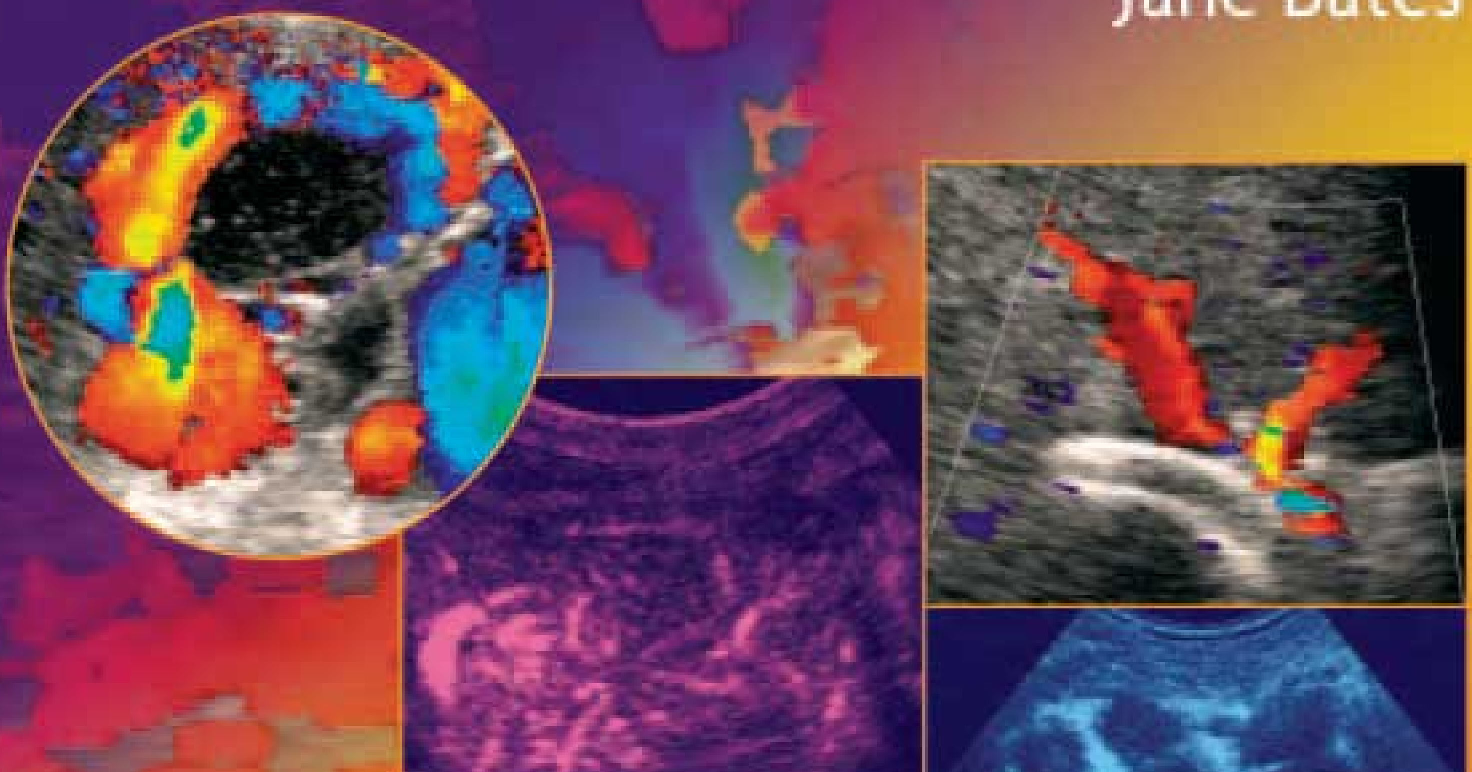
SECOND EDITION

Abdominal ULTRASOUND

HOW, WHY AND WHEN

Jane Bates



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Abdominal Ultrasound

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Designer: Judith Wright

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Jane A. Bates MPhil DMU DCR

Lead Practitioner, Ultrasound Department, St James's University Hospital, Leeds, UK

CHURCHILL LIVINGSTONE

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Contributors

Rosemary Arthur FRCR Consultant Radiologist Department of X-ray & Ultrasound, The General Infirmary at Leeds, Leeds, UK

Simon T. Elliott MB ChB FRCR Consultant Radiologist Department of Radiology, Freeman Hospital, Newcastle-upon-Tyne, UK

Grant M. Baxter FRCR Consultant Radiologist Western Infirmary University NHS Trust, Glasgow, UK

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Preface

Ultrasound continues to be one of the most important diagnostic tools at our disposal. It is used by a wide range of healthcare professionals across many applications. This book is intended as a practical, easily accessible guide to sonographers and those learning and developing in the field of abdominal ultrasound. The most obvious drawbacks of ultrasound diagnosis are the physical limitations of sound in tissue and its tremendous dependence upon the skill of the operator. This book seeks to enable the operator to maximize the diagnostic information and to recognize the limitations of the scan.

Where possible it presents a wider, more holistic approach to the patient, including presenting symptoms, complementary imaging procedures and further management options. It is not a comprehensive account of all the pathological processes likely to be encountered, but is intended as a springboard from which practical skills and clinical knowledge can develop further.

This book aims to increase the sonographer's awareness of the contribution of ultrasound within the general clinical picture, and introduce the sonographer to its enormous potential.

The author gratefully acknowledges the help and support of the staff of the Ultrasound Department at St James's University Hospital, Leeds.

Leeds 2004 Jane Bates

Abbreviations

ADPCDK	autosomal dominant polycystic disease of the kidney
AFP	alpha-fetoprotein
AI	acceleration index
AIDS	acquired immune deficiency syndrome
AIUM	American Institute for Ultrasound in Medicine
ALARA	as low as reasonably achievable
ALT	alanine aminotransferase
AP	anteroposterior
APKD	autosomal dominant (adult) polycystic kidney
ARPCDK	autosomal recessive polycystic disease of the kidney
AST	aspartate aminotransferase
AT	acceleration time
AV	arteriovenous
BCS	Budd–Chiari syndrome
CAPD	continuous ambulatory peritoneal dialysis
CBD	common bile duct
CD	common duct
CF	cystic fibrosis
CT	computed tomography
DIC	disseminated intravascular coagulation
DICOM	Digital Imaging and Communications in Medicine
DMSA	dimercaptosuccinic acid
DTPA	diethylene triaminepenta-acetic acid
EDF	end-diastolic flow
ERCP	endoscopic retrograde cholangiopancreatography
ESWL	extracorporeal shock wave lithotripsy
EUS	endoscopic ultrasound
FAST	focused assessment with sonography for trauma
FDA	Food and Drug Administration
FPS	frames per second
HA	hepatic artery
HCC	hepatocellular carcinoma
HELLP	haemolytic anaemia, elevated liver enzymes and low platelet count
HIDA	hepatic iminodiacetic acid
HPS	hypertrophic pyloric stenosis
HV	hepatic vein
INR	international normalized ratio
IOUS	intraoperative ultrasound
IVC	inferior vena cava
IVU	intravenous urogram
KUB	kidneys, ureters, bladder
LFT	liver function test
LPV	left portal vein
LRV	left renal vein
LS	longitudinal section
LUQ	left upper quadrant
MCKD	multicystic dysplastic kidney

MHA	middle hepatic artery
MHV	middle hepatic vein
MI	mechanical index
MPV	main portal vein
MRA	magnetic resonance angiography
MRA	main renal artery
MRCP	magnetic resonance cholangiopancreatography
MRI	magnetic resonance imaging
MRV	main renal vein
ODS	output display standard
PAC	photographic archiving and communications
PACS	photographic archiving and communications systems
PBC	primary biliary cirrhosis
PCKD	polycystic kidney disease
PCS	pelvicalyceal system
PD	pancreatic duct
PI	pulsatility index
PID	pelvic inflammatory disease
PRF	pulse repetition frequency
PSC	primary sclerosing cholangitis
PTLD	post-transplant lymphoproliferative disorder
PV	portal vein
RAS	renal artery stenosis
RCC	renal cell carcinoma
RF	radiofrequency
RHV	right hepatic vein
RI	resistance index
RIF	right iliac fossa
RK	right kidney
RPV	right portal vein
RRA	right renal artery
RRV	right renal vein
RUQ	right upper quadrant
RVT	renal vein thrombosis
SA	splenic artery
SLE	systemic lupus erythematosus
SMA	superior mesenteric artery
SV	splenic vein
TB	tuberculosis
TGC	time gain compensation
THI	tissue harmonic imaging
TI	thermal index
TIB	bone-at-focus index
TIC	cranial index
TIPS	transjugular intrahepatic portosystemic shunt
TIS	soft-tissue thermal index
TORCH	toxoplasmosis, rubella, cytomegalovirus and HIV
TS	transverse section
UTI	urinary tract infection
VUJ	vesicoureteric junction
WRMSD	work-related musculoskeletal disorders
XGP	xanthogranulomatous pyelonephritis

Chapter 1

Optimizing the diagnostic information

CHAPTER CONTENTS

Image optimization 1
The use of Doppler 2
Getting the best out of Doppler 5
Choosing a machine 6
Recording of images 9
Safety of diagnostic ultrasound 10
Medicolegal issues 12
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IMAGE OPTIMIZATION

Misinterpretation of ultrasound images is a significant risk in ultrasound diagnosis. Because ultrasound scanning is operator-dependent, it is imperative that the sonographer has proper training in order to achieve the expected diagnostic capabilities of the technique. The skill of effective scanning lies in the operator's ability to maximize the diagnostic information available and in being able to interpret the appearances properly. This is dependent upon:

- Clinical knowledge—knowing what to look for and why, knowing how to interpret the appearances on the image and an understanding of physiological and pathological processes.
- Technical skill—knowing how to obtain the most useful and relevant images, knowledge of artifacts and avoiding the pitfalls of scanning.
- Knowledge of the equipment being used—i.e. making the most of your machine.

The operator must use the controls to their best effect (see Box 1.1). There are numerous ways in which different manufacturers allow us to make compromises during the scanning process in order to improve image quality and enhance diagnostic information.

The quality of the image can be improved by:

- Increasing the frequency—at the expense of poorer penetration (Fig. 1.1).
- Increasing the line density—this may be achieved by reducing the frame rate and/or reducing the sector angle and/or depth of field (Fig. 1.2).

Box 1.1 Making the most of your equipment

- Use the highest frequency possible—try increasing the frequency when examining the pancreas or anterior gallbladder.
- Use the lowest frame rate and highest line density possible. Restless or breathless patients will require a higher frame rate.
- Use the smallest field practicable—sections through the liver require a relatively wide sector angle and a large depth of view, but when examining an anterior gallbladder, for example, the field can be greatly reduced, thereby improving the resolution with no loss of frame rate.
- Use the focal zone at relevant correct depth.
- Use tissue harmonic imaging to increase the signal to noise ratio and reduce artefact.
- Try different processing curves to highlight subtle abnormalities and increase contrast resolution.

- Using the focal zones correctly—focus at the level under investigation, or use multiple focal zones at the expense of a decreased frame rate (Fig. 1.3).
- Utilizing different pre- and post-processing options, which may highlight particular areas (Fig. 1.4).
- Using tissue harmonics to reduce artefact (Fig. 1.5). This technique utilizes the second harmonic rather than the fundamental frequency using either filtration or pulse inversion.[1] This results in a higher signal-to-noise ratio which demonstrates particular benefits in many difficult scanning situations, including obese or gassy abdomens.

It is far better to have a scan performed properly on a low-tech piece of equipment by a knowledgeable and well-trained operator than to have a poorly performed scan on the latest high-tech machine (Fig. 1.6). A good operator will get the best out of even the lowliest scanning device and produce a result that will promote the correct patient management. A misleading result from a top-of-the-range scanner can be highly damaging and at best delay the correct treatment or at worst promote incorrect management. The operator should know the limitations of the scan in terms of equipment capabilities, operator skills, clinical problems and patient limitations, take those limitations into account and communicate them where necessary.

THE USE OF DOPPLER

The use of Doppler ultrasound is an integral part of the examination and should not be considered as a separate entity. Many pathological processes in the abdomen affect the haemodynamics of relevant organs and the judicial use of Doppler is an essential part of the diagnostic procedure. This is discussed in more detail in subsequent chapters.

Colour Doppler is used to assess the patency and direction of flow of vessels in the abdomen,

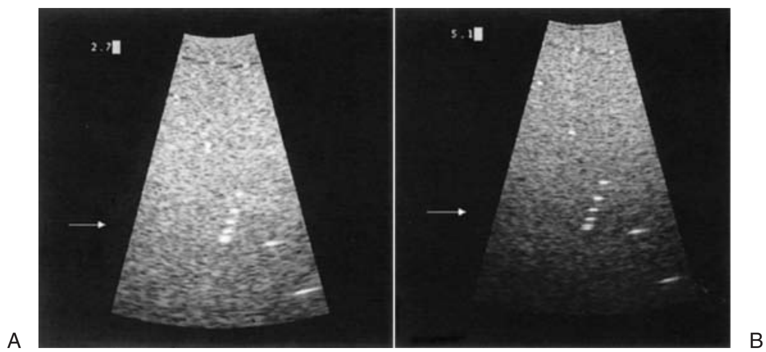

Figure 1.1 The effect of changing frequency. (A) At 2.7 MHz the wires are poorly resolved and the background 'texture' of the test object looks coarse. (B) The same transducer is switched to a resonant frequency of 5.1 MHz. Without changing any other settings, the six wires are now resolved and the background texture appears finer.

