efsumb-portal.org/ep/article.php?id=147]. The patient should be examined from the sub- to the intercostals in the decubitus position as well in the modified, slightly oblique, positions with the right arm above the head and the right leg stretched during all respiration cycles to identify the best approach and to avoid artefacts caused by the thorax. Examination in the standing position is also helpful owing to the liver moving caudally with gravity. Scanning from the sub- or intercostal probe positions (depending on the individual anatomy) avoids interposed lung, which can occur in the right posterolateral (superficial) parts of the liver when using the intercostal approach. There are other examination techniques that can also be used, but these will not be mentioned here in detail. The anatomy and examination technique are explained in the videos available online [http://www.efsumb-portal.org/ep/article.php?id=147].

Size

The liver is a very complex constructed and shaped organ.

Measurements

The measurement of the volume of a liver could be done by CT with help of 3D reconstruction. Exact measurement is important only for scientific purposes. The most important question is whether there is a significant enlargement, or reduction of the normal liver size. Acute liver poisoning, acute hepatitis, fatty liver, alcoholic steatohepatitis (ASH), non-alcoholic steatohepatitis or amyloidosis can lead to liver enlargement. One measurement of liver size is done in the mid-clavicular line from highest peak of the diaphragm down to the caudal liver end. This has a maximum dimension 18 cm. Another possibility to measure the liver size is in the mid-clavicular line to measure ventrodorsal dimension (depth) and cranio-caudal dimension (length). The maximum length is 15 cm and depth 13 cm, maximum for both dimensions together is 28 cm [Figure 13]. In many diseases, the caudate lobe is larger than the rest. In the liver cross section, measurement of this lobe relative to the rest, the quotient should be normally less than 0.55 [Figure 14 and 15].

Figure 13 Measurement of liver size: Length CC,cranio-caudal; depth VD, ventrodorsal and the maximum distance of diaphragmatic dome to the lower edge of the liver in the MCL Max.
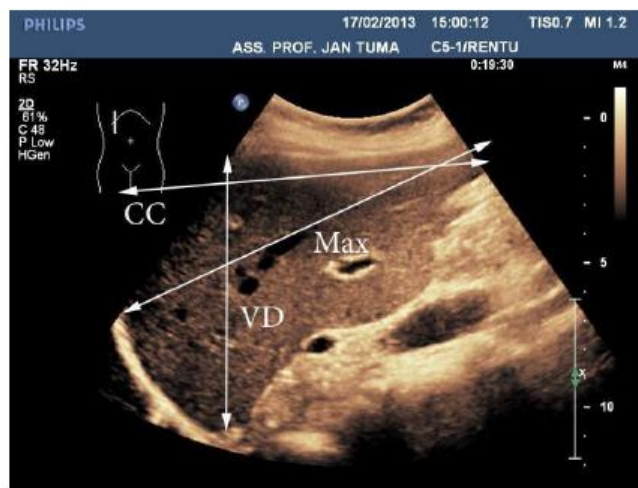

Figure 14 Measurement of the size of the caudate lobe and the overlying segments.

Figure 15 Measurement of the size of the caudate lobe and the right lobes. The ratio of caudate lobe LC / right lobes, RL should be <0.55 (here 0.34, normal).

Shape and contour

The liver in the sagittal section through the left lobe has a triangular shape with a sharp angle. This angle may be greater and the shape sometimes also rounder, if the sagittal sections moves slowly from left to right [Video 05.04 JT]. There are also several variations of this form, pyknic people tend to have a short and deep liver [Figure 16], the people with asthenic habitus or slim people are more equipped with a flat and long liver [Figure 17].

There is also a very long so-called Riedel's lobe [Figure 18]which is nothing more than a normal variation and has no pathological significance. Shape variations of the left lobe range from virtually absent, very short to very long, expanding almost to the spleen[Figure 19 and 20].

Figure 16 Pyknic habitus: A short and deep liver (in the form of a dolphin-head).

Figure 17 Asthenic habitus: liver in the form of a swallow's wings.

Figure 18 Riedel`s lobe: a normal variant of a very long right lobe.

**Figure 19 Very short left lobe (often in pyknics).**

The contour of the liver is absolutely smooth. In the early stages of cirrhosis, there are only very subtle irregularities of contour. There is a very fine representation of the contour with a high resolution probe.

Figure 18 Very long left liver lobe (often in asthenics) above the spleen. L Liver. The spleen is also indicated. The images also show shear wave elastography using acoustic radiation force impulse (ARFI) for the liver (a) and the spleen (b).

a

b
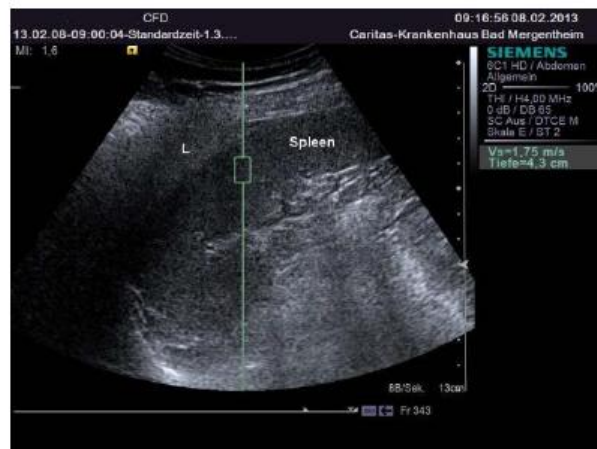
Surface, outline

The normal liver surface should be smooth with no protruding lumps or indentations. The inferior liver border in the normal patient should have an acute angled edge. Liver surface border delineation and other ultrasound criteria are described in the respective chapters.

Texture and echogenicity (echopattern)

The normal echogenicity of the parenchymatous organs in the upper abdomen is something fundamentally different in the different age groups. In young patients, adolescents and also in asthenic patient one sees a tendency of hypoechoic liver and pancreas than in obese and elderly patients. In addition to this weight and age dependence, there are also differences between the various organs. Normally the most echogenic is the spleen, followed by the liver and then the slightly hypoechoic renal cortex, and finally the very hypoechoic renal medulla. Our eyes distinguish relative differences (contrast) between the individual echogenicity but poorly identifies its absolute values. Thus a direct measurement of the brightness of the organs in relation to one another in digital images would be advantageous but this is not practical.

In conclusion the normal liver parenchyma is of medium homogenous echogenicity. It is usually slightly darker than the spleen and slightly brighter than the renal cortex, independent of age except in childhood. Liver surface and vessel borders are smooth and vascular architecture, with its classic branching dichotomy, is perceived as a harmonic and detailed aspect. The normal parenchyma image varies very little between individuals.

Consistency (Elasticity)

The consistency of the liver or its elasticity is an important parameter, which help us to differentiate between a healthy liver, which is elastic, and a fibrotic liver or cirrhosis, which are stiff. The examination technique is important here. The probe is taken in the right hand and the left hand performs a sagittal motion above the left lobe [Video 05.08 and 05.11]. When one is familiar with this technique, it may be a rough classification of elasticity: grade 1: normal liver; grade 2: slight or moderately stiffened fibrotic liver; grade 3: stiff fibrotic and cirrhotic liver. More exact measurements of elasticity are more sophisticated techniques of strain imaging (elastography) [see Chapter 2].

In cirrhosis hepatic arteries are prominent, in contrast to the smaller branches of portal veins. The intrahepatic bile ducts are not visible under normal conditions. In case that the intrahepatic bile ducts are enlarged this is called "shotgun phenomenon", i.e. the tubular structures of the portal vein and biliary system are visible in parallel [Figure 21].

Figure 19 The "shotgun phenomenon". The intrahepatic bile ducts are not visible under normal conditions but can be identified because of the parallel trajectory to the hepatic artery, if they are enlarged, then there is the so-called shotgun phenomenon (arrows).

Figure 20 Porta hepatis with portal vein, PV, hepatic artery, HA and ductus hepatocholedochus, DHC. Vena cava, VC is also shown.
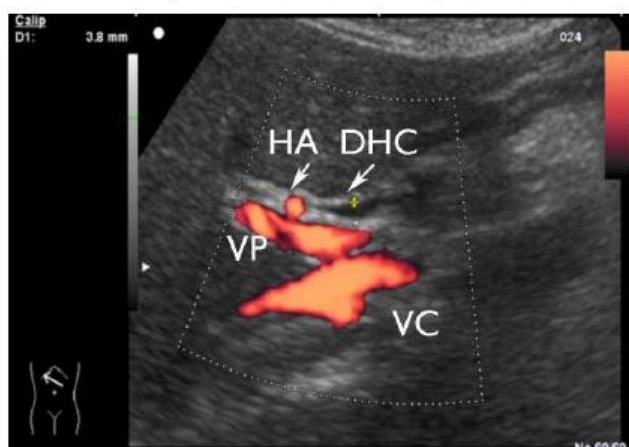
Hepatic vessels

Liver anatomy and blood supply

Hepatic perfusion is characterised by two vascular systems with completely different haemodynamics and one outflow system:

- Arterial inflow (high pressure, low flow resistance)
- Portal-venous inflow (low pressure, low flow resistance)
- Venous outflow (low pressure and low flow resistance)

The liver hilum is composed of the portal vein, the hepatic artery and the biliary duct [Figure 22] [Images & video 7, http://www.efsumb-portal.org/ep/article.php?id=147]. Colour Doppler imaging is used to distinguish between blood vessels and bile ducts in which no fast flows are present, and thus no Doppler signals can be derived here.