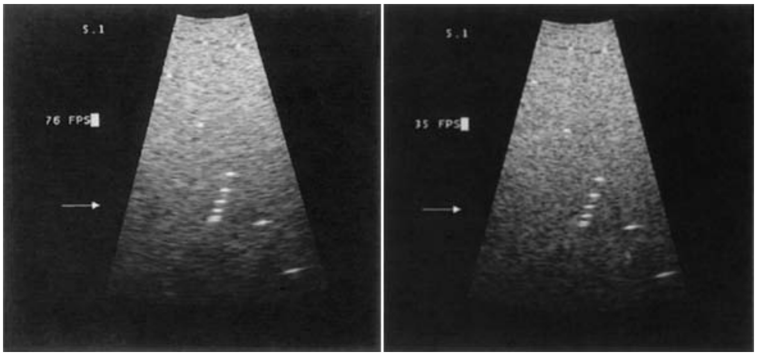

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Figure 1.2 The effect of frame rate. (A) 76 frames per second (FPS). (B) 35 FPS—the resulting higher line density improves the image, making it sharper.

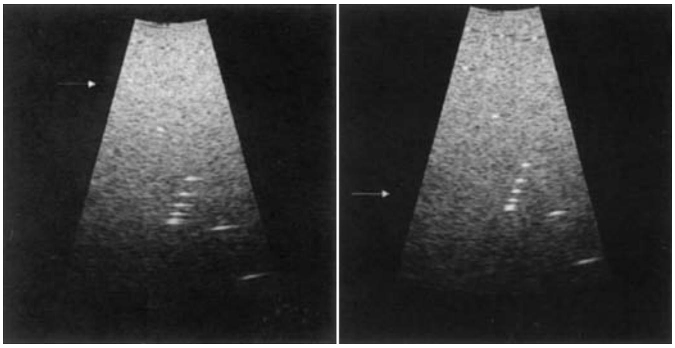

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Figure 1.3 The effect of focal zone placement. (A) With the focal zone in the near field, structures in the far field are poorly resolved. (B) Correct focal zone placement improves both axial and lateral resolution of the wires.

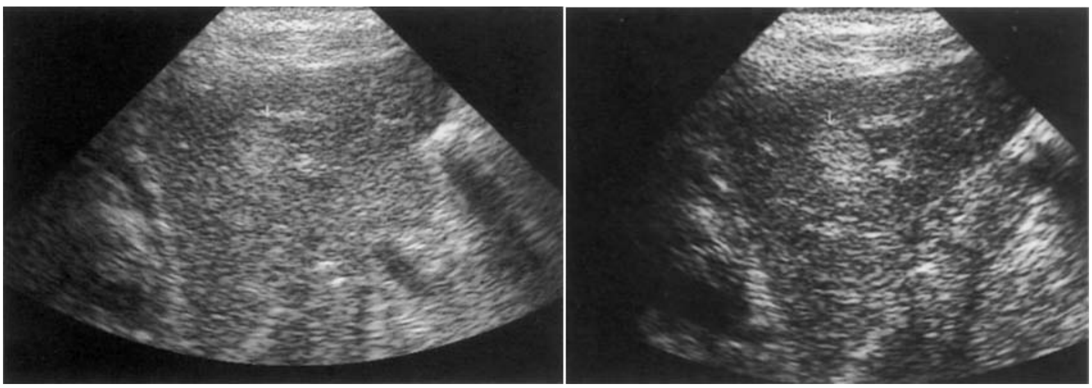

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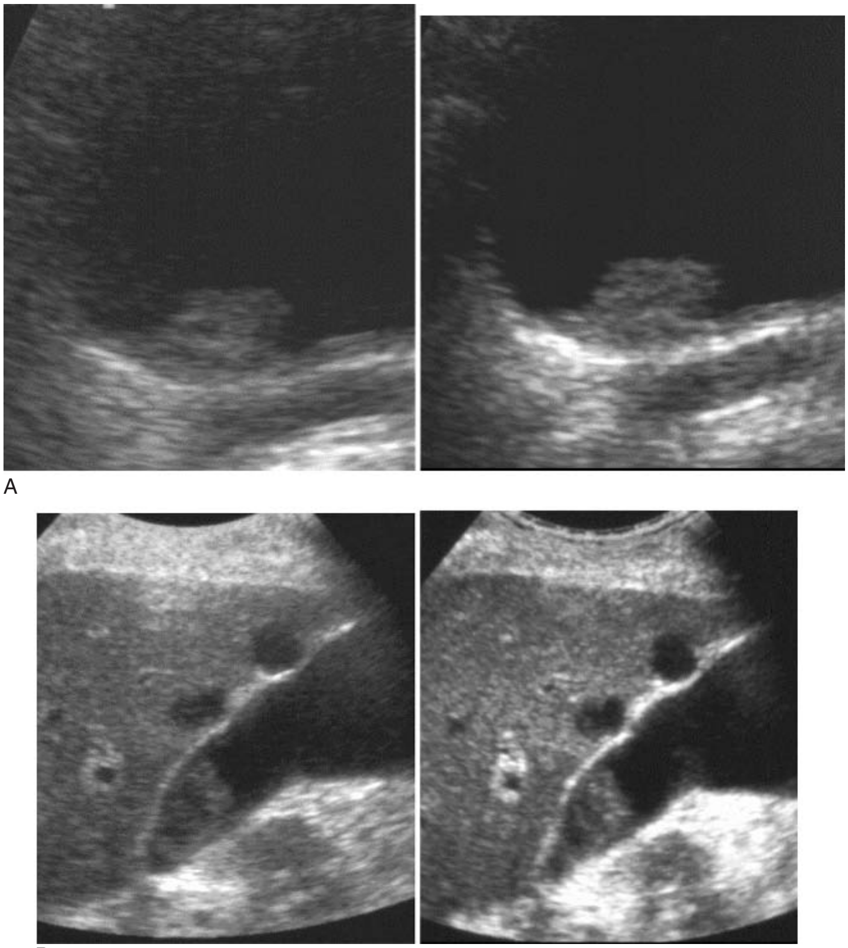
Figure 1.4 The effect of using post-processing options. (A) A small haemangioma in the liver merges into the background and is difficult to detect. (B) A post-processing option, which allocates the range of grey shades in a non-linear manner, enhances contrast resolution and improves detection of focal lesions.



A

B

Figure 1.5 The effect of tissue harmonic imaging (THI): (A) a bladder tumour in fundamental imaging mode (left) is shown with greater definition and loss of artifact in THI (right). (B) In an obese patient, cysts near the gallbladder (left) are shown in greater detail using pulse inversion tissue harmonics (right). A small nodule is demonstrated in the lower cyst.

to establish the vascularity of masses or lesions and to identify vascular disturbances, such as stenoses. Flow information is colour-coded (usually red towards and blue away from the transducer) and superimposed on the image. This gives the operator an immediate impression of a vascular map of the area (Fig. 1.7). This Doppler information is obtained simultaneously, often from a relatively large area of the image, at the expense of the grey-scale image quality. The extra time taken to obtain the Doppler information for each line results in a reduction in frame rate and line density which worsens as the colour Doppler area is enlarged. It is advisable, therefore, to use a compact colour 'box' in order to maintain image quality.

Power Doppler also superimposes Doppler information on the grey-scale image, but without any directional information. It displays only the amount of energy (Fig. 1.8). The advantage of this is that the signal is stronger, allowing identification of smaller vessels with lower velocity flow than colour Doppler. As it is less angle-dependent than colour Doppler it is particularly useful for vessels which run perpendicular to the beam, for example the inferior vena cava (IVC).

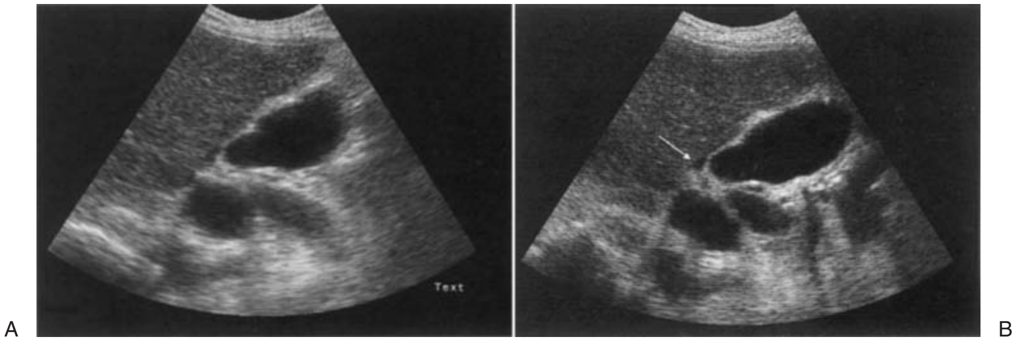


Figure 1.6 The importance of using the equipment properly. (A) Incorrect use of equipment settings makes it difficult to appreciate the structures in the image. (B) By increasing the resonant frequency, decreasing the frame rate and adjusting the focal zone correctly, a small rim of fluid around the gallbladder is seen and the gallbladder wall and vessels posterior to the gallbladder are made clear.

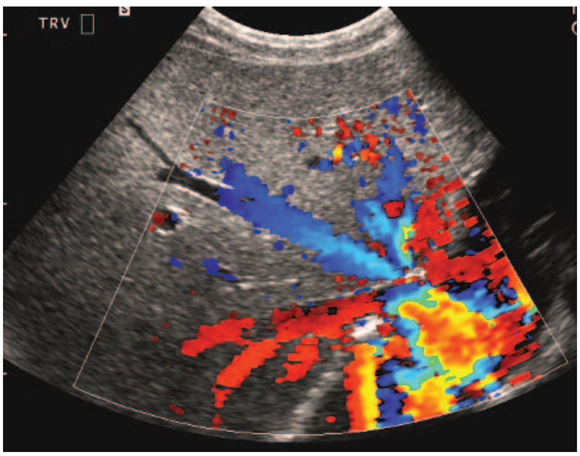


Figure 1.7 Colour Doppler of the hepatic vein confluence. The right hepatic vein appears red, as it is flowing towards the transducer. The left and middle hepatic veins are in blue, flowing away from the transducer. Note the peripheral middle hepatic vein, which appears to have no flow; this is an artifact due to the angle of that part of the vessel to the beam.

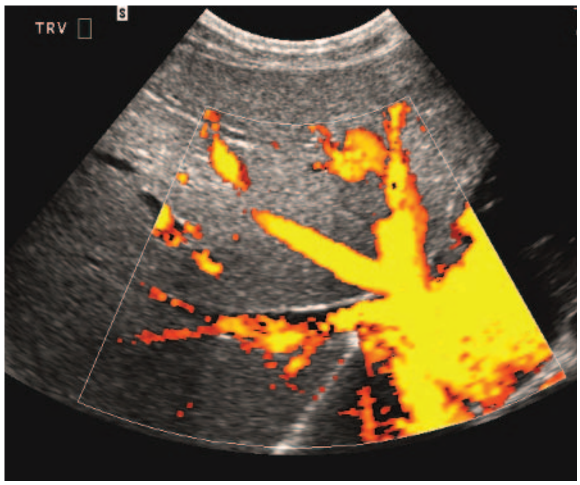


Figure 1.8 Power Doppler of the hepatic vein confluence. We have lost the directional information, but flow is demonstrated in all parts of the vessel—even those perpendicular to the beam.

Pulsed Doppler uses pulses of Doppler from individual elements or small groups of elements within the array. This allows the operator to select a specific vessel, which has been identified on the grey-scale or colour Doppler image, from which to obtain a spectrum. This gives further information regarding the flow envelope, variance, velocity and downstream resistance of the blood flow (Fig. 1.9).

Getting the best out of Doppler

Familiarity with the Doppler controls is essential in order to avoid the pitfalls and increase confidence in the results.

It is relatively straighforward to demonstrate flow in major vessels and to assess the relevant spectral waveform; most problems arise when trying to diagnose the *lack* of flow in a suspected thrombosed vessel, and in displaying low-velocity

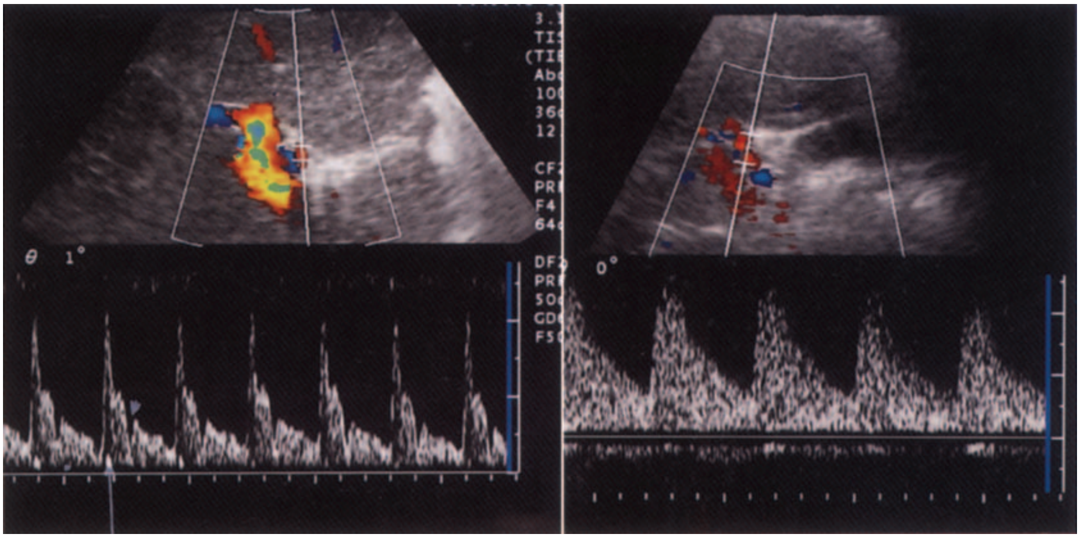


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Figure 1.9 Flow velocity waveforms of hepatic arteries. (A) High-resistance flow with low end-diastolic flow (EDF) and a dichrotic notch (arrowhead). The clear 'window' during systole (arrow) indicates little variance, with the blood flowing at the same velocity throughout the vessel. During diastole, the area under the envelope is 'filled in', indicating greater variance in flow. (B) By contrast, this hepatic artery trace indicates low-resistance flow with good EDF and no notch. Variance is apparent throughout the cycle.

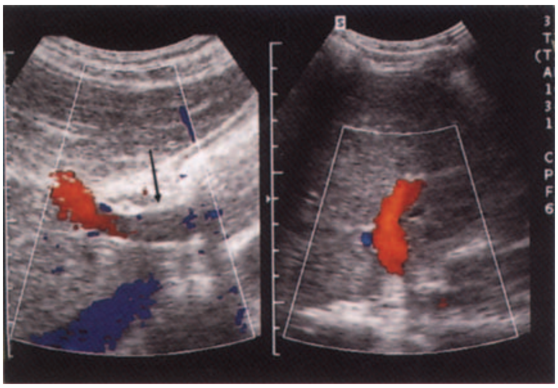

Figure 1.10 On the left, the portal vein appears to have no flow (arrow) when it lies at 90° to the beam—a possible misinterpretation for thrombosis. When scanned intercostally, the vein is almost parallel to the beam and flow is easily demonstrated.

flow in difficult-to-access vessels. Doppler is known to produce false-positive results for vessel occlusion (Fig. 1.10) and the operator must avoid the pitfalls and should ensure that the confidence levels are as high as possible (see Box 1.2).

CHOOSING A MACHINE

The ultrasound practitioner is confronted with a confusing range of equipment and choosing the right machine for the job can be a daunting task.

An informed and useful choice is more likely when the purchaser has considerable experience within the particular clinical field. Many machines, purchased in the first enthusiastic flush of setting up a new service, for example, turn out to be unsuitable two or three years later.

Mistakes are made by insufficient forward planning. A number of machines (usually at the cheaper end of the market), though initially purchased for specific, sometimes narrow, purposes, end up being expected to perform more complex and wider-ranging applications than originally planned.

Take careful stock of the range of examinations you expect your machine to perform. Future developments which may affect the type of machine you buy include:

- Increase in numbers of patients calculated from trends in previous years.

Box 1.2 Steps to take if you can't detect flow with Doppler

- Ensure the angle of insonation between the vessel and the transducer is <60°. Colour and pulsed Doppler are highly angle-dependent.
- Ensure the Doppler gain is set at the correct level. (Colour and pulsed Doppler gain settings should be just below background noise level.)
- Ensure the Doppler power/output setting is sufficient.
- Ensure the pulse repetition frequency (PRF) is set correctly. A low PRF ('range' or 'scale' setting) is required to pick up low-velocity flow.
- Ensure the wall thump filter setting is low. (If the setting is too high, real low-velocity flow is filtered out.)
- Use power Doppler, which is more sensitive and is not angle-dependent.
- Know the limitations of your machine. Machines differ in their ability to detect low-velocity flow.
- If in doubt, test it on a reference vessel you *know* should contain flow.

- Increase in range of possible applications, an impending peripheral vascular service, for example, or regional screening initiative.
- Clinical developments and changes in patient management which may require more, or different, ultrasound techniques, for example, medical therapies which require ultrasound monitoring, applications involving the use of contrast agents, surgical techniques which may require intraoperative scanning, increases or decreases in hospital beds, introduction of new services and enlargement of existing ones.
- Impending political developments by government or hospital management, resulting in changes in the services provided, the funding or the catchment area.
- Other impending ultrasound developments, such as the use of contrast media or ultrasound-guided therapies which may be required in future.

The following points are useful to bear in mind when purchasing new equipment:

Probe number and design (Fig 1.11)

Consider the footprint, shape and frequencies required: most modern transducers are broadband in design, enabling the user to access a wider range of frequencies. This is a big advantage as this limits the number of probes required for a general service. A curved array probe is suitable for most general abdominal applications, operating in the 3.5–6 MHz region. Additional higher-frequency probes are useful for paediatrics and for superficial structures. A small footprint is essential if neonatal and paediatric work is undertaken and a 5–8 MHz frequency will be required.

A biopsy attachment may be needed for invasive procedures, and, depending on the range of work to be undertaken, linear probes, endoprobes, intraoperative probes and other designs can be considered.

Image quality

There are very few applications where this is not of paramount importance and abdominal scanning requires the very best you can afford. A machine capable of producing a high-quality image is likely

Figure 1.11 Curved arrays (left and centre) suitable for abdominal scanning. A 5 MHz linear array (right) is useful for superficial structures, e.g. gallbladder and anterior abdominal wall.

to remain operational for much longer than one capable of only poor quality, which will need replacement much sooner. A poor-quality image is a false economy in abdominal scanning.

Machine capabilities and functions

The availability and ease of use of various functions differ from machine to machine. Some of the important issues to consider when buying a machine include:

- probe selection and switching process, simultaneous connection of several probes
- dynamic frequency capability
- dynamic focusing control, number and pattern of focal zones
- functions such as beam steering, sector angle adjustment, zoom, frame rate adjustment, trackerball controls
- time gain compensation and power output controls
- cine facility—operation and size of memory
- programmable presets
- tissue harmonic and/or contrast harmonic imaging
- body marker and labelling functions
- measurement packages—operation and display
- colour/power and spectral Doppler through all probes
- Doppler sensitivity
- Doppler controls—ease of use, programmable presets
- output displays
- report package option.

Ergonomics

Good ergonomics contribute considerably to the success of the service provided. The machine must be usable by various operators in all the required situations. There is a significant risk of work-related musculoskeletal disorders (WRMSD)[2] if careful consideration is not given to the scanning environment (see p. 12). When choosing and setting up a scanning service, forethought should be given not only to the design of the ultrasound machine, but also to the seating arrangements and examination couch. These should all be adjustable in order to facilitate the best scanning position for the operator.

Other considerations include:

- System dimensions and steering. The requirement for the system to be portable, for example for ward or theatre work, or mobile for transportation to remote clinics. Machines used regularly for mobile work should be robust and easy to move.
- Moveable (swivel and tilt) monitor and control panel, including height adjustment for different operators and situations.
- Keyboard design, to facilitate easy use of the required functions, without stretching or twisting.
- Hand-held portable machines are an option that may be considered.

Maintenance issues

It is useful to consider the reliability record of the chosen equipment, particularly if it is to operate in out-reach clinics, or without available backup in the case of breakdown. Contacting other users may prove useful.

Various maintenance contract options and costs are available, including options on the replacement of probes, which should be taken into account when purchasing new equipment.

Upgradeability

A machine which is potentially upgradeable has a longer, more cost-effective life and will be supported by the manufacturer over a longer period of time. Consideration should be given to future software upgrades, possible effects and costs and other available options for the future, such as additional transducers or add-on Doppler facilities.

Links to image-recording devices

Most ultrasound machines are able to link up to most types of imaging facility, whether it be a simple black and white printer or a radiology-wide photographic archiving and communications (PAC) system. There may be costs involved, however, in linking your new machine to your preferred imaging device.

Equipment manufacturers now follow the DICOM standard. **D**igital **I**maging and **Co**mmunications in **M**edicine is the industry standard for transferring medical images and related information between computers. This facilitates compatibility between different pieces of equipment from different manufacturers and potentially enables them to be linked up.

RECORDING OF IMAGES

There are no hard and fast rules about the recording of ultrasound scans and departmental practices vary. It is good practice for departments to have guidelines for taking and retaining images within individual schemes of work, outlining the minimum expected.[3]

The advantages of recording images are:

- They provide a record of the quality of the scan and how it has been conducted: the organs examined, the extent of the scan, the type and standard of equipment, the settings used and other scanning factors. This can be an invaluable tool in providing a medicolegal defence.
- They provide an invaluable teaching aid.
- They help to ensure quality control within departments: promoting the use of good technique, they can be used to ensure protocols are followed and provide an excellent audit tool.
- They can be used to obtain a second opinion on difficult or equivocal cases and provide a basis for discussion with clinical colleagues.

The disadvantages are:

- The cost of buying, running and maintaining the recording device or system.
- The quality of images in some cases may not accurately reflect that of the image on the ultrasound monitor.
- The scanning time must be slightly increased to accommodate the taking of images.
- Storage and retrieval of images may be time- and space-consuming.
- Hard copy may be mislaid or lost.
- If the examination has been *badly* performed, the hard copy may demonstrate that too!

Generally speaking the recording of images is encouraged. It reduces the operator's vulnerability to litigation and supports the ultrasound diagnosis.[4] It is only possible to record the *entire* examination by using videotape, which is rarely practical in larger departments. The operator must take the responsibility for ensuring the scan has been performed to the required standard; any images produced for subsequent discussion are only *representative* of the examination and have been chosen by the operator as an appropriate selection. If you have missed a small metastasis in the liver while scanning, or a gallstone in the gallbladder, you are unlikely to have included it on an image.

Choice of image-recording device depends on many factors. Considerations include:

- image quality—resolution, grey-scale, storage life
- capital cost of the system—including the installation together with the installation of any other necessary equipment, such as a processor
- cost of film
- processing costs if applicable—this includes the cost of chemicals, the cost of buying and maintaining a processor and possibly a chemical mixer
- maintenance costs
- reliability of the system
- storage of images in terms of available space and cost
- location and size of the imaging system
- other considerations
  —ease of use
  —mobility
  —colour capability
  —ability to produce slides/teaching aids
  —shelf life of unused film and stored images.

Numerous methods of recording images are available to suit all situations. Small printers, attached to ultrasound scanners, are easy to use, cheap to buy and run and convenient if the machine is used on wards or distant satellite units. However, systems which produce hard copy, however good, are inevitably of inferior image quality to electronic image capture.

Multi-system departments are tending towards networked systems which produce high-quality images, and can be linked to multiple machines and modalities. These are, of course, more expensive to purchase and install, but are generally reliable and produce consistent, high-quality image.

Ultimately, the goal of the filmless department is being realized in PACS (photographic archiving and communications systems). Digital imaging networks are convenient, quick and relatively easy to use. The image quality is excellent, suffering little or no degradation in capture and subsequent retrieval, and the system can potentially be linked to a conventional imager should hard copy be required.

The number of workstations in the system can be virtually unlimited, depending on the system, affording the operator the flexibility of transmitting images immediately to remote locations, for example clinical meetings, outpatient clinics, etc. It is also possible to download images from scans done with mobile equipment, remote from the main department, on to the PACS.

Digital storage and retrieval avoid loss of films and afford considerable savings in time, labour and space. Increasingly it is also possible to store moving clips—useful for dynamic studies such as those involving contrast agents and for teaching purposes.

Many systems also incorporate a patient registration and reporting package, further streamlining the ultrasound examination. Not all systems store images in colour and there are considerable differences between the facilities available on different systems. The potential purchaser is advised to plan carefully for the needs of the ultrasound service.

The capital costs for PACS are high, but these can, to a certain extent, be offset by subsequently low running costs and potential savings in film, processing materials, equipment maintenance, and manual storage and retrieval.

SAFETY OF DIAGNOSTIC ULTRASOUND

Within the field of clinical diagnostic ultrasound, it is currently accepted that there is insufficient evidence for any deleterious effects at diagnostic levels and that the benefits to patients outweigh the risks. As new techniques and technological developments come on to the market, new biophysical conditions may be introduced which require evaluation with regard to safety[5] and we cannot afford to become complacent about the possible effects. The situation remains under constant review.

Several international bodies continue to consider the safety of ultrasound in clinical use. The European Federation of Societies for Ultrasound in Medicine and Biology (EFSUMB) has confirmed the safety of diagnostic ultrasound and endorsed its ‘informed’ use.[6] Whilst the use of pulsed Doppler is considered inadvisable for the developing embryo during the first trimester, no such exceptions are highlighted for abdominal ultrasound.

The European Committee for Ultrasound Radiation Safety (ECURS) confirms that no deleterious effects have yet been proven in clinical medicine. It recommends, however, that equipment is used only when designed to national or international safety standards and that it is used only by competent and trained personnel.

The World Federation for Ultrasound in Medicine and Biology (WFUMB) confirms that the use of B-mode imaging is not contraindicated,[7] concluding that exposure levels and duration should be reduced to the minimum necessary to obtain the required diagnostic information.

Ultrasound intensities used in diagnostic ultrasound vary according to the mode of operation. Pulsed Doppler usually has a higher level than B-mode scanning, which operates at lower intensities, although there may be overlap with colour or power Doppler.

The American Institute for Ultrasound in Medicine (AIUM) has suggested that ultrasound is safe below 100 W/cm.[8] This figure refers to the spatial peak temporal average intensity (I_{SPTA}).

The use of intensity, however, as an indicator of safety is limited, particularly where Doppler is concerned, as Doppler intensities can be considerably greater than those in B-mode imaging. The Food and Drug Administration (FDA) sets maximum intensity levels allowed for machine output, which differ according to the application.[9]

Biological effects of ultrasound

Harmful effects from ultrasound have been documented in laboratory conditions. These include thermal effects and mechanical effects.