The normal flow patterns in the hepatic artery, in the portal vein and in the hepatic vein are illustrated [Figures 23-25].

Portal vein

Formed by the confluence of the splenic and superior mesenteric vein, the portal vein can be displayed sonographically by scanning more or less perpendicular to the lower costal margin (orientation can be achieved by reference to the right shoulder to the umbilicus), preferably in a left decubitus position and on variably deep inspiration [Images & video 7, http://www.efsumb-portal.org/ep/article.php?id=147]. Intrahepatically, the portal vein bifurcates into a main left and right branch. The first (right) portal vein branch splits into an anterior and a posterior branch, which itself leads to the segments V to VIII. The latter (left) main portal branch bifurcates into segments II and III and, into the left medial branches for segments I (caudate lobe), IVa and IVb. The portal vein shows typically hyperechoic boundaries.

Portal vein diameter and flow pattern is measured using an intercostal approach at an angle close to $0°$, just before the portal vein splits into the right and left branches. Biphasic fast Fourier transformation (FFT) Doppler spectrum of the portal vein should be documented during a 5 - 8 sec suspended respiration at a mid-respiration level, avoiding respiratory and thoracic pressure influences. The sample gate is adjusted to the inner diameter of the vessel and the FFT spectral analysis is recorded. The maximum (V_{max}) and minimum (V_{min}) velocity in centimetres per second of an undulational circle are set automatically or manually. The differences in V_{max} and V_{min} are calculated as a parameter of biphasic oscillations as well as the portal vein resistance index (($V_{max}–V_{min})/V_{max}$) in a similar way to the resistance index of arterial vessels. Normal portal venous blood flow undulates slightly (normal values, 12 - 24 cm/s using the intercostal approach [Figure 23].

Figure 21 The portal vein (arrows) is scanned using a transcostal approach on (a) colour Doppler imaging and (b) continuous duplex scanning with a normal flow pattern range of 12 – 24 cm/s.

a

b
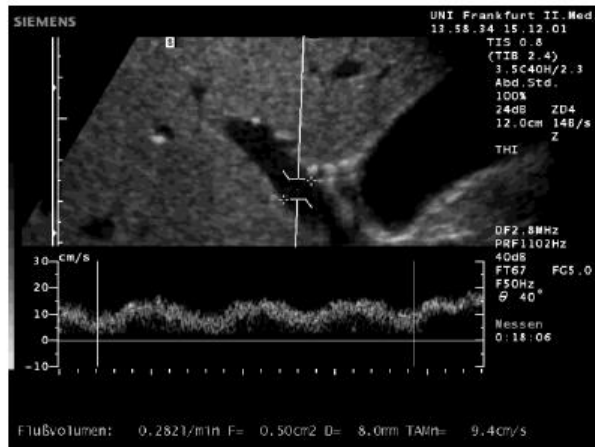
Hepatic veins

The three hepatic veins are positioned in between the liver segments. Their course, in addition to the Glisson's triad, is helpful in defining liver lobes and liver segments. The number and course of the hepatic veins are somewhat variable. The hepatic veins are bordered with a hypoechoic thin wall [Figure 24].

Figure 22 Hepatic vein blood profile. (a,b) The normal hepatic flow profile is triphasic in the right liver vein (RLV); the portal vein is also indicated (PV). Atrial contraction is shown by 1,2 and 3 indicate biphasic flow in the direction to the heart.

a
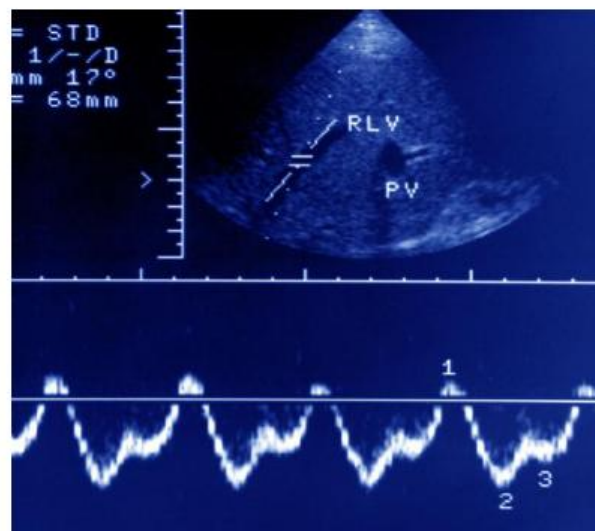
b

Hepatic artery

The common hepatic artery originates from the coeliac axis, branching into the gastroduodenal artery and the proper hepatic artery (arteria hepatica propria). Anatomical variations are frequent (in up to 50% of the population), and include the origin of the left proper hepatic artery from the left gastric artery, as well as the variable arterial supply to the liver by superior mesenteric arterial branches. The hepatic artery runs with the portal vein, the right main arterial branch frequently meanders around the portal vein and is displayed sonographically as short segments medially (or less often laterally) of the portal vein. The arteries are in most cases visible only centrally [Figure 25 and 26].

Figure 23 Extrahepatic hepatic arterial vessels. (a) B-mode ultrasound, (b) colour Doppler imaging of the coeliac trunk, which supplies the arterial blood for the liver and the perihepatic structures. The liver hilum is often best examined in a left lateral decubitus position [Images & video 7, http://www.efsumb-portal.org/ep/article.php?id=147].

a
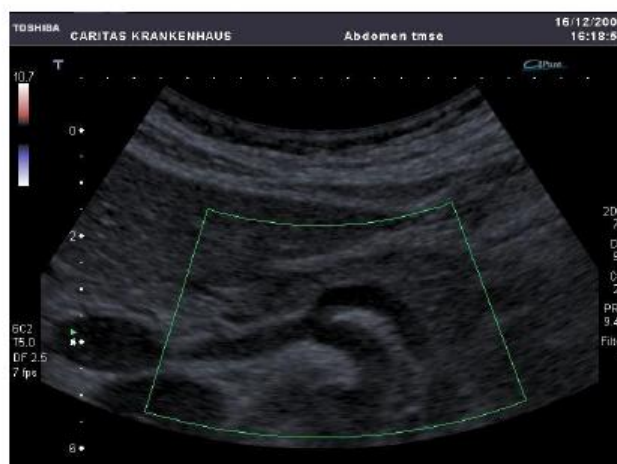
b

Figure 24 Hepatic artery flow profile.

Bile ducts

Bile ducts accompany the portal vein and hepatic artery branches from the liver hilum into the liver lobules. Intrahepatically, they form the ductus principalis dexter and the ductus principalis sinister, which join as the common bile duct (CBD). The extrahepatic course of the CBD is cranially (prepancreatic), often ventral to the portal vein and caudally (intrapancreatic) more dorsolateral [Images & video 5, http://www.efsumb-portal.org/ep/article.php?id=147].

Clinical impact

An important role in assessing the various stages of cirrhosis is the measurement of the portal venous flow. The patient should be positioned for this measurement in left oblique position so that an optimal representation of the portal vein is made possible with only minimal or zero Doppler angle. Normal values for the time-averaged maximum velocity (TAMV) is over 12 cm/sec and the average minute volumes are between 500 and 1500 ml/Min. The hepatic artery flow curve may also change form during physiological states, as well as in liver disease. However, this has more of a scientific value and is not used in routine diagnostics. This is partly due to the

complexity of the process and partly to the large variability in the measured values. The compensatory rise in arterial flow in the event of a reduction of portal vein flow in liver cirrhosis is a known mechanism that can also be reversible if, for example, the stabilized cirrhosis and especially the edematous component of the reduced elasticity are declining.

Lymph nodes

Improvement of sonographic technology, techniques and knowledge of well-defined anatomical sites of perihepatic lymph nodes (between the inferior cava and portal vein next to the right renal artery) have led to improved identification of not only enlarged, but also normal sized lymph nodes in the liver hilum by ultrasound [Images & video 6, http://www.efsumb-portal.org/ep/article.php?id=147]. Normal lymph node size is up to 19 mm. Perihepatic lymph nodes in the hepatoduodenal ligament are commonly found next to the cystic duct are, therefore, called cystic duct lymph nodes [Figure 27 and 28]. However, lymphatic vessels are too small to be visualised on ultrasound.

Figure 25 Perihepatic lymph nodes in the hepatoduodenal ligament (LK) are commonly found next to the cystic duct and are therefore known as cystic duct lymph node. They are shown here in a post-mortem examination on (a) ultrasound and (b) macroscopically. VCl, inferior vena cava.

a

b

Figure 28 Two groups of lymph nodes can normally be detected in anatomical examinations: the dorsal group in the hepatoduodenal ligament adjacent to the common hepatic bile duct and cystic duct ("cystic duct nodes", seen in (a) and (b) between markers (+). VCI, inferior vena cava; VP, portal vein; and (c) ventral in the hepatoduodenal ligament adjacent to the orifice of the foramen epiploicum next to the common hepatic artery (between markers).

a

b
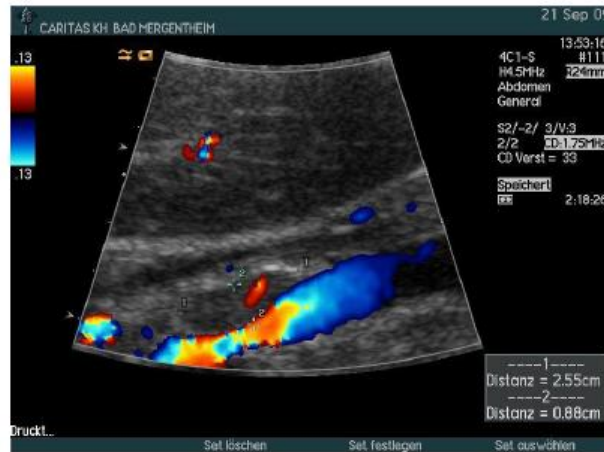
c

Situs inversus

The liver is a large organ, located mainly below the right diaphragm. This position is typical. Abnormality may be a situs inversus, i.e. the liver is located primarily below the left diaphragm, and all intra-abdominal organs are situated vice versa [Figure 29].

Figure 29 Situation at a situs inversus: shown here with the reverse probe.

This can be demonstrated with ease when the probe is held reversed. Another variant is the diaphragmatic hernia, which allows a larger portion of the liver to be above the diaphragm. In this situation the liver itself is located supra- and infradiaphragmal.

VIP: Very Important (and most frequent) Pathologies, diffuse liver diseases

Ultrasound criteria for analysing diffuse liver disease include the evaluation of:
- Liver parenchyma (echo-texture, ultrasound attenuation, vascular architecture, etc.) as well as the liver surface (a high frequency transducer can be helpful to detect details of superficially located structures).
- Liver hilum structures including perihepatic lymph nodes in the hepatoduodenal ligament, lymph nodes in inflammatory liver disease or neoplastic infiltration.
- Hepatic vessel flow patterns using colour and pulsed wave Doppler imaging (CDI).

Hepatic steatosis (fatty liver)

Hepatic steatosis (fatty liver) is the most common liver pathology. Sensitivity and specificity of the detection of hepatic steatosis by B-mode ultrasound examination can be very high in the hands of an expert investigator, who consistently applies specific criteria in patients with significant fatty liver disease. In transabdominal ultrasound, hepatic steatosis is characterised by increased echogenicity, which is often compared with spleen or kidney parenchyma at the same depth [Figure 30].

Figure 26 Sonographic signs of hepatic steatosis (fatty liver) include hepatomegaly with rounded borders, increased echogenicity, ultrasound attenuation caused by absorption, scattering and beam divergence,and decreased detail display of intrahepatic vascular architecture. There is an exaggeration of the difference between the

kidney parenchyma and liver echogenicity. The right kidney is shown between callipers (+).
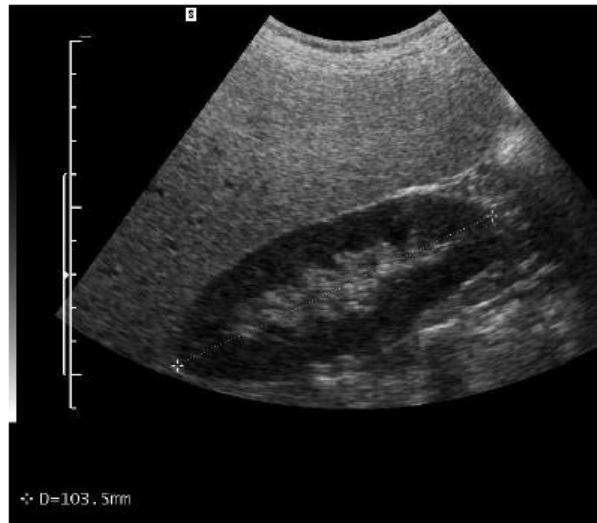
Supporting findings include ultrasound attenuation (the decrease in intensity as sound travels through a material, caused by absorption, scattering and beam divergence). Attenuation decreases the detail of vascular architecture, and it can cause a loss of visibility deeper within the liver and impeded imaging of the diaphragm.

The flow in the normal hepatic vein is triphasic, however, it may be monophasic in diffuse diseases such as fatty liver [Figure 31].

Figure 27 Fatty liver. In fatty liver the normally observed triphasic flow is changed to a monophasic flow pattern due to elastic changes within the liver parenchyma.
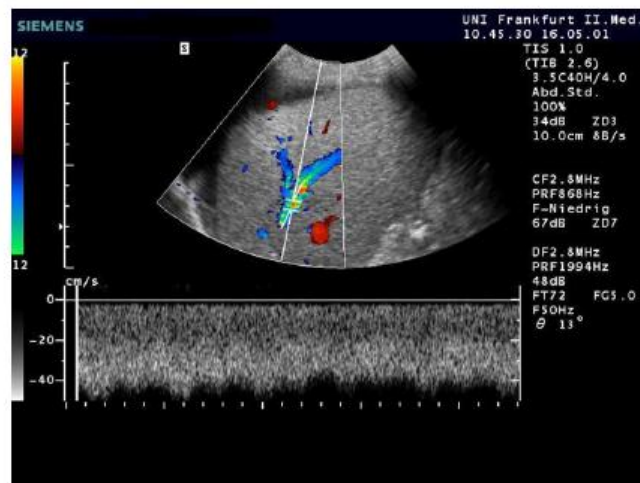
In the vast majority of patients with hepatic steatosis, distinctive hypoechoic areas in the liver hilum can be demonstrated by ultrasound examination. It is believed that the presence of focal hypoechoeic areas (FHA) within the liver hilum (and elsewhere in

the liver) corresponds to parenchymal islands, with, or close to, normal fat content (owing to a locally different blood supply), which are surrounded and contrasted by bright echogenic parenchyma with fatty infiltration. This may cause differential diagnostic difficulties of liver tumors.

Reversed change, i.e. hyperechoic area in an inconspicuous liver can also be confusing. Hyperechoic areas correspond to a focal steatosis, hypoechoic to focal non-steatosis. Pathophysiologically, areas of different fat content are caused by the different arterial and portal venous blood supply in comparison with the surrounding liver parenchyma, which is mainly portal venous and therefore contains a higher fat and insulin concentration in focal fatty infiltration.

The described differences in echogenicity are not associated with architectural changes in contrast to true neoplasia[Figure 32 and 33].

In patients with steatosis the portal venous flow is flattened and is demonstrated by a low resistance index.

Figure 28 Hepatic steatosis. Perhaps the most objective, and therefore the most important, sign of hepatic steatosis is the circumscribed focal hypoechoic areas in the liver hilum examined in a left posterior oblique position. (a) B-mode ultrasound demonstrates a focal liver lesion in between callipers (+). (b)Colour Doppler imaging indicates a centrally located vessel of undetermined origin. (c) Contrast enhanced ultrasound shows the typical enhancement pattern. Typically a centrally located arterial vessel can be displayed in the arterial phase (arrow) and (d) a portal vein branch in the portal venous phase (arrow) and homogenous enhancement in the late phase [EFSUMB Case of the Month, www.EFSUMB.org; see also video].
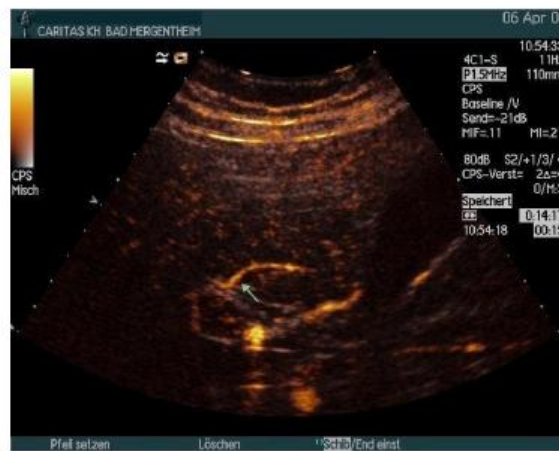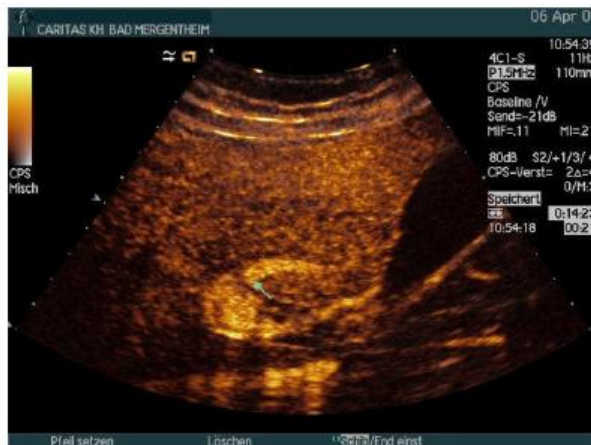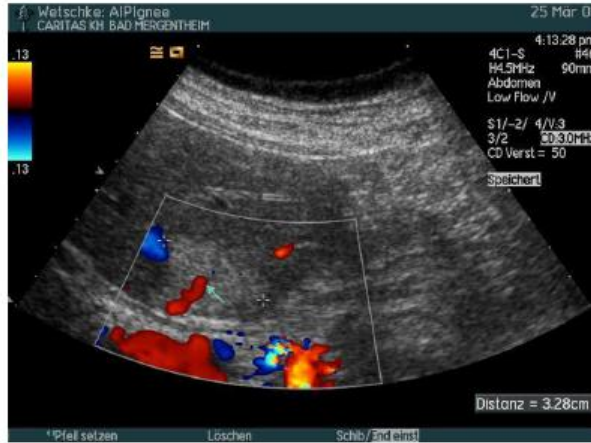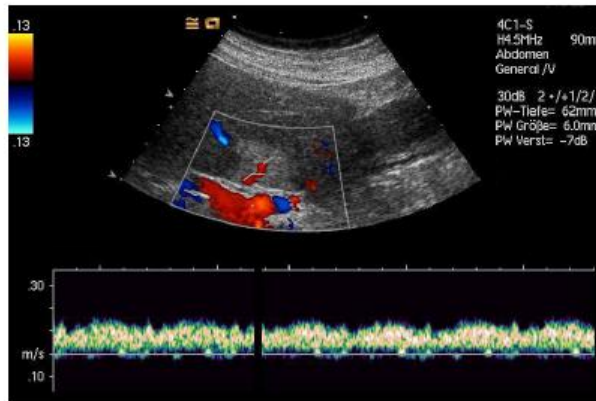
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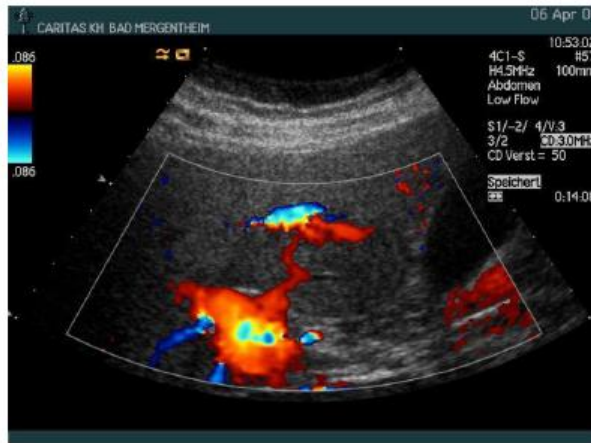
c