Thermal effects are demonstrated as a slight rise in temperature, particularly in close proximity to the transducer face, during ultrasound scanning. This local effect is usually of no significance but the operator must be aware of the phenomenon. The most significant thermal effects occur at bone/tissue interfaces and are greater with pulsed Doppler. Increases in temperature of up to 5°C have been produced. Areas at particular risk are fetal bones and the interfaces in transcranial Doppler ultrasound scans.

Pulsed Doppler has a greater potential for heating than B-mode imaging as it involves greater temporal average intensities due to high pulse repetition frequency (PRF) and because the beam is frequently held stationary over an area while obtaining the waveform. Colour and power Doppler usually involve a greater degree of scanning and transducer movement, which involves a potentially lower heating potential than with pulsed Doppler. Care must be taken to limit the use of pulsed Doppler and not to hold the transducer stationary over one area for too long.

Mechanical effects, which include cavitation and radiation pressure, are caused by stresses in the tissues and depend on the amplitude of the ultrasound pulse. These effects are greatest around gas-filled organs, such as lungs or bowel and have, in laboratory conditions, caused small surface blood vessels in the lungs to rupture. Potentially, these effects could be a hazard when using contrast agents which contain microbubbles.

Safety indices (thermal and mechanical indices)

In order to inform users about the machine conditions which may potentially be harmful, mechanical and thermal indices are now displayed as an output display standard (ODS) on all equipment manufactured after 1998. This makes operators aware of the ultrasound conditions which may exceed the limits of safety and enables them to take avoiding action, such as reducing the power or restricting the scanning time in that area.

In simple terms the mechanical index (MI) is related to amplitude and indicates how 'big' an ultrasound pulse is, giving an indication of the chances of mechanical effects occurring. It is therefore particularly relevant in the abdomen when scanning gas-filled bowel or when using microbubble contrast agents. Gas bodies introduced by contrast agents increase the probablility of cavitation.

The thermal index (TI) gives an indication of the temperature rise which might occur within the ultrasound beam, aiming to give an estimate of the reasonable worst-case temperature rise. The TI calculation alters, depending upon the application, giving rise to three indices: the soft-tissue thermal index (TIS), the bone-at-focus index (TIB) and the bone-at-surface, or cranial index (TIC). The first of these is obviously most relevant for abdominal applications. In well-perfused tissue, such as the liver and spleen, thermal effects are less likely due to the cooling effect of the blood flow.

The display of safety indices is only a general indication of the possibility of biological hazards and cannot be translated directly into real heating or cavitation potential.[10] These 'safety indices' are limited in several ways. They require the user to be educated with respect to the implications of the values shown and they do not take account of the duration of exposure, which is particularly important in assessing the risk of thermal damage.[4] In addition, the TI does not take account of the patient's temperature, and it is logical to assume that increased caution is therefore required in scanning the febrile patient.

MI and TI are also unlikely to portray the optimum safety information during the use of contrast agents, in which, theoretically, heating effects and cavitation may be enhanced.[5]

Other hazards

Whilst most attention in the literature is focused on the possible biological effects of ultrasound, there are several other safety issues which are within the control of the operator.

Electrical safety All ultrasound machines should be subject to regular quality control and should be regularly checked for any signs of electrical hazards. Loose or damaged wiring, for example, is a common problem if machines are routinely used for mobile work. Visible damage to a transducer, such as a crack in the casing, should prompt its immediate withdrawal from service until a repair or replacement is effected.

Microbiological safety It is the responsibility of the sonographer to minimize the risks of cross-infection. Most manufacturers make recommendations regarding appropriate cleaning agents for transducers, which should be carefully followed. Sterile probe covers should be used in cases where there is an increased risk of infection.

Operator safety By far the most serious hazard of all is that of the untrained or badly trained operator. Misdiagnosis is a serious risk for those not aware of the pitfalls. Apart from the implications for the patient of subsequent incorrect management, the operator risks litigation which is difficult or impossible to defend if they have had inadequate training in ultrasound.

Work-related musculoskeletal disorders

There is increasing concern about WRMSD related to ultrasound scanning, as workloads increase and it has been estimated that a significant proportion of sonographers who practise full-time ultrasound scanning may be affected.[2] One contributing factor is the ergonomic design of the ultrasound machines, together with the position adopted by the operator during scanning. While more attention is now being paid by ultrasound manufacturers to designs which limit WRMSD, there are various other contributing factors which should be taken into account when providing ultrasound services. Well-designed, adjustable seating for operators, adjustable patient couches, proper staff training for manoeuvring patients and a varied work load all contribute to minimizing the potential problems to staff.

Hand-held, portable ultrasound machines are now available. Provided they are of sufficient functionality to provide the service required, they may also potentially limit the problems encountered when manoeuvring larger scanners around hospital wards and departments.

The safe practice of ultrasound

It is fair to say that the safety of ultrasound is less of an issue in abdominal scanning than in obstetric or reproductive organ scanning. Nevertheless it is still incumbent upon the operator to minimize the ultrasound dose to the patient in any practicable way.

The use of X-rays is governed by the ALARA principle—that of keeping the radiation dose As Low As Reasonably Achievable. Although the risks associated with radiation are not present in the use of ultrasound, the general principle of keeping the acoustic exposure as low as possible is still good practice and many people still refer to ALARA in the context of diagnostic ultrasound (see Box 1.3).

MEDICOLEGAL ISSUES

Litigation in medical practice is increasing and the field of ultrasound is no exception to this. Although currently the majority of cases involve firstly obstetric and secondly gynaecological ultrasound, it is prudent for the operator to be aware of the need to minimize the risks of successful litigation in all types of scanning procedures.

Patients have higher expectations of medical care than ever before and ultrasound practitioners should be aware of the ways in which they can protect themselves should a case go to court. The

Box 1.3 Steps for minimizing the ultrasound dose

- Ensure operators are *properly trained*, preferably on recognized training programmes.
- Minimize the output (or power) level. Use amplification of the *received* echoes to manipulate the image in preference to increasing the transmitted power.
- Minimize the time taken to perform the exam.
- Don't rest the transducer on the skin surface when not scanning.
- Make sure the clinical indications for the scan are satisfactory and that a proper request has been received. Don't do unnecessary ultrasound examinations.
- Be aware of the safety indices displayed on the ultrasound machine. Limit the use of pulsed Doppler to that necessary to contribute to the diagnosis.
- Make the best use of your equipment—maximize the diagnostic information by manipulating the controls effectively.

onus is upon the defendant to prove that he or she acted responsibly and there are several helpful guidelines which should routinely be followed (see Box 1.4).[11]

The medicolegal issues surrounding ultrasound may be different according to whether the operator is medically or non-medically qualified. Depending on their profession, operators are constrained by codes of conduct of their respective colleges and/or Councils.[12] Either way, the operator is legally accountable for his or her professional actions.

If non-medically qualified personnel are to perform and report on scans (as happens in the UK, USA and Australia), this task must be properly delegated by a medically qualified practitioner, for example a radiologist in the case of abdominal scanning. As the role of sonographers continues to expand, it is noteworthy that the same standard of care is expected from medically and non-medically qualified staff alike.[13] To avoid liability, practitioners must comply with the Bolam test, in which they should be seen to be acting in accordance with practice accepted as proper by a responsible body of relevant medical people.

Box 1.4 Guidelines for defensive scanning *(adapted from Meire HB[11])*

- Ensure you are properly trained. Operators who have undergone approved training are less likely to make mistakes.
- Act with professionalism and courtesy. Good communication skills go a long way to avoiding litigation.
- Use written guidelines or schemes of work.
- Ensure a proper request for the examination has been received.
- A written report should be issued by the operator.
- Record images to support your findings.
- Clearly state any limitations of the scan which may affect the ability to make a diagnosis.
- Make sure that the equipment you use is adequate for the job.

DEPARTMENTAL GUIDELINES/SCHEMES OF WORK

It is generally considered good and safe practice to use written guidelines for ultrasound examinations.[3]

These serve several purposes:

- They may be used to support a defence against litigation (provided, of course, that the operator can prove he or she has followed such guidelines).
- They serve to impose and maintain a minimum standard, especially within departments which may have numerous operators of differing experience levels.
- They serve to inform operators of current practice.

Guidelines should ideally be:

- Written by, and have input from, those practising ultrasound in the department (usually a combination of medically and non-medically qualified personnel), taking into account the requirements of referring clinicians, available equipment and other local operational issues.
- Regularly reviewed and updated to take account of the latest literature and practices.
- Flexible, to allow the operator to tailor the scan to the patient's clinical presentation and individual requirements.

Guidelines which are too prescriptive and detailed are likely to be ignored by operators as impractical. The guidelines should be broad enough to allow operators to respond to different clinical situations in an appropriate way while ensuring that the highest possible standard of scan is always performed. In cases when it is simply not possible to adhere to departmental guidelines, the reasons should be stated on the report, for example when the pancreas cannot be demonstrated due to body habitus or overlying bowel gas.

QUALITY ASSURANCE

The principles of quality assurance affect various aspects of the ultrasound service offered. These include staff issues (such as education and training, performance and continuing professional development), patient care, the work environment (including health and safety issues) and quality assurance of equipment. Quality assurance checks on ultrasound equipment, unlike most other aspects of an ultrasound service, involve measurable and reproducible parameters.

Equipment tests

After installation, a full range of equipment tests and safety checks should be carried out and the results recorded. This establishes a baseline performance against which comparisons may later be made. These tests should normally be carried out by qualified medical physicists.

It is useful to take a hard-copy image of a tissue-mimicking phantom, with the relevant settings marked on it. These images form a reference against which the machine's subsequent performance can be assessed. If your machine seems to be performing poorly, or the image seems to have deteriorated in some way, you will have the proof you require.

A subsequent, regular testing regime must then be set up, to ensure the standards of quality and safety are maintained. This programme can be set up in conjunction with the operators and the medical physics department and relevant records should be kept. The use of a tissue-mimicking phantom enables the sonographer to perform certain tests in a reproducible and recordable manner (Fig. 1.12).

Checks should be carried out for all probes on the machine.

Suggested equipment checks include:

- caliper accuracy
- system sensitivity and penetration
- axial and lateral resolution
- slice thickness
- grey scale
- dead zone
- checks on the various machine controls/functions
- output power
- safety checks: electrical, mechanical, biological and thermal, including a visual inspection of all probes and leads
- imaging device checks for image quality, settings, dynamic range, functionality and electrical safety

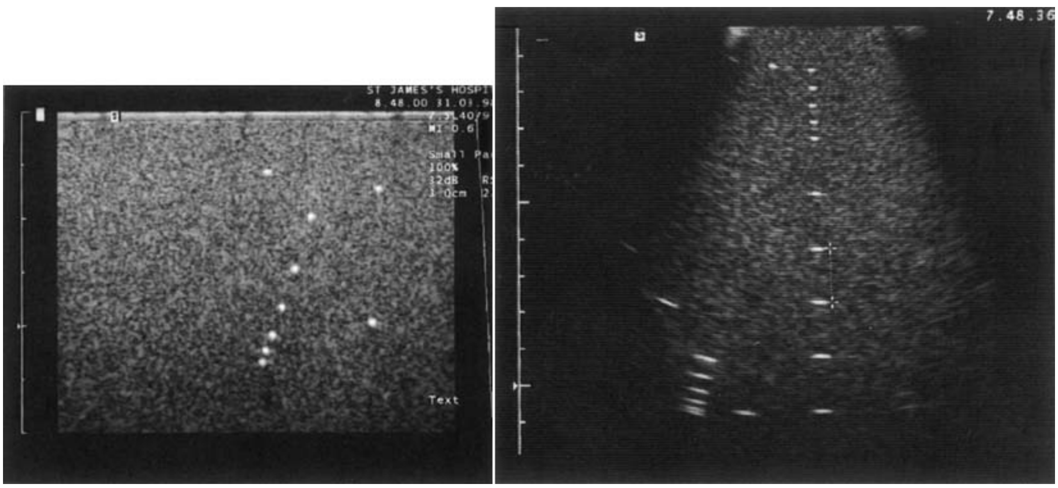

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Figure 1.12 Tissue-mimicking phantom. (A) When using a high-frequency linear array, cross-sections of the wires in the phantom are clearly demonstrated as small dots. (B) When using a curved array of a lower frequency, such as that used for abdominal scanning, the lateral resolution is seen to deteriorate in the far field as the beam diverges. The wires are displayed correctly in the near field but appear as short lines in the far field. Spacing of the wires is known, allowing caliper accuracy to be assessed.

- biopsy guide checks
- colour, power and spectral Doppler checks (complex, requiring specialized equipment).

Some of these checks can be easily and quickly carried out by users in the department on a regular basis, for example caliper checks and biopsy guide checks. Others are more complex and may be appropriately undertaken by specialist medical physicists. All equipment should undergo regular servicing and any interim faults should naturally be reported.

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Chapter 2

The normal hepatobiliary system

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INTRODUCTION

Ultrasound is the dominant first-line investigation for an enormous variety of abdominal symptoms because of its non-invasive and comparatively accessible nature. Its success, however, in terms of a diagnosis, depends upon numerous factors, the most important of which is the *skill of the operator*.

Because of their complexity and extent, the normal appearances and haemodynamics of the hepatobiliary system are dealt with in this chapter, together with some general upper-abdominal scanning issues. The normal appearances of the other abdominal organs are included in subsequent relevant chapters.

It is good practice, particularly on the patient's first attendance, to scan the whole of the upper abdomen, focusing particularly on the relevant areas, but also excluding or identifying any other significant pathology. A full abdominal survey would normally include the liver, gallbladder, biliary tree, pancreas, spleen, kidneys and retroperitoneal structures. Apart from the fact that many pathological processes can affect multiple organs, a number of significant (but clinically occult) pathological processes are discovered incidentally, for example renal carcinoma or aortic aneurysm. A thorough knowledge of anatomy is assumed at this stage, but diagrams of upper abdominal sectional anatomy are included in the appendix to this chapter for quick reference (see pp. 36–39).

It is important always to remember the operator-dependent nature of ultrasound scanning (see Chapter 1); although the dynamic nature of the scan is a huge advantage over other forms of imaging, the operator must continuously adjust technique to obtain the maximum diagnostic information. In any abdominal ultrasound survey the operator assesses the limitations of the scan and the level of confidence with which pathology can be excluded or confirmed. The confidence limits help in determining the subsequent investigations and management of the patient.

It is important, too, to retain an open mind about the diagnosis when embarking on the scan; an operator who decides the likely diagnosis on a clinical basis may sometimes be correct but, in trying to fit the scan to match the symptoms, risks missing significant pathology.

GENERAL POINTERS ON UPPER-ABDOMINAL TECHNIQUE

Scanning technique is not something that can be learnt from a book. There is absolutely no substitute for regular practical experience under the supervision of a qualified ultrasound practitioner.

There are, however, some general approaches which help to get the best from the scanning procedure:

- Scan in a systematic way to ensure the whole of the upper abdomen has been thoroughly interrogated. The use of a worksheet, which indicates the structures to be examined, is advisable when learning.[1]
- Always scan any organ in *at least* two planes, preferably at right angles to each other. This reduces the risk of missing pathology and helps to differentiate artefact from true pathology.
- Where possible, scan in at least two patient positions. It is surprising how the available ultrasound information can be enhanced by turning your patient oblique, decubitus or erect. Inaccessible organs flop into better view and bowel moves away from the area of interest.
- Use a combination of sub- and intercostal scanning for all upper-abdominal scanning. The different angles of insonation can reveal pathology and eliminate artefact.
- Don't limit yourself to longitudinal and transverse sections. Use a variety of planes and angulations. Trace ducts and vessels along their courses. Use the transducer like a pair of eyes.
- Deep inspiration is useful in a proportion of patients, but not all. Sometimes it can make matters worse by filling the stomach with air and obscuring large areas. An intercostal approach with the patient breathing gently often has far more success.
- Positioning patients supine, particularly if elderly or very ill, can make them breathless and uncomfortable. Raise the patient's head as much as necessary; a comfortable patient is much easier to scan.
- Images are a useful record of the scan and how it has been performed, but don't make these your primary task. *Scan first*, sweeping smoothly from one aspect of the organ to the other in two planes, then take the relevant images to support your findings.
- Make the most of your equipment (see Chapter 1). Increase the confidence level of your scan by fully utilizing all the available facilities, using Doppler, tissue harmonics, changing transducers and frequencies and manipulating the machine settings and processing options.

THE LIVER

Normal appearance

The liver is a homogeneous, mid-grey organ on ultrasound. It has the same, or slightly increased echogenicity when compared to the cortex of the right kidney. Its outline is smooth, the inferior margin coming to a point anteriorly (Fig. 2.1). The liver is surrounded by a thin, hyperechoic capsule, which is difficult to see on ultrasound unless outlined by fluid (Fig. 2.2).

The smooth parenchyma is interrupted by vessels (see below) and ligaments (Figs 2.3–2.15) and the liver itself provides an excellent acoustic window on to the various organs and great vessels situated in the upper abdomen.

The ligaments are hyperechoic, linear structures; the falciform ligament, which separates the anatomical left and right lobes is situated at the

Figure 2.1 Longitudinal section (LS) through the right lobe of the liver. The renal cortex is slightly less echogenic than the liver parenchyma.

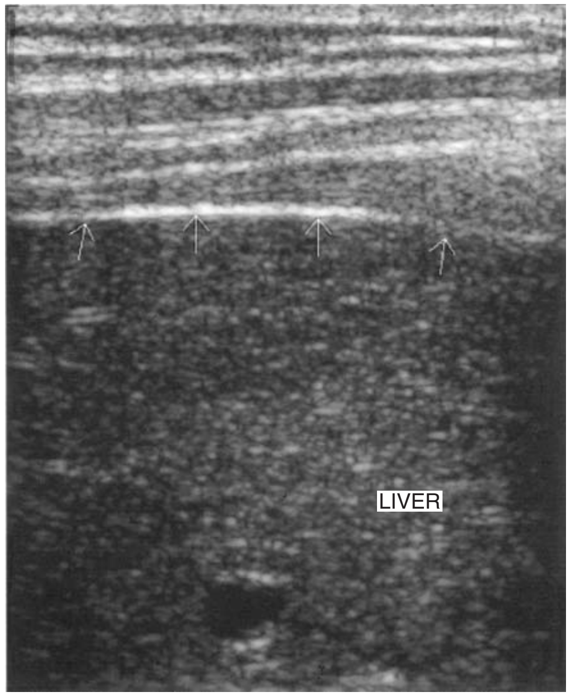

Figure 2.2 The capsule of the liver (arrows) is demonstrated with a high-frequency (7.5 MHz) probe.

superior margin of the liver and is best demonstrated when surrounded by ascitic fluid. It surrounds the left main portal vein and is known as the ligamentum teres as it descends towards the infero-anterior aspect of the liver (Figs 2.9 and 2.15). The ligamentum venosum separates the caudate lobe from the rest of the liver (Fig. 2.6).

The size of the liver is difficult to quantify, as there is such a large variation in shape between normal subjects and direct measurements are notoriously inaccurate. Size is therefore usually assessed subjectively. Look particularly at the inferior margin of the right lobe which should come to a point anterior to the lower pole of the right kidney (Fig. 2.1). A relatively common variant of this is the *Reidel's lobe*, an inferior elongation of segment VI on the right. This is an extension of the right lobe over the lower pole of the kidney, with a rounded margin (Fig. 2.16), and is worth remembering as a possible cause of a palpable right upper quadrant 'mass'.

To distinguish mild enlargement from a Reidel's lobe, look at the left lobe. If this also looks bulky, with a rounded inferior edge, the liver is enlarged. A Reidel's lobe is usually accompanied by a smaller, less accessible left lobe.

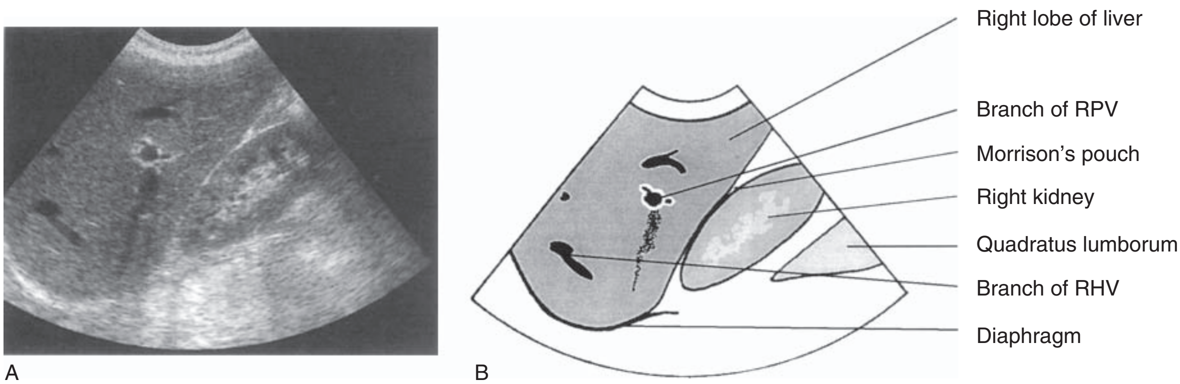

Figure 2.3 LS through the right lobe of the liver and right kidney. RPV = right portal vein; RHV = right hepatic vein.

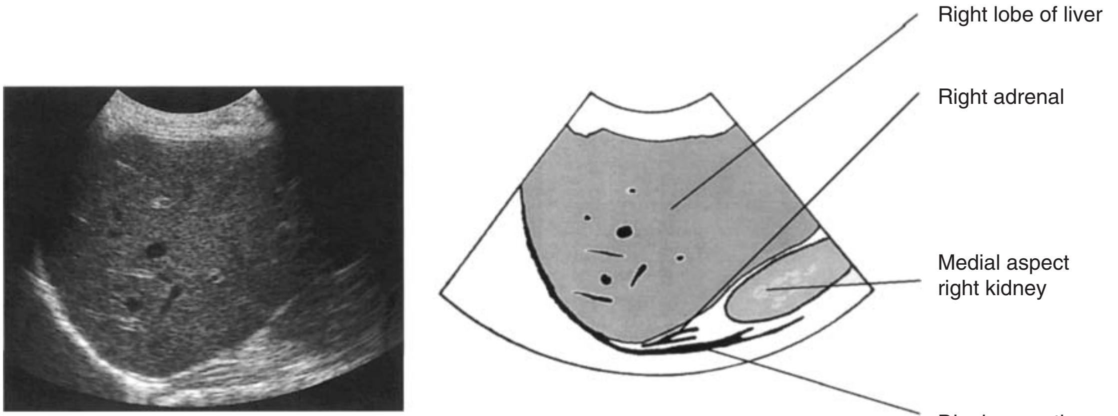

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Figure 2.4 LS, right lobe, just medial to the right kidney.

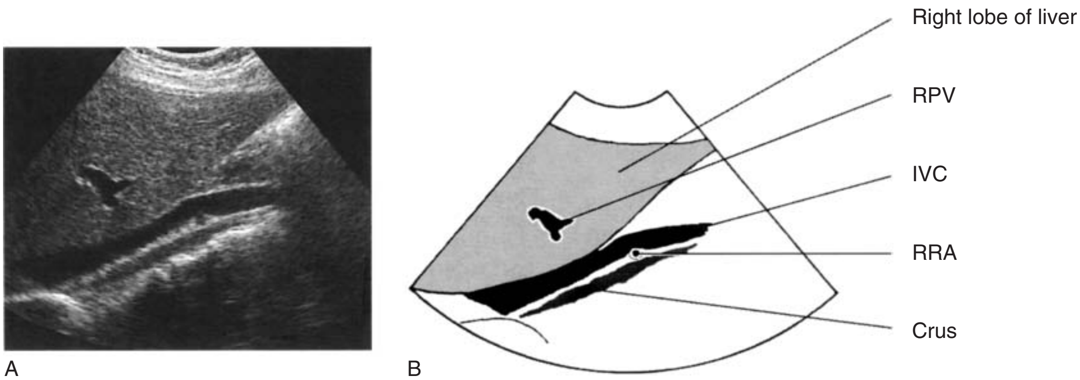

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Figure 2.5 LS, right lobe, angled medially towards the inferior vena cava (IVC). RRA = right renal artery.

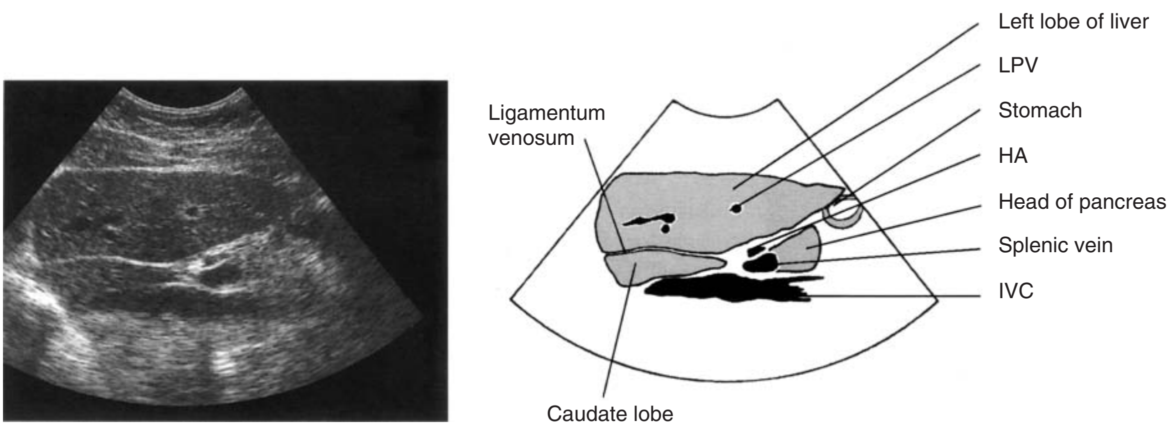

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Figure 2.6 LS, midline, through the left lobe, angled right towards the IVC. LPV = left portal vein; HA = hepatic artery.