d

Figure 29 Hepatic steatosis indicated by focal hyperechoic areas in the liver hilum. They are characterised by centrally located (portal) vein branches identified by colour Doppler imaging (a), spectral analysis

(b) and CEUS (c). Such lesions are also typically found subcapsular next to the teres ligament [EFSUMB Case of the Month, www.EFSUMB.org; see also video].

a

b

c

Liver cirrhosis

The accuracy of ultrasound in the correct diagnosis of liver cirrhosis in patients with complications (ascites, splenomegaly and collaterals) is high (>90%). In the initial stages and in micronodular cirrhosis, it may be overlooked in up to 30% of cases.

In the initial stage, the liver is enlarged whereas in late stages of cirrhosis, the liver shrinks significantly. Disproportional segment atrophy and hypertrophy are typical. The rounded shape of the lower edge is visible initially, mostly in a stage of steatohepatitis and incipient cirrhosis. The contour is not smooth, very fine surface irregularities are visible with high-resolution linear probe [Figure 34 and 35]. The hardening of the liver (decrease in elasticity) will be visualized by palpation under ultrasound control [**Video 05.08 and 05-11 JT**].

Figure 30 Typical signs of liver cirrhosis include (a) inhomogenous echo-texture and irregular liver surface delineation (arrow); (b) distinctive nodules are also suggestive. Sometimes it may be difficult to identify the liver parenchyma, in these cases the organ is indicated as well: Leber (liver).
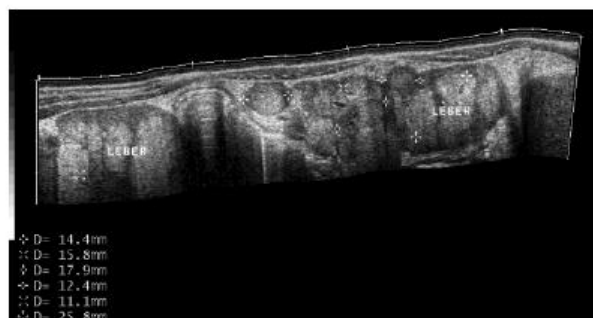
a

b

Figure 31 Fine granulated surface of the cirrhotic liver (arrows).

Perfusion is also an important parameter in the assessment of cirrhosis, the increase in portal pressure is discussed in the next paragraph. By an increased portal pressure the secondary enlargement of the spleen and formation of esophageal and abdominal varices could develop.

The echotexture of the healthy liver is very fine and homogenous. In cirrhotic liver, we observe coarsening of inhomogeneous echotexture [Figure 36].

Figure 32 Liver lobes and segments may behave differently during the course of a disease, as shown in this patient with systemic scleroderma and gradual shrinkage of the right liver lobe (between +). The changes to the liver evolved gradually over 10 years.

Architectural disproportions with hypertrophy of the caudate lobe and atrophy of the remaining liver may develop [Figure 37].

Figure 33 Hypertrophy of caudate lobe in cirrhotic liver. The remaining liver is atrophic.

Nodular liver surface (especially when using high frequency transducers) has an excellent positive predictive value (close to 100%) for cirrhosis. A disproportional volume enlargement of the caudate lobe in relation to the right and left lobe can be indicative of liver cirrhosis, but this sign is of limited value in daily clinical practice. Coarse liver parenchyma and a disturbed or destroyed vascular architecture as a sign of portal hypertension, such as slow and reversed portal flow and collateral vessels, are other indicators of liver cirrhosis. In Doppler studies, a rise in the arterioportal peak velocity ratio (maximum velocity of the hepatic artery divided by the maximum velocity of the vena portae) of more than 3.5 is predictive of cirrhosis. The positive predictive value for the detection of portal hypertension is excellent; the signs include reversed portal flow and the detection of collateral vessels. An enlarged portal vein diameter greater than 1.25 cm or a reduced portal vein flow velocity [Figure 38] indicates cirrhosis with a sensitivity and specificity of approximately 80%. However, all these parameters are of limited value in daily clinical practice.

Figure 38 Cirrhosis with ascites. The portal vein flow is slowed considerably (TAMV 3.5 cm / sec). V max in the portal vein (PV) is only 10 cm / sec, Vmax in the hepatic artery (HA) is 80 cm / sec and HA/PV ratio is considerably increased to 8.0 (normal <3.5).

VIP: Very Important (and most frequent) Pathologies, focal liver diseases

The definition of a Focal Liver Lesion (FLL) is the difference in echogenicity between a circumscribed area and the surrounding liver tissue. Differences in ultrasound echogenicity show usually, although not necessarily, a pronounced difference in X-ray attenuation and MR as well. Consequently, most FLL are visualised by all three sectional imaging modalities, whereas a few are shown by only one or two of these modalities.

FLL are characterized by the location (segment), number (single or multiple), size, shape, boundary, echogenicity and vascularity. Ultrasound contrast agents (UCA) have improved the detection/exclusion rate of FLL in diffuse liver disease. FLL can be divided into benign and malignant lesions. Typical benign focal liver lesions are cysts, calcifications, hemangioma, focal nodular hyperplasia (FNH) and the rare hepatocellular adenoma (HCA). Malignant lesions can be divided into primary (hepatocellular carcinoma (HCC), cholangiocellular carcinoma (CCC)) and secondary (metastases) focal liver lesions.

FLL are detected and characterised sonographically by echogenicity differences from the surrounding liver tissue, as well as by the detection of hyper- or hypovascularisation (on colour Doppler ultrasound). Conventional B-mode ultrasound makes it possible to unequivocally detect typical liver cysts and calcifications. However, detection and characterisation of liver tumours still represents a challenge to all imaging modalities despite the advances in imaging techniques (*i.e.* ultrasound, CT and MRI scanning).

Liver cysts

Liver cysts are frequent findings and easily diagnosed using conventional B-mode ultrasound. They are characterised as round, anechoic, smoothly delineated

structures with refraction shadows at the edges, entry and exit wall echo and dorsal echo enhancement. Cysts with all these sonographic characteristics are defined as typical [Figure 39] whereas cysts showing only some of those are defined as atypical.

Figure 39 Typical liver cyst: thin wall, anechoic, distal echo enhancement (DE), tangential lateral shadow (TLS), entry echo (EE, black), exit echo (EE, white).

Calcification

Calcifications are characterised as hyperechoic structures, which normally show acoustic shadowing distally owing to reflection/attenuation of the ultrasound [Figure 40].

Figure 34 Calcifications with shadowing within the liver.

Hemangioma

Hepatic hemangioma is known to be the most common benign liver tumour, with an incidence at autopsy and imaging studies of up to 7%. Up to 10% of patients with hemangioma cannot be reliably diagnosed using imaging methods. In these patients

with malignant underlying disease ultrasound guided liver biopsy and examination of the specimen are required for a final diagnosis. Most hemangiomas demonstrate typical sonomorphological features in conventional B-mode ultrasound [Figure 43]. They are characterised as less than 3 cm in diameter, lobulated with a well-defined outline, located adjacent to liver vessels, demonstrate an hyperechoic texture and occasionally posterior acoustic enhancement owing to blood filled capillaries. Conventional colour Doppler ultrasound often detects little or no blood flow inside the hemangioma because the blood flow velocity in the capillary hemangioma is too slow. The supplying and draining vessels ("**feeding vessels**") may be visualised (depending on the ultrasound systems performance) at the edge of the lesion [Figure 41].