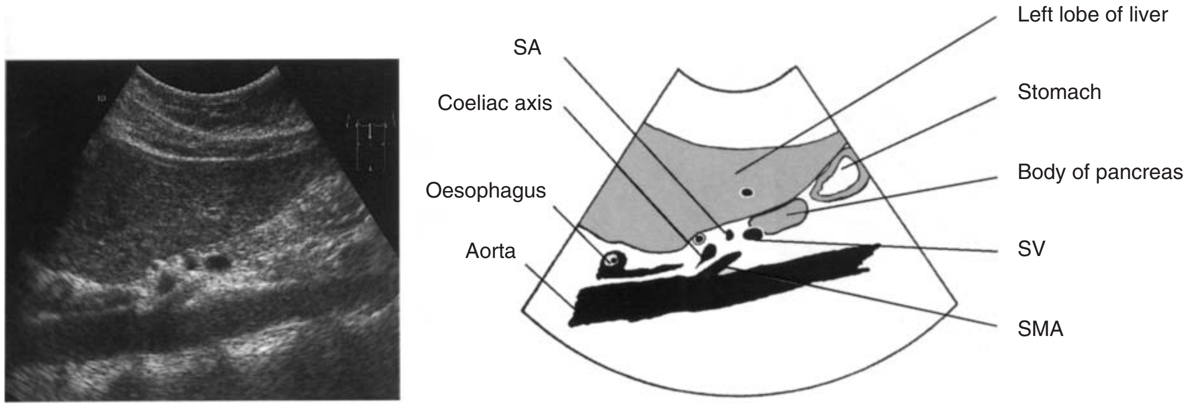

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Figure 2.7 LS through the midline. SV = splenic vein; SA = splenic artery; SMA = superior mesenteric artery.

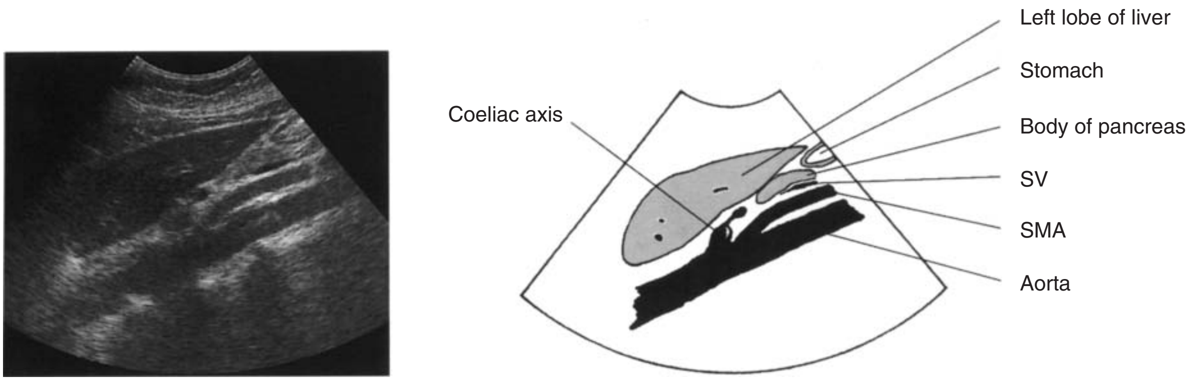

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Figure 2.8 LS just to the left of midline.

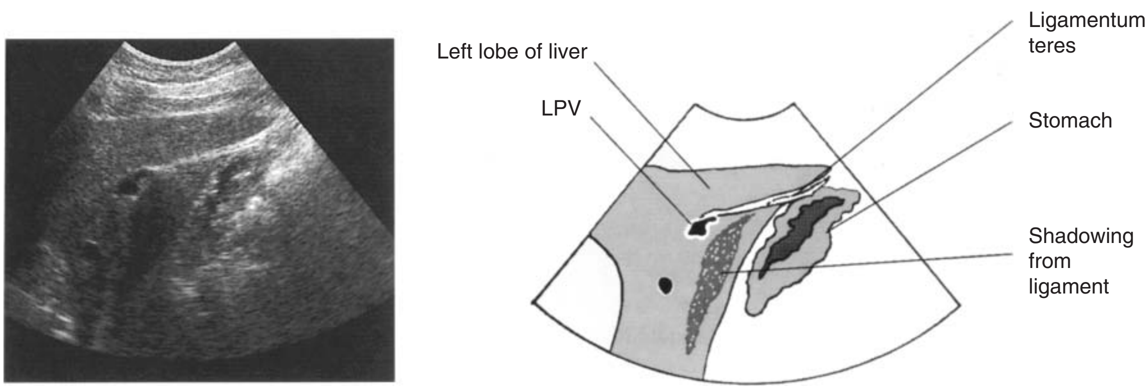

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Figure 2.9 LS, left lobe of liver.

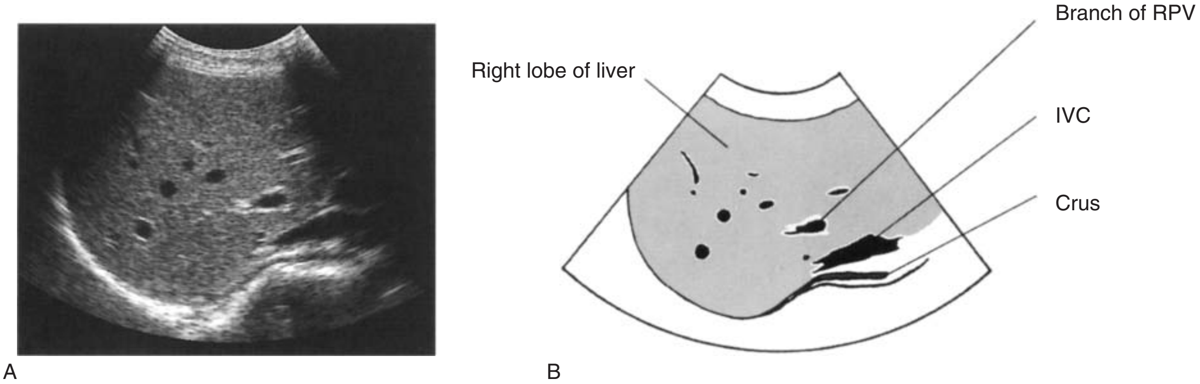


Figure 2.10 Transverse section (TS) through the liver, above the confluence of the hepatic veins.

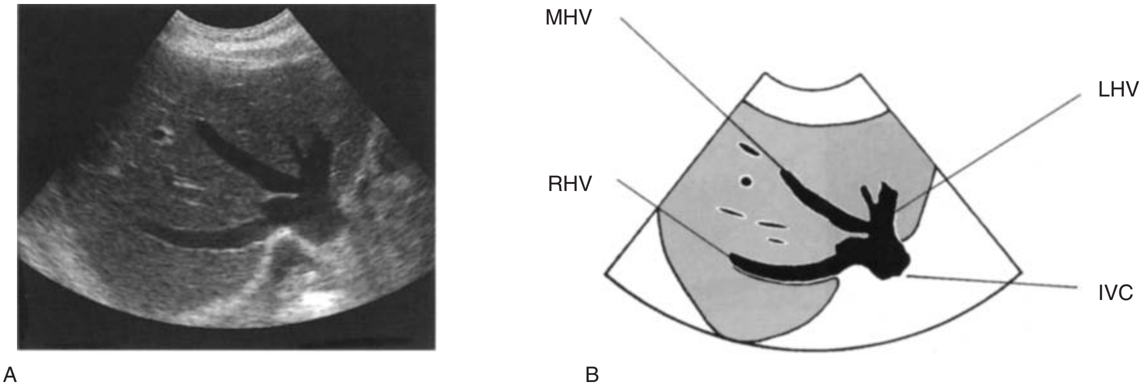


Figure 2.11 TS at the confluence of the hepatic veins (HV).

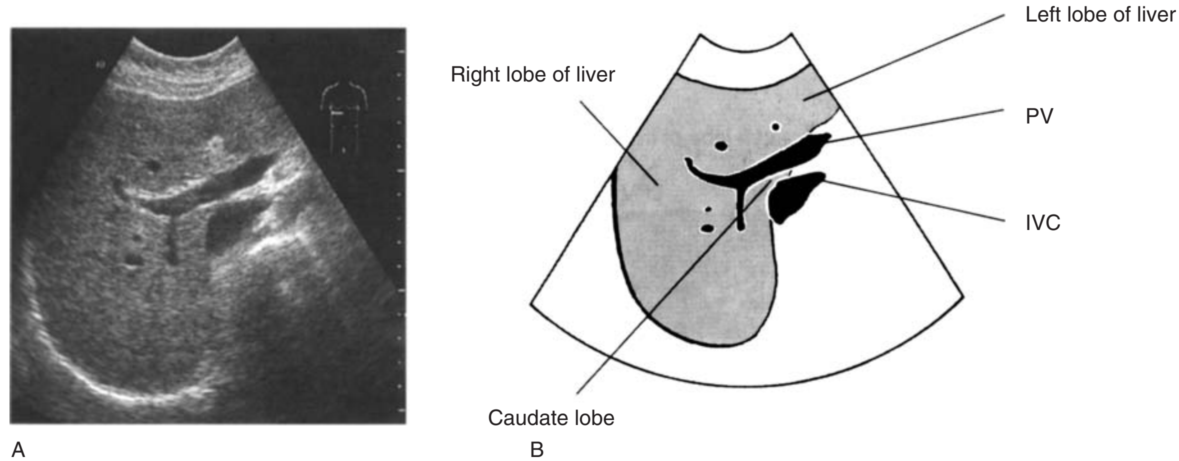


Figure 2.12 TS at the porta hepatis. PV = portal vein.

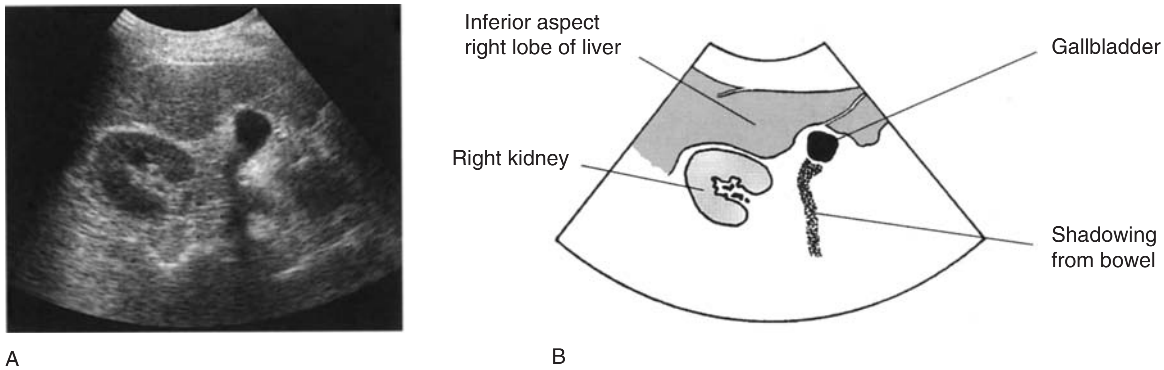


Figure 2.13 TS through the right kidney.

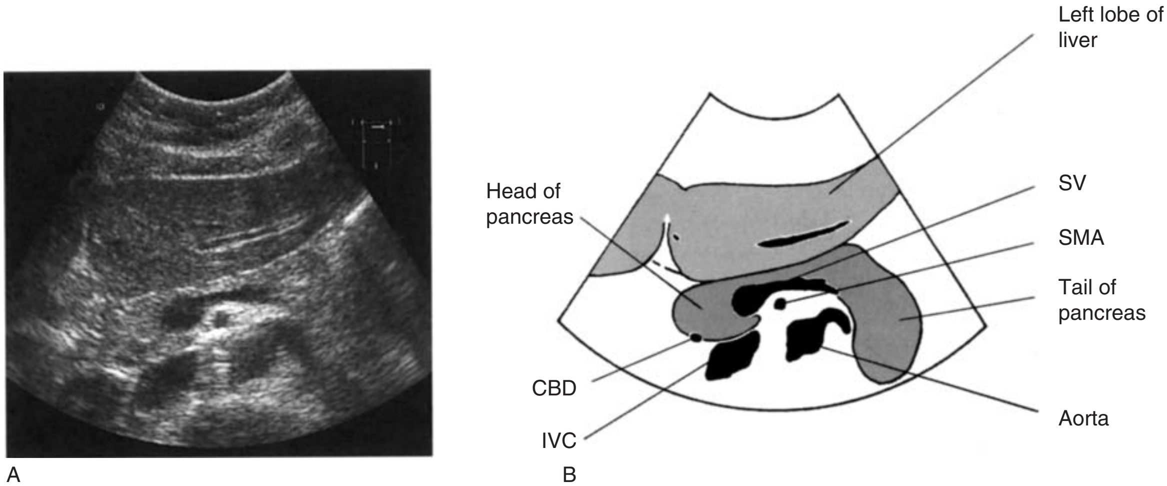


Figure 2.14 TS at the epigastrium. CBD = common bile duct.

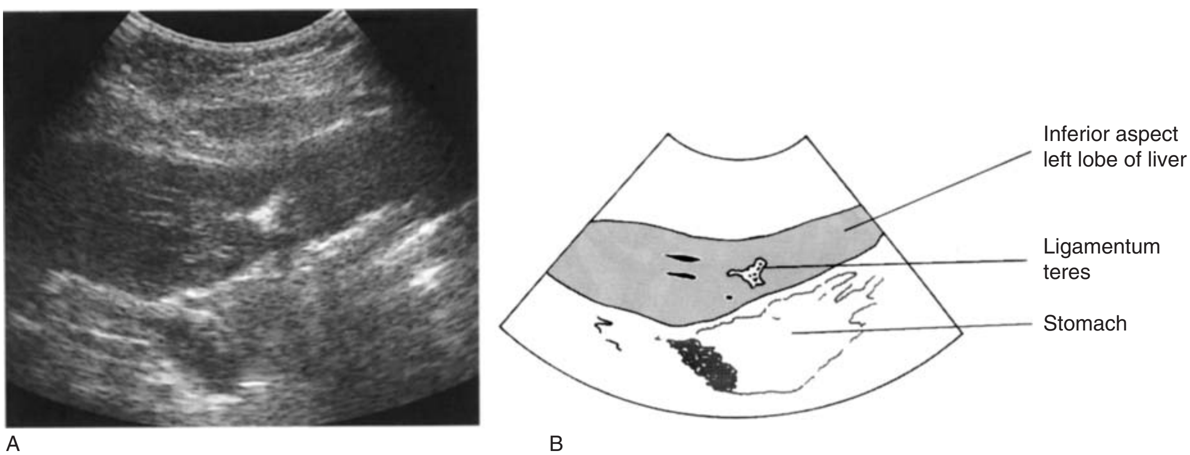


Figure 2.15 TS at the inferior edge of the left lobe.

Figure 2.16 LS through the right lobe, demonstrating a Reidel's lobe extending below the right kidney. (Compare with the normal liver in Figure 2.1.)

The segments of the liver

It is often sufficient to talk about the 'right' or 'left' lobes of the liver for the purposes of many diagnoses. However, when a focal lesion is identified, especially if it may be malignant, it is useful to locate it precisely in terms of the surgical segments. This allows subsequent correlation with other imaging, such as computerized tomography (CT) or magnetic resonance imaging (MRI), and is invaluable in planning surgical procedures.

The segmental anatomy system, proposed by Couinaud in 1954,[2] divides the liver into eight segments, numbered in a clockwise direction. They are divided by the portal and hepatic veins and the system is used by surgeons today when planning surgical procedures (Fig. 2.17). This system is also used when localizing lesions with CT and MRI.

Identifying the different segments on ultrasound requires the operator to form a mental three-dimensional image of the liver. The dynamic nature of ultrasound, together with the variation in planes of scan, makes this more difficult to do than for CT or MRI. However, segmental localization of hepatic lesions by an experienced operator can be as accurate with ultrasound as with MRI.[3] Systematic scanning through the liver, in transverse section, identifies the main landmarks of the hepatic veins (Fig. 2.11) separating segments VII, VIII, IV and II in the superior part of the liver. As the transducer is moved inferiorly, the portal vein appears, and below this segments V and VI are located.

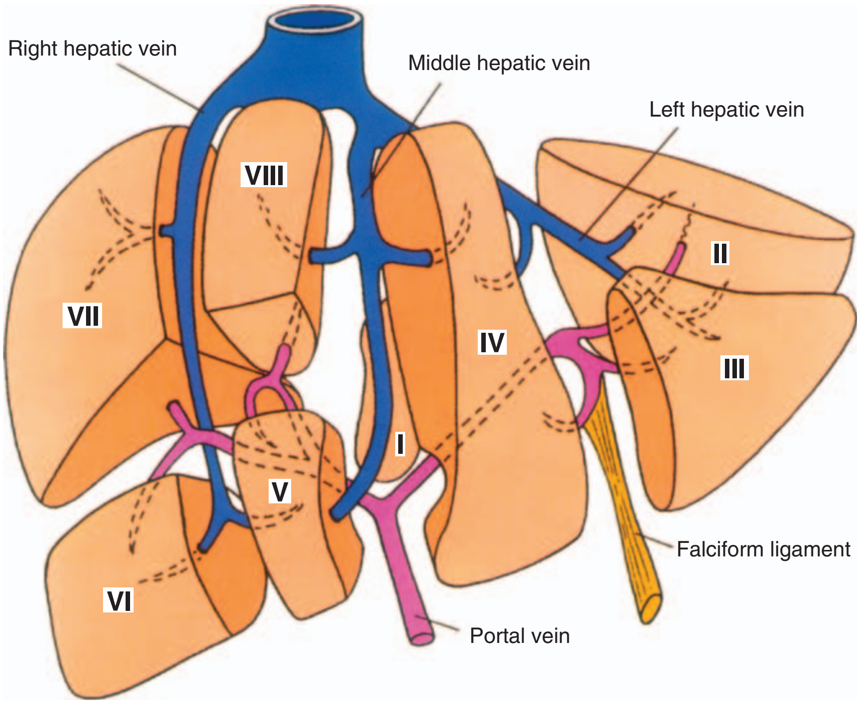


Figure 2.17 The surgical segments of the liver (after Couinaud[2]).

Hepatic vasculature

The *portal veins* radiate from the porta hepatis, where the main portal vein (MPV) enters the liver (Fig. 2.18). They are encased by the hyperechoic, fibrous walls of the portal tracts, which make them stand out from the rest of the parenchyma. Also contained in the portal tracts are a branch of the hepatic artery and a biliary duct radical. These latter vessels are too small to detect by ultrasound in the peripheral parts of the liver, but can readily be demonstrated in the larger, proximal branches (Fig. 2.19).

At the porta, the *hepatic artery* generally crosses the anterior aspect of the portal vein, with the common duct anterior to this (Fig. 2.20). In a common variation the artery lies anterior to the duct. Peripherally, the relationship between the vessels in the portal tracts is variable, (Fig. 2.21).

The three main *hepatic veins*, left, middle and right, can be traced into the inferior vena cava (IVC) at the superior margin of the liver (Fig. 2.11). Their course runs, therefore, approximately perpendicular to the portal vessels, so a section of liver with a longitudinal image of a hepatic vein is likely to contain a transverse section through a portal vein, and vice versa.

Unlike the portal tracts, the hepatic veins do not have a fibrous sheath and their walls are therefore less reflective. Maximum reflectivity of the vessel walls occurs with the beam perpendicular (Fig. 2.22).

The anatomy of the hepatic venous confluence varies. In most cases the single, main right hepatic vein (RHV) flows directly into the IVC, and the middle and left have a common trunk. In 15–35% of patients the left hepatic vein (LHV) and middle hepatic vein (MHV) are separate. This usually has no significance to the operator. However, it may be a significant factor in planning and performing hepatic surgery, especially tumour resection, as the surgeon attempts to retain as much viable hepatic tissue as possible with intact venous outflow (Fig. 2.23).[4]

Haemodynamics of the liver

Pulsed and colour Doppler to investigate the hepatic vasculature are now established aids to diagnosis in the upper abdomen. Doppler should always be used in conjunction with the real-time image and in the context of the patient's presenting symptoms. Used in isolation it can be highly misleading. Familiarity with the normal Doppler

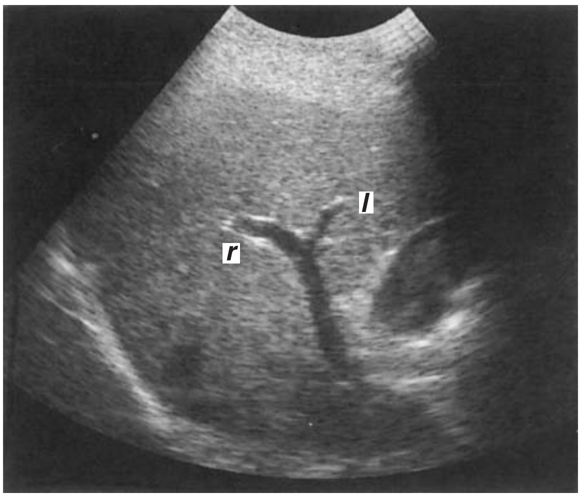


Figure 2.18 The right and left branches of the portal vein.

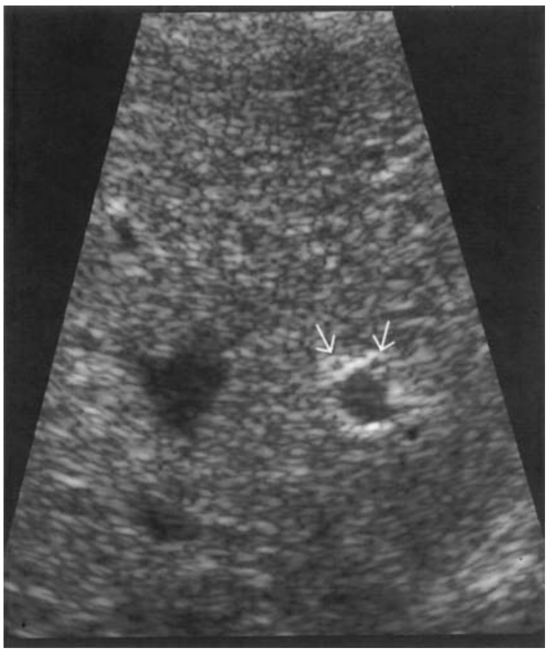
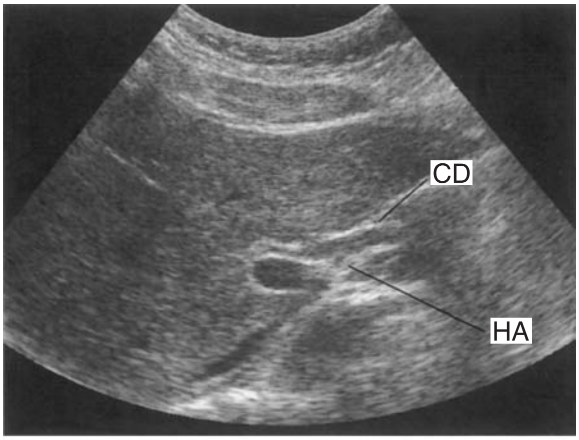


Figure 2.19 The portal vein radical is associated with a branch of the hepatic artery and a biliary duct (arrows) within the hyperechoic fibrous sheath.



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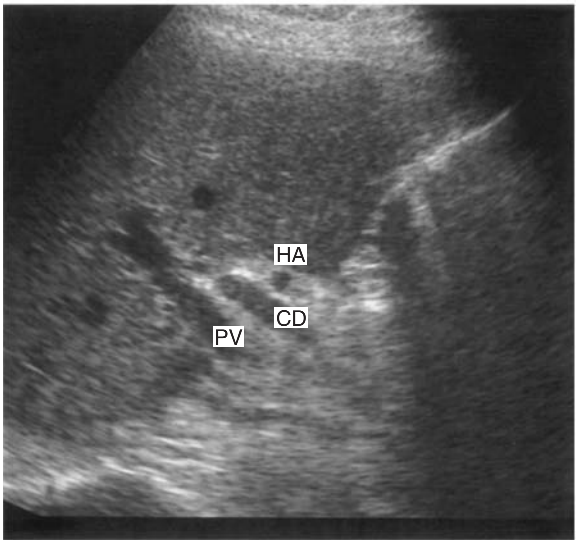


B

Figure 2.20 (A) The porta hepatis. (B) A variant with the hepatic artery anterior to the duct. CD = common duct.

spectra is an integral part of the upper-abdominal ultrasound scan.

Doppler of the portal venous and hepatic vascular systems gives information on the patency, velocity and direction of flow. The appearance of the various spectral waveforms relates to the downstream resistance of the vascular bed (see Chapter 1).

The portal venous system

Colour Doppler is used to identify blood flow in the splenic and portal veins (Figs 2.24 and 2.25). The direction of flow is normally hepatopetal, that is towards the liver. The main, right and left portal branches can best be imaged by using a right oblique approach through the ribs, so that the course of the vessel is roughly towards the transducer, maintaining a low (< 60°) angle with the beam for the best Doppler signal.

The normal portal vein diameter is highly variable but does not usually exceed 16 mm in a resting state on quiet respiration.[5] The diameter increases with deep inspiration and also in response to food and to posture changes. An increased diameter may also be associated with portal hypertension in chronic liver disease (see Chapter 4). An absence of postprandial increase in diameter is also a sign of portal hypertension.

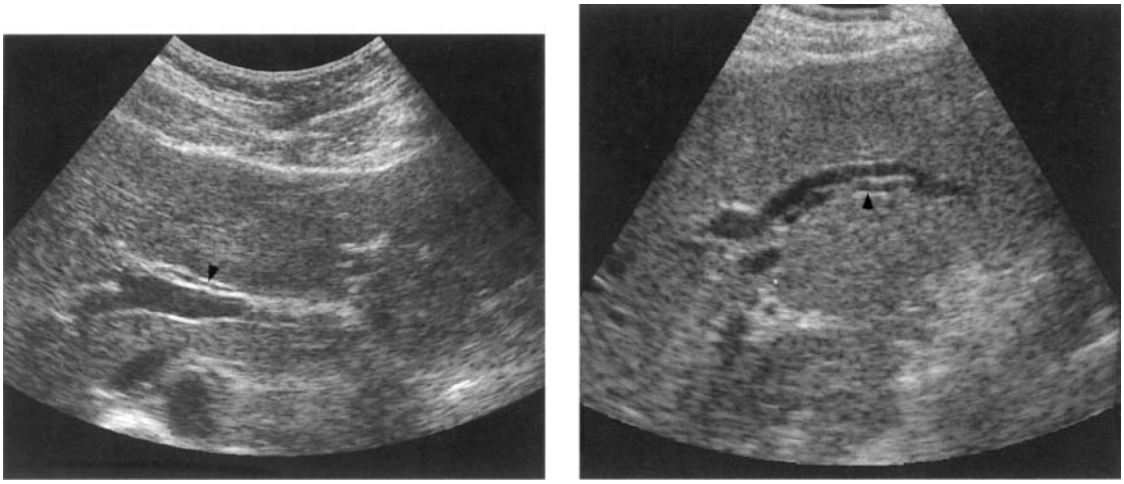
The normal portal vein (PV) waveform is monophasic (Fig. 2.26) with gentle undulations which are due to respiratory modulation and cardiac activity. This characteristic is a sign of the normal, flexible nature of the liver and may be lost in some fibrotic diseases.

The mean PV velocity is normally between 12 and 20 cm per second[6] but the normal range is wide. (A low velocity is associated with portal hypertension. High velocities are unusual, but can be due to anastomotic stenoses in transplant patients.)