## Table 1   Typical haemangioma: diagnostic criteria

B-mode criteria
Less than 3 cm in diameter
Hyperechoic structure
Homogeneous inside
Round or slightly oval shape
Smooth outline
Absence of any halo sign
Possible detection of feeding and draining vessel
Absence of any signs of invasive growth
Posterior acoustic enhancement

Figure 35 Typical B-mode sonomorphology of liver hemangioma: hyperechoic tumour with a sharp boundary (a). CDI shows no relevant perfusion of hemangioma (b).

a

b
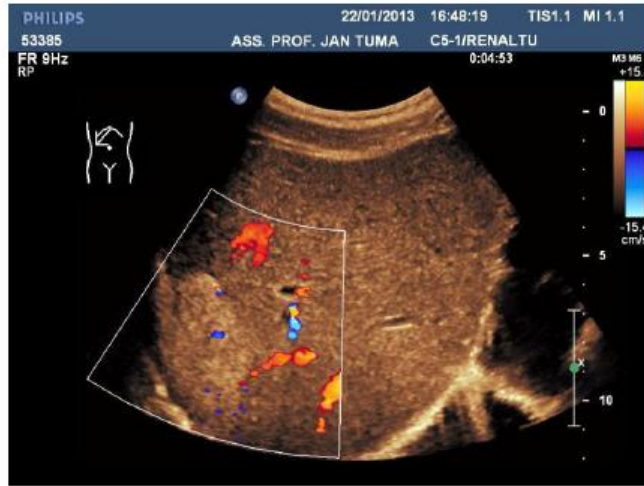
CEUS has markedly improved the correct diagnosis of hemangioma, which is now possible in > 95% of patients. CEUS demonstrates typical hemangioma imaging characteristics, i.e. peripheral nodular contrast enhancement and the iris phenomenon in a high percentage of patients with an undetermined lesion [Figure 42 and 43]. Most importantly they are hyper-enhancing in the portal venous and late phases.

Figure 36 Hemangioma with typical peripheral nodular contrast enhancement and centripetal fill-in. The lesion is displayed in the conventional B-mode scanning (a) and in contrast images (b-e) [EFSUMB Case of the Month, http://www.efsumb.org/asp/detail06.asp?ref=289&url=/case-month/case-archive.asp?ref=1].
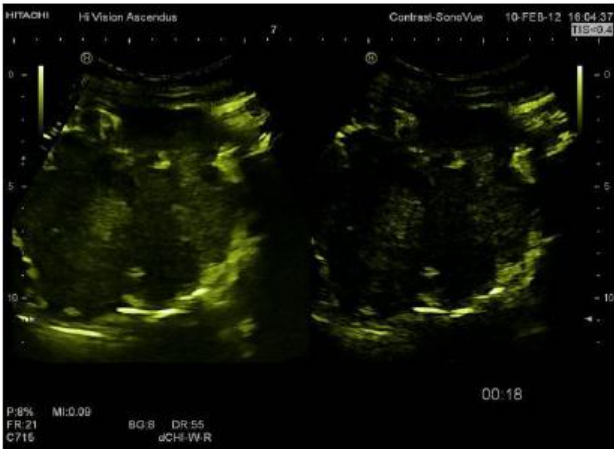
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e

f

g

Figure 37 Hemangioma (so-called giant hemangioma). B-mode (a), arterial (b,c) (using Microbubble Tracing Imaging [MTI]) and portal venous phases (d) are shown with peripheral nodular contrast enhancement and centripetal fill-in. It is important for diagnosis that the nodules are hyper-enhancing during all phases and that bubble destruction is avoided [(4)].
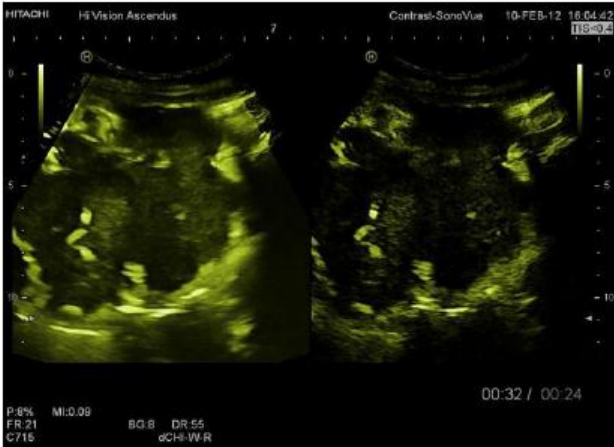
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Focal nodular hyperplasia (FNH)

FNH like HCA represent an important entity, benign, mostly incidentally discovered, which occur predominantly in young and middle-aged women. Differentiation between the two is essential because of the different therapeutic approaches. HCA is an indication for surgery because of the risk of hemorrhage and potential malignant transformation; in contrast FNH can be managed conservatively. Until recently non-invasive differentiation of, especially, atypical FNH from HCA and other benign or malignant neoplasia has remained challenging; there have been no satisfactory tests apart from histological examination of a liver biopsy sample. Histological features of FNH are controversial in the literature. Congenital absence of portal veins has been reported in a few patients, mainly children. Helical CT and MRI do provide some useful information in the diagnosis of FNH, especially when the lesion depicts typical features, such as a central scar and uniform hypervascularity. Typical features are only reported in approximately 50% of patients. FNH is typically an isoechoic tumour of variable size, with a central scar and calcifications (in 50 – 80%). CDI reveals an arterially hypervascularised tumour (in >90%) with characteristic central arterial blood supply [Figure 44].

Figure 38 Focal nodular hyperplasia. B-mode US (a) shows an unclear hyper- and hypoechoic lesion; Colour Doppler Imaging (CDI) (b) shows a typical central arterial vascular supply. Clear hyper-enhancement is seen in the arterial (c) using Microbubble Tracing Imaging [MTI]) and portal venous (d) phases [(4)].
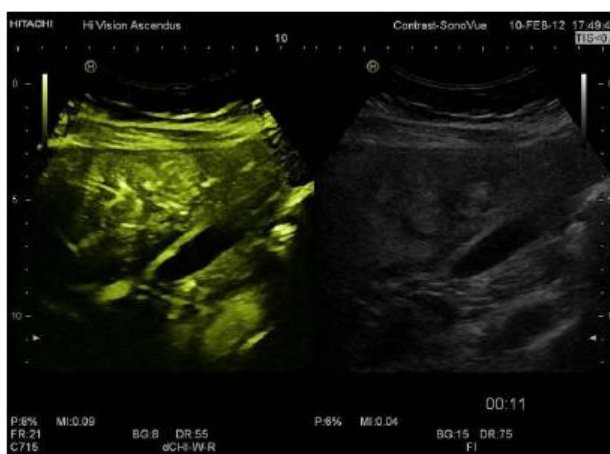
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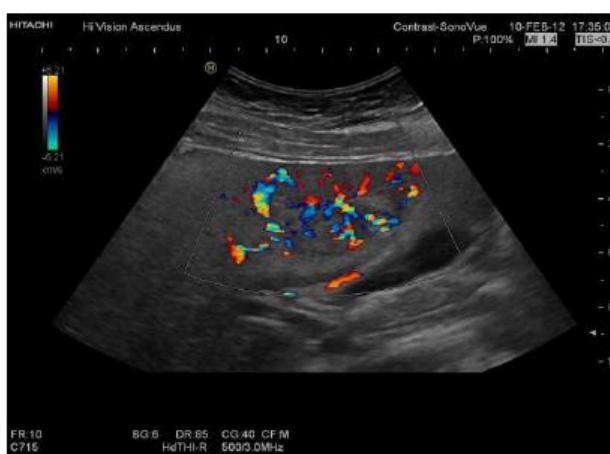
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d

Figure 39 Focal nodular hyperplasia (FNH). In patients with FNH typically central arterial enhancement can be shown in comparison to the hepatic artery with wheel-spoke phenomenon and portal venous enhancement in comparison to the portal vein (a). In about one third of patients arterial vascular supply is eccentric (b). Additional tumours can be found in up to 30 % of patients (c) [EFSUMB Case of the Month http://www.efsumb.org/asp/detail06.asp?ref=291&url=/case-month/case-archive.asp?ref=1].

a
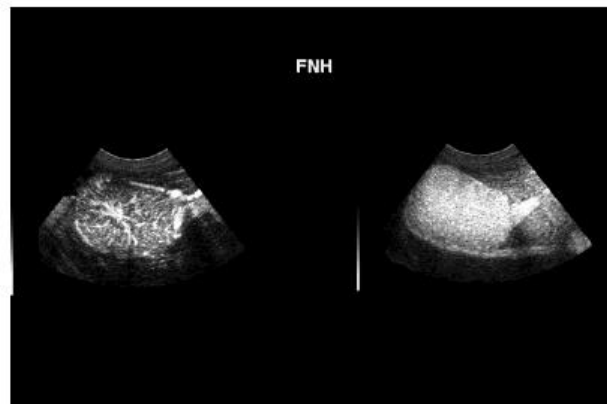
b

c

In many patients, increased blood flow compared with the surrounding liver tissue can be detected even in colour Doppler mode, which causes a so-called wheel-spoke phenomenon [Figure 44].

Hyperperfusion can be identified in native imaging and is by no means obligatory; it is reported in only approximately 50-70% of patients. Inter-observer reliability in recognising the wheel-spoke appearance is very low. The examination of the hepatic arterial and portal venous/sinusoidal phase by contrast enhanced phase inversion ultrasound allows for a reliable differentiation between FNH and HCA. This important finding can be explained by the lack of portal veins in contrast with FNH, which presents (atypical) portal veins in many but not all patients.

In contrast enhanced examination, FNH typically appears as a hyperperfused tumour-like lesion relative to the surrounding liver tissue in the early arterial phase. The lesion's hyperperfusion is easily visible with contrast enhancement during continuous scanning, compared with the surrounding hepatic arteries. Depending on the patient's cardiac output, some 8 to 20 s after injection of the echo-signal enhancer into the cubital vein there is a rapid take-up of the substance with demonstration of the arterial vascular pattern and enhancement from the centre outwards. During the portal venous phase FNH is isoechogenic with the portal vein, and, therefore, slightly hyperperfused in comparison with the surrounding liver parenchyma [Figure 44 and 45].
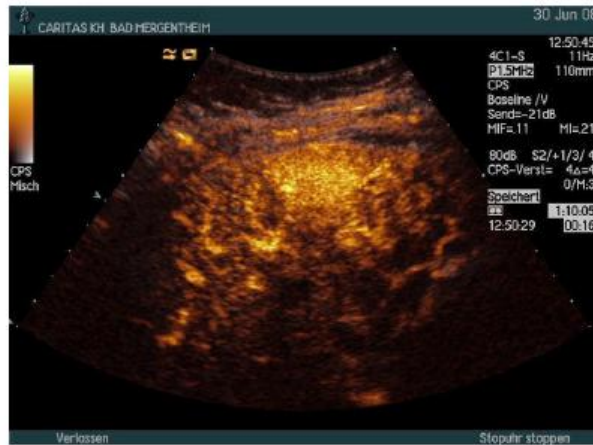
Hepatocellular adenoma

Hepatocellular adenoma

In B-mode ultrasound, of an otherwise normal liver, HCA is usually isoechogenic with the surrounding liver tissue. Owing to this lack of echogenicity, an adenoma can be very difficult to differentiate from the surrounding liver tissue.

HCA exhibit predominantly marginal arterial hypervascularity, which can be shown by CDI and CEUS.

Histologically no portal veins (and in addition, no bile ducts) are present in adenomas, therefore, CEUS demonstrates only homogeneous enhancement during hepatic arterial phase (8 to 25 s after injection) but no portal venous enhancement resulting in slightly hypoenhancing (hypoechoic) appearance in comparison with the surrounding liver parenchyma since some overlap of the arterial and capillary phase (continuing over some minutes) may be observed [Figure 46 and 47].

Figure 40 Hepatocellular adenoma (HCA). (a) B-mode ultrasound shows an unspecific slightly hyperechoic focal liver lesion. (b,c) Contrast enhanced ultrasound (CEUS) revealed only arterial phase enhancement after administration of SonoVue®. (d) At the end of the arterial phase (<30 s after administration of SonoVue®) a hypoechoic liver tumour was detected on CEUS, which is the typical enhancement pattern of HCA in comparison with focal nodular hyperplasia (FNH), which showed more portal venous enhancement than the surrounding liver parenchyma in 96% of 300 patients with FNH [(1)].

a

b

c

d

Figure 41 Differential diagnosis of FNH and HCA using Dynamic Vascular Pattern (DVP) recognition. FNH shows hyper-enhancement (orange, contrast enhancement line always above the parenchyma [white line]) during both arterial and portal venous phase (a,b) whereas HCA show only hyper-enhancement (orange) during the arterial phase and slightly hypoenhancement (blue, contrast enhancement line in the arterial phase above and in the portal venous phase below the liver parenchyma) during the portal venous phase [(2)].
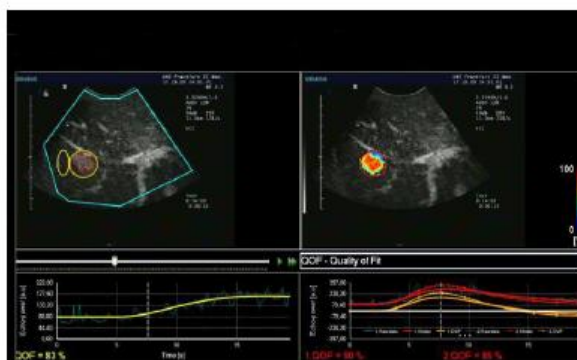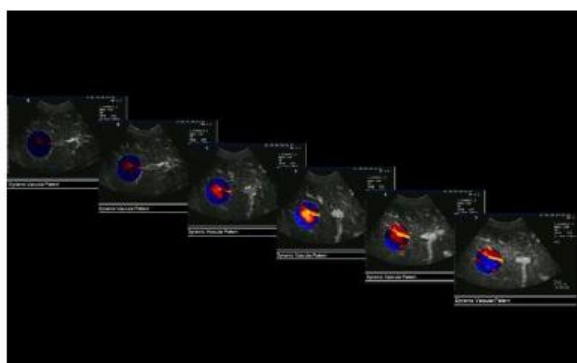
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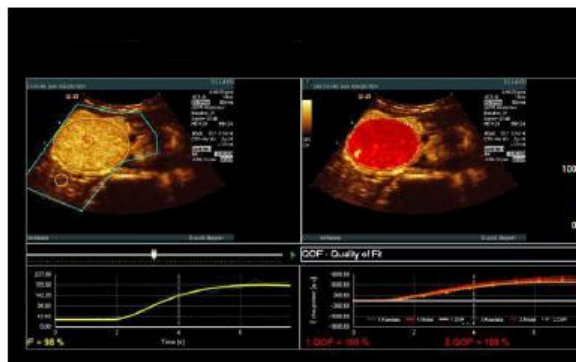
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Abscess

The **patient's** medical history and occasionally the physical examination (febrile temperature or signs of sepsis) are most helpful in differentiating abscesses from necrotic metastases. Phlegmonous inflammation and abscesses demonstrate the variable and sometimes confusing change in B-mode ultrasound image over time. The initial phlegmonous inflammation is often isoechoic in comparison with the surrounding liver parenchyma and is sometimes difficult to recognise. In older (chronic) abscesses hypervascularitiy of the nodule border might be confused with a pseudotumour of the liver, even histologically. Small disseminate candida abscesses might be confused with lymphoma or circumscribed hemophagocytosis syndrome (especially in young patients). Puncture and drainage (if necessary) are the diagnostic and therapeutic interventions. Abscesses of up to 5 cm can be drained in one procedure; however, larger abscesses need to be treated over a number of days.

The initial phlegmonous inflammation is often hypervascular in comparison with the surrounding liver parenchyma, but is difficult to recognise. In older (chronic) abscesses hypervascularitiy of the nodule border is typical. In typical cases CEUS shows sharply delineated hypervascularity (demonstrating the pseudocapsule) and no gas bubbles inside the lesion [Figure 48].

Figure 48 Liver abscess. (a) Typical liver abscesses demonstrating gas inside the lesion (arrow). (b,c) In CEUS, there will be no central signal at all, but a pronounced hyperperfusion at the abscess border. The underlying cause in this patient, choledocholithiasis, is detectable (not shown).

a

b

c

Hematoma

Hematoma can be clinically diagnosed in most cases. The spontaneously evolving and painful hematoma is typical for amyloidosis of the liver. B-mode ultrasound image appearance depends on the stage of the hematoma. Very early hematomas are hyperechoic, and later stages are iso- or mostly hypoechoic [Figure 49 and 50]. Therefore, a change in morphology is typical for hematomas. CDI demonstrates no flow pattern as there is no vascularity. CEUS is helpful in defining circumscribed *vs* diffuse infiltrating hematoma. CEUS might be helpful in clinically uncertain cases with similar results to those shown for CT [Figure 50 and 51].

Figure 49 Hypoechoic liver hematoma. CEUS demonstrates non perfused area of hematoma and early vessel invasion in the border area.
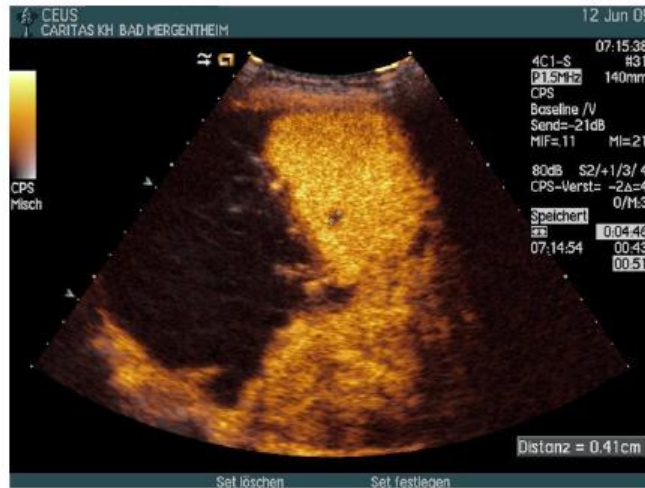
a

b

Figure 42 Spontaneously evolving and painful haematoma is typical for amyloidosis of the liver.
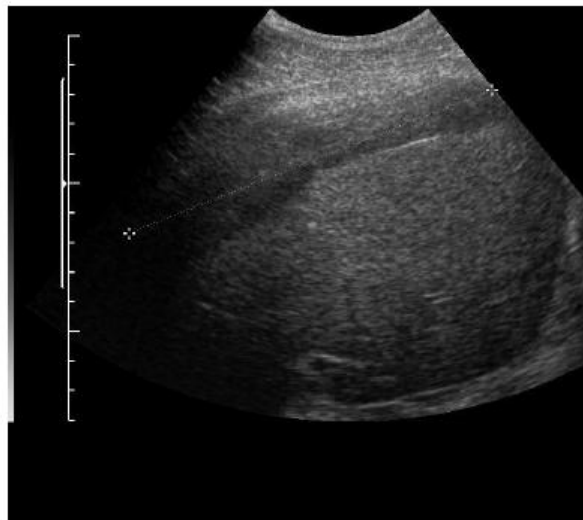

Figure 43 Focal hypoechoic liver lesions (a). CEUS (left picture) shows non perfused area: hemorrhage, no tumour (b).

a

b

Hepatocellular carcinoma (HCC)

This is the most important and severe tumour that occurs on cirrhotic liver. There are no typical criteria in B-mode ultrasound in small HCC (<30mm). However a lesion which appears in the 4 − 6 months after systematic evaluation should be suspected as being a HCC. In general, the echogenicity of the lesion depends on its size and on the morphology of the surrounding liver tissue (cirrhotic vs non-cirrhotic). In normal liver, HCC is usually iso- or slightly hypoechoic compared with the surrounding liver tissue. On cirrhotic liver, HCC in an early stage can be very difficult to identify because of the tumour morphology responsible for an iso-, hypo- or hyperechoic aspect. Dysplastic nodules are sometimes difficult to differentiate. However, nodules between 10 − 20 mm developed on cirrhotic liver represent dysplastic nodules. HCC are, in most cases, distinctly hypervascularised using conventional CDI [Figure 52].
From a differential diagnostic point of view it is then necessary to consider metastases of hyperperfused tumours, e.g. a hypernephroma, breast carcinoma, lung cancer or more typical carcinoid tumours. Metastases of primary extrahepatic tumours are, however, rare in a cirrhotic liver. On CEUS, HCC typically exhibits hyperperfusion of the tumour compared with the surrounding liver tissue at this point

there is no discernible contrast effect in the surrounding liver. In the HCC a typically chaotic vascular pattern is observed, which is a sign of neovascularisation of the tumour. Regenerative nodules may also exhibit an additional arterial enrichment. Analysis of the portal venous phase makes it possible to differentiate these isoenhancing nodules from the weakly contrasting HCC [Figure 53]. CEUS has proven to be effective in the differential diagnosis of cirrhotic nodules (regenerative and hyperplastic nodules).

Figure 44 Hypoechoic hepatocellular carcinoma with typically peripheral located hypervascularity using colour Doppler imaging.
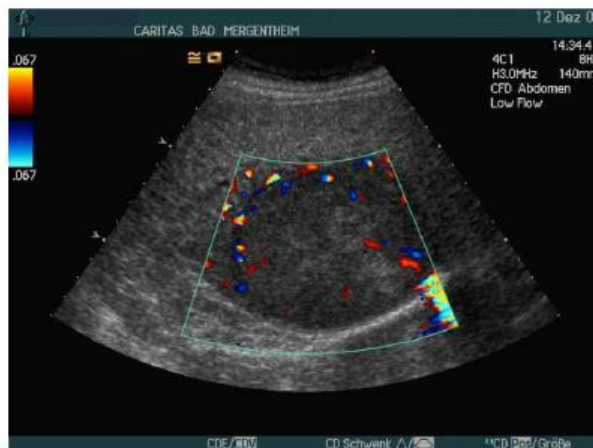

Figure 45 Hepatocellular carcinoma (HCC) in B-mode: the findings are nonspecific (a). CEUS in HCC: in very early perfusion (11 s after bolus injection of contrast agent) is visible rapid filling of highly pathological tumour vessels (b). CEUS in HCC 13 s after bolus: tumour with pathological vessels, now begins perfusion of the parenchyma (c). CEUS in HCC 67 s after bolus: comparably good perfusion of the tumour and liver parenchyma (d). CEUS in HCC in very late phase 4. 30 s after bolus: clear hypoperfusion of the tumour relative to the remaining liver (e).

a

b

c

d

e

Cholangiocellular carcinoma

Cholangiocellular carcinoma (CCC) is the second primary liver neoplasia. CCC can occur extrahepatically along the bile ducts [Figure 54], in the liver hilum as so-called Klatskin tumours (the hilar CCC is the most common) [Figure 55], but they may also appear as primary solid tumours in the liver (peripheral CCC). For the peripheral type there are no typical sonographic characteristics, and the diagnosis is usually made incidentally within the framework of a biopsy of a mass found in the liver. Ultrasound examination shows a solid mass, which can have any echogenicity and exhibits signs of a malignant growth. The liver metastases of a peripheral CCC are often situated like satellites around the primary focus. The majority of circumscribed CCCs are often slightly hypervascularized. In contrast to HCC which most often can be observed in liver cirrhosis CCC most commonly occurs in the non-cirrhotic liver.

Figure 46 Extrahepatic CCC (10 mm) in the common bile duct (CBD). CEUS was helpful in the differential diagnosis since CCC enhance whereas sludge and bile duct stones do not [(3)].
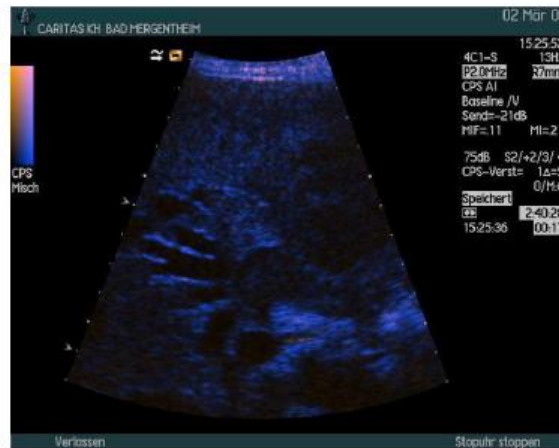

Figure 47 Cholangiocellular carcinoma in the Klatskin-position. Cholangiocellular carcinomas can occur in the liver hilum as shown here. Contrast enhanced ultrasound reveals rim like arterial

enhancement and portal venous hypoenhancement, typically observed in malignant liver infiltration [EFSUMB case of the month details].
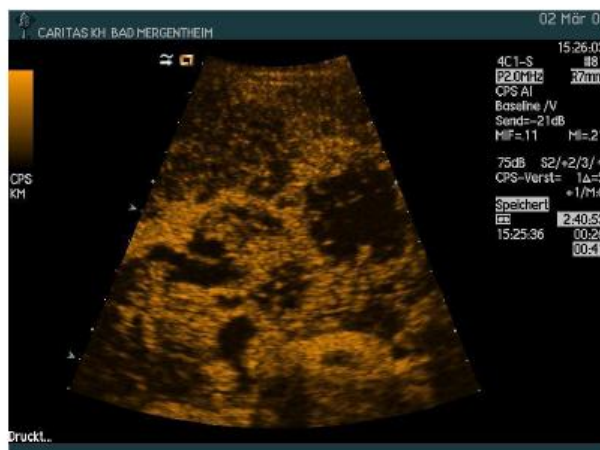
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Lymphoma

Lymphoma represent the third and very rare primary liver lesion.

Metastases of the liver

The parenchymal liver is the organ in which metastases of extrahepatic tumours are usually encountered. The special features of portal vein circulation favour hematogenous metastasis in the liver. Size of the metastases can be from microscopically detectable (cellular) infiltration to huge masses measuring more than 20 cm; the echogenicity varies widely [Figure 56].

Figure 48 Metastases of breast cancer with hypoechoic halo boundary.

Figure 49 Large metastases of colon carcinoma.

Intraoperative ultrasound (IOUS) may be helpful during surgery in certain cases. On CDI, metastases are, as a rule, poorly vascularised and their essential characteristic is a predominantly arterial blood supply (with little or no portal venous blood supply). Like echogenicity (most often hypoechoic), the vascularisation depends on the size, biological behaviour and nature of the primary tumour. Irregular vascularisation is often observed with broken-off vessels and peripherally situated arterio (porto-) venous shunt formation. The metastases of neuroendocrine tumours (e.g. metastases of renal cell carcinomas) may be more richly vascularised than other metastases. However, no conclusions are possible about the primary tumour on the basis of the echo-texture and vascularisation pattern observed.

CEUS has markedly improved the detection rate of liver metastases. Liver metastases can be reliably diagnosed as hypoenhancing lesions during the liver specific portal venous sinusoidal phase [Figure 57]. False-negative findings are rarely encountered whereas false-positive findings have to be ruled out by puncture and histological examination, *e.g.* abscess, necrosis, fibrous tissue and others.

Metastases may be already contrasted in the arterial phase, even though early arterial enhancement (in less than 15 s) is not typical and often the only observation is a degree of signal enhancement with a marginal emphasis ("**halo sign**" or "**rim sign**") [Figure 58]. Contrast of the vessels proceeds from the periphery towards the centre and the vascular pattern is irregular. In poorly vascularised metastases contrast enhanced colour Doppler ultrasound often reveals only small blood vessels situated at the edges (or within the lesion), and in many patients vascularisation cannot be imaged at all. In the portal venous phase metastases are contrasted increasingly as signal "**black spots**" against the background of uniformly enhanced normal liver tissue [Figure 59].

Figure 50 (a) Metastases have a wide variety of B-mode ultrasound appearance and can be confused with any kind of liver lesion. Colour Doppler imaging is helpful in only few patients. (b-f) Hypervascular metastases reveal the typical peripheral rim sign using contrast enhanced ultrasound in the arterial phase, which can also be encountered in hepatocellular adenoma and hepatocellular carcinoma, and is, therefore, not pathognomonic. (g) Metastases

typically exhibit a sharp contrast to normal liver tissue in the liver specific portal venous (sinusoidal) phase.
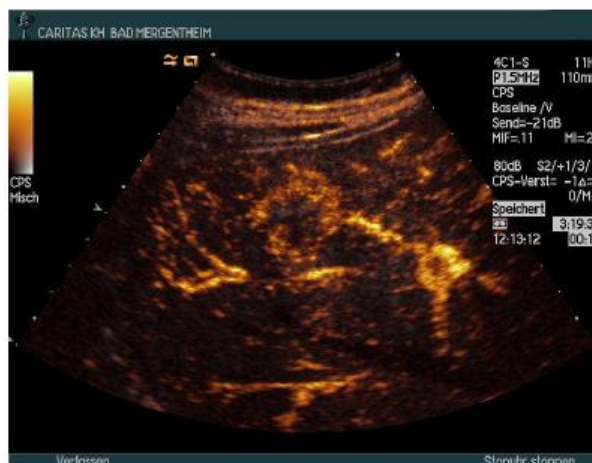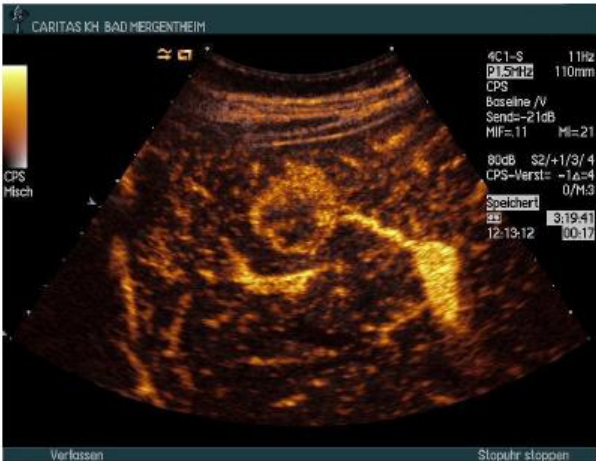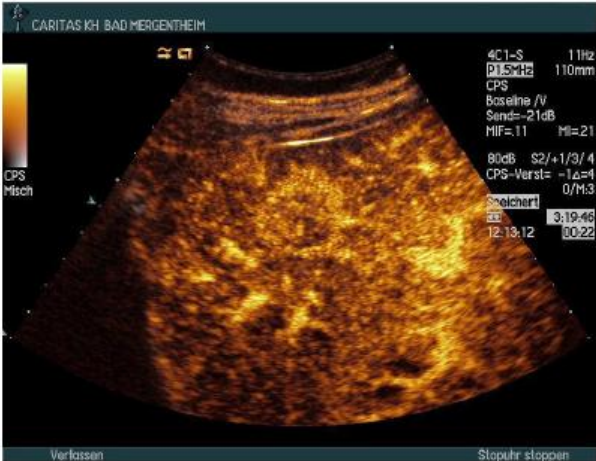
a

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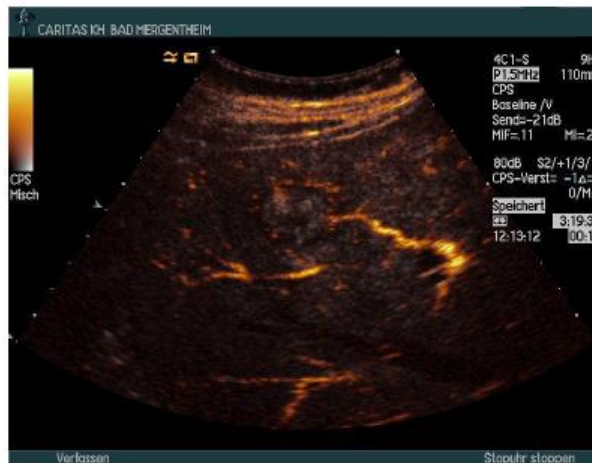
c

d

e

f

g

Figure 51 Small hypoechoic focal liver lesion (a). CEUS shows strong perfusion of this area 14 s after bolus injection (b). After 30 s this area is already dark, almost no longer perfused. This is very typical for metastases – of neuroendocrine tumour in this case (c).

a

b

c

Unlike the portal venous "**black spot**" effect of metastases, as a rule, large hemangiomas show a decrease in the unenhanced signal area (the iris diaphragm phenomenon). Any differential diagnosis must take into account complications of the underlying disease and complications of therapy (*e.g.* neutropenia with bacterial and/or mycotic abscesses).

Benign liver lesions are found with the same frequency (5 – 20%) in patients with metastases as in a healthy population (*e.g.* liver cysts, calcifications, hemangiomas, FNH and adenomas).

Hepatic vascular diseases

Colour Doppler imaging for analysis of hepatic vessel flow pattern

Colour Doppler imaging (CDI) is an accurate and well-established technique in evaluating portal hypertension, portal vein thrombosis, Budd-Chiari-syndrome and other forms of veno-occlusive disease (VOD). CDI is routinely used to evaluate patients prior to liver transplantation to determine portal vein patency, signs of portal hypertension and hepatic artery patency post-operatively. CDI is also important to monitor flow direction and patency of spontaneous and artificial portosystemic shunts, *e.g.*transjugular intrahepatic portosystemic shunts (TIPSS). Post-liver transplantation patients are monitored by analysing the hepatic artery profile; stenosis and rejection are indicated by changes in the resistance flow pattern (*e.g.pulsus parvus et tardus*).

Portal hypertension

Signs of portal hypertension (dilatation of the portal vein > 14 mm, low or absence of respiratory variability of the veins, splenomegaly > 120 mm in long axis or volume > 200 ml, ascites and collateral vessels) can be shown on ultrasound. Also portal vein thrombosis can be identified. CDI examination is recommended in patients with suspected portal hypertension because CDI is helpful in the detection of the presence and direction of blood flow within the portal venous system. Hepatofugal flow in the portal vein is found in approximately 10% of patients with liver cirrhosis, it can be observed when intrahepatic resistance is greater than the resistance of portosystemic collaterals [Figure 62]. Prevalence does not differ in relation to the

aetiology of liver cirrhosis, but it is stage dependent and is often found more frequently in Child B and C cirrhosis compared with Child A cirrhosis. The clinical significance of this Doppler phenomenon is still unclear, especially in relation to repeat variceal bleeding [Figure 60].

## Figure 52 Reverse flow in the portal vein as a result of portal hypertension.

Chronic heart failure

Doppler spectral evaluation reveals tetraphasic flow in the right liver vein and highly undulating flow patterns in the portal vein, which reverses during intensified therapy [Figure 61 and 62]. Increased pulsatile flow (high resistance index) in the portal vein has predominantly been found in patients with severe right heart failure, demonstrating that right atrial pressure is negatively correlated with portal vein pulsatility ratio.

Figure 53 Right heart failure with hepatic veins jammed.

Figure 54 Increased pulsatile flow in the portal vein, which is predominantly found in patients with severe right heart failure and demonstrates that right atrial pressure is negatively correlated with the portal vein pulsatility ratio.
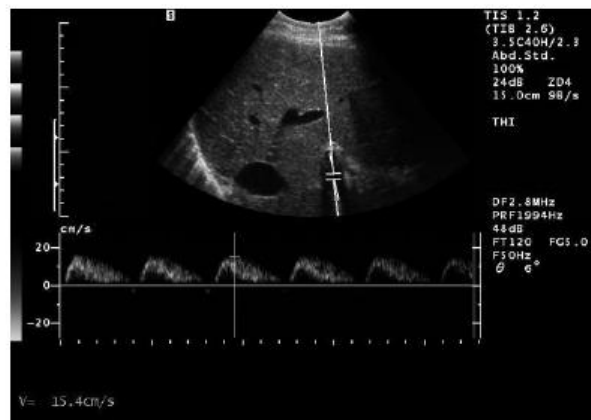
Analysis of the flow pattern in the hepatic veins is also helpful to characterise diffuse parenchymal liver disease [Figure 31].

Clinical importance of liver ultrasound in clinical practice

Ultrasound is the first and most important imaging method in suspected liver disease, both for proving (*e.g.* metastatic disease) and excluding pathology. It is the single best tool in the evaluation of FLL. It is unrivalled by any other imaging modality owing to its real-time, dynamic nature, high-resolution and good safety record. It is invaluable in the differential diagnosis of jaundice, in describing liver cirrhosis complications and in any form of ultrasound guided intervention. In summary ultrasound is an indispensable tool in clinical hepatology.

Ultrasound of the liver
- is the first and most important imaging method in suspected liver disease;
- is first line indication for the evaluation of elevated liver functions tests and cholestasis indicating enzymes; differential diagnosis of icterus (diagnosis/exclusion of cholestasis); monitoring of complications of liver cirrhosis (ascites, portal hypertension, HCC); and tumour detection, exclusion and follow-up;
- CEUS is especially helpful for tumour detection and characterisation and prevents unnecessary further imaging;
- is essential for guidance of liver/biliary tree interventions such as biopsy;
- is the most important imaging method for oncological follow-up;
- limitations include the exact measurement of the size of the liver (which is of limited value in clinical practice); and the diagnosis of early cirrhotic stages and in the differential diagnosis of diffuse parenchymal diseases.

Recommended reading

- Dietrich CF, Serra C, Jedrejczyk M. Ultrasound of the liver. In: Dietrich CF. EFSUMB Course Book on Ultrasound, London 2012, pp 31-90.
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4. Dietrich CF, Maddalena ME, Cui XW, Schreiber-Dietrich D, Ignee A. Liver tumor characterization--review of the literature. Ultraschall Med 2012; 33 Suppl 1:S3-10.