The hepatic veins

The hepatic veins drain the liver into the IVC, which leads into the right atrium. Two factors shape the hepatic venous spectrum: the flexible nature of the normal liver, which can easily expand to accommodate blood flow, and the close proximity of the right atrium, which causes a brief 'kick' of blood back into the liver during atrial systole (Fig. 2.27). This causes the spectrum to be triphasic. The veins can be seen on colour Doppler to be predominantly blue with a brief red flash during atrial contraction. Various factors cause alterations to this waveform: heart conditions, liver diseases and extrahepatic conditions which compress the liver, such as ascites. Abnormalities of the hepatic vein waveform are therefore highly unspecific and should be taken in context with the clinical picture.

As you might expect, the pulsatile nature of the spectrum decreases towards the periphery of the liver, remote from the IVC.



A B

Figure 2.21 The relationship of the biliary duct to the portal vein varies as the vessels become more peripheral. In (A) the duct lies anterior to the LPV; in (B) the duct is posterior to the LPV.

Figure 2.22 The left hepatic vein. Vessel walls are not as reflective as portal veins; however, maximum reflectivity is produced when the beam is perpendicular to the walls, as at the periphery of this vessel.

The hepatic artery

The main hepatic artery arises from the coeliac axis and carries oxygenated blood to the liver from the aorta. Its origin makes it a pulsatile vessel and the relatively low resistance of the hepatic vascular bed means that there is continuous forward flow throughout the cardiac cycle (Fig. 2.28). In a normal subject the hepatic artery may be elusive on colour Doppler due to its small diameter and tortuous course. Use the MPV as a marker, scanning from the right intercostal space to maintain a low angle with the vessel. The hepatic artery is just anterior to this and of a higher velocity (that is, it has a paler colour of red on the colour map (Fig. 2.24)).

THE GALLBLADDER

The normal gallbladder is best visualized after fasting, to distend it. It should have a hyperechoic, thin wall and contain anechoic bile (Fig. 2.29). Measure the wall thickness in a longitudinal section of the gallbladder, with the calipers perpendicular to the wall itself. (A transverse section may not be perpendicular to the wall, and can overestimate the thickness.)

After fasting for around six hours, it should be distended with bile into an elongated pear-shaped sac. The size is too variable to allow direct measurements to be of any use, but a tense, rounded shape can indicate pathological, rather than physiological dilatation.

Because the size, shape and position of the gallbladder are infinitely variable, so are the techniques required to scan it. There are, however, a number of useful pointers to maximize visualization of the gallbladder:

- Use the highest frequency possible: 5.0 MHz or higher is especially useful for anterior gallbladders.
- Use a high line density to pick up tiny stones or polyps (reduce the sector angle and the frame rate if possible). Make sure the focal

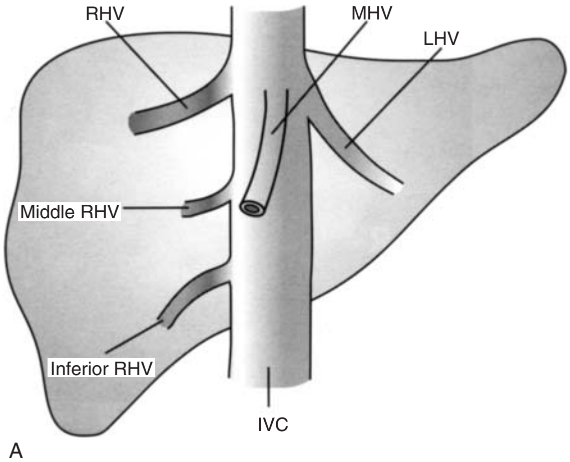


Figure 2.23 (A) Configuration of the hepatic venous system. (B) Inferior middle hepatic vein (arrow) arising from the IVC.

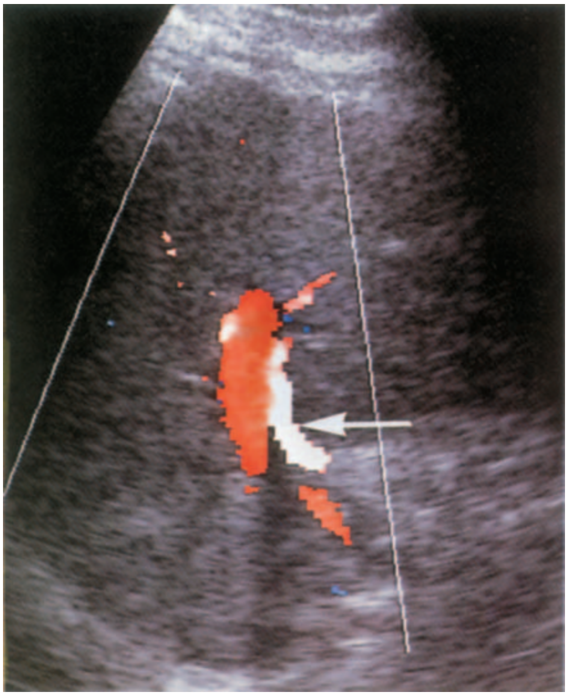


Figure 2.24 Main portal vein at the porta hepatis demonstrating hepatopetal flow. The higher velocity hepatic artery lies adjacent to the Main portal vein (arrow).

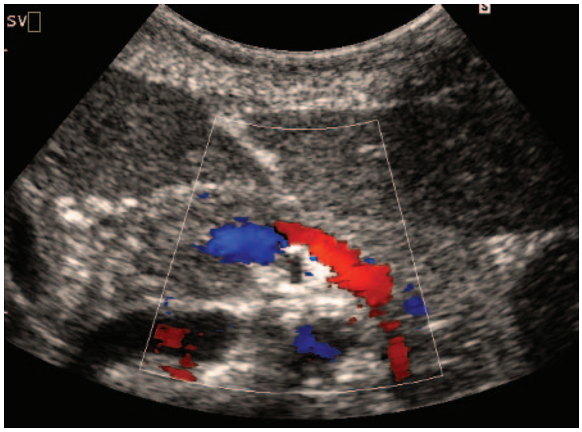


Figure 2.25 TS through the epigastrium, demonstrating the normal splenic vein with flow towards the liver. Note the change from red to blue as the vessel curves away from the transducer.

zone is set over the back wall of the gallbladder to maximize the chances of identifying small stones (see Chapters 1 and 3).

- Alter the time gain compensation (TGC) to eliminate or minimize anterior artefacts and reverberation echoes inside the gallbladder, particularly in the near field.
- Use tissue harmonic imaging to reduce artifact within the gallbladder and sharpen the image of the wall (particularly in a large abdomen).
- Always scan the gallbladder in at least two planes (find the gallbladder's long axis, incorporating the neck and fundus; sweep from side to side, then transversely from neck to fundus) and two patient positions. You will almost certainly miss pathology if you do not.

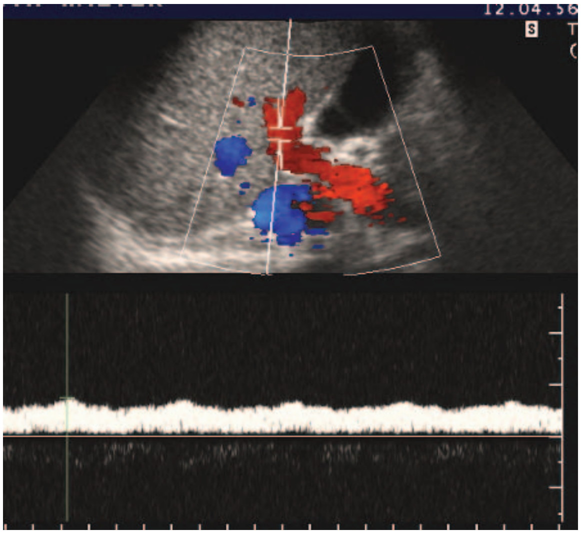


Figure 2.26 Normal portal vein waveform. Respiratory modulations are evident.

- The gallbladder may be 'folded' (the so-called Phrygian cap). To interrogate its contents fully, unfold it by turning the patient decubitus (right side raised), almost prone or erect (Fig. 2.30).
- Bowel gas over the fundus can also be moved by various patient positions.

Normal variants of the gallbladder

The mesenteric attachment of the gallbladder to the inferior surface of the liver is variable in length. This gives rise to large variations in position; at one end of the spectrum the gallbladder, attached only at the neck, may be fairly remote from the liver, even lying in the pelvis; at the other the gallbladder fossa deeply invaginates the liver and the gallbladder appears to lie 'intrahepatically' enclosed on all sides by liver tissue.

The presence of a true septum in the gallbladder is rare. A folded gallbladder frequently gives the impression of a septum but this can be distinguished by positioning the patient to unfold the gallbladder.

Occasionally a gallbladder septum completely divides the lumen into two parts. True gallbladder duplication is a rare entity (Fig. 2.31) and it is important not to mistake this for a gallbladder with a pericholecystic collection in a symptomatic patient. Occasionally the gallbladder is absent altogether.

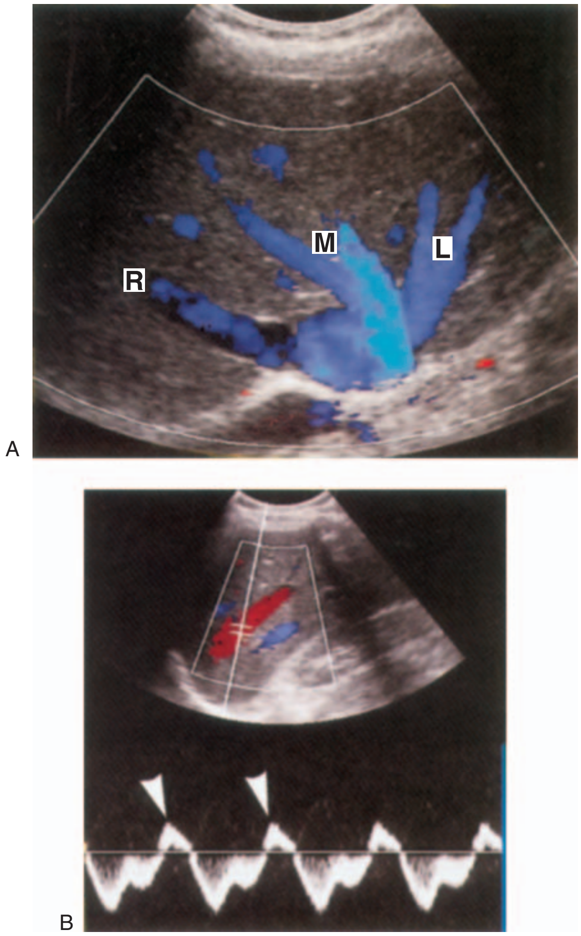
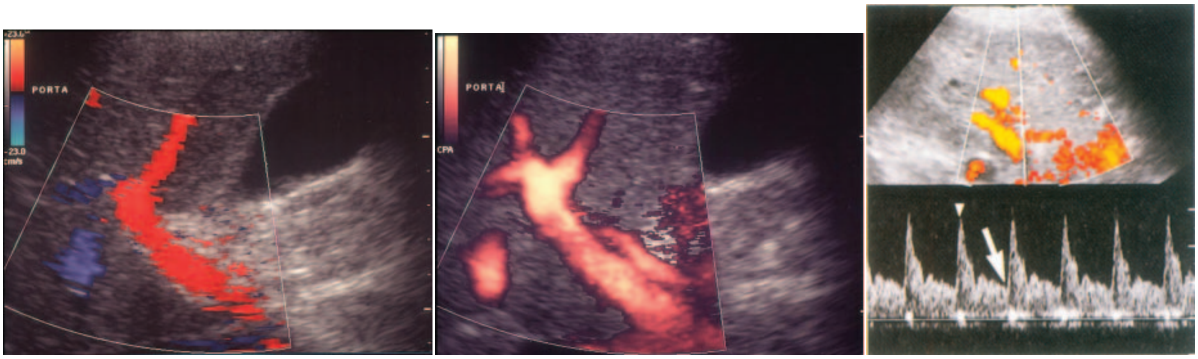


Figure 2.27 (A) The confluence of the right, middle and left hepatic veins with the IVC. (B) Normal hepatic venous waveform. The reverse flow in the vein (arrows) is due to atrial systole. Note that the image has also been frozen during atrial systole, as the hepatic vein appears red.

Pitfalls in scanning the gallbladder

If the gallbladder cannot be found

- Check for previous surgery; a cholecystectomy scar is usually obvious, but evidence of laparoscopic surgery may be difficult to see in the darkened scanning room.
- Check the patient has fasted.



A B C

Figure 2.28 (A) The hepatic artery may be difficult to locate with colour Doppler in some subjects. (B) The same patient using power Doppler; visualization is improved. (C) The normal hepatic artery waveform demonstrates a relatively high-velocity systolic peak (arrowhead) with good forward end-diastolic flow (arrow).

- Look for an ectopic gallbladder, for example positioned low in the pelvis.
- Check that a near-field artefact has not obscured an anterior gallbladder, a particular problem in very thin patients.
- Ensure the scanner frequency and settings are optimized, find the porta hepatis and scan just below it in transverse section. This is the area of the gallbladder fossa and you should see at least the anterior gallbladder wall if the gallbladder is present (Fig. 2.32).
- A contracted, stone-filled gallbladder, producing heavy shadowing, can be difficult to identify due to the lack of any contrasting fluid in the lumen.

Duodenum mimicking gallbladder pathology

- The close proximity of the duodenum to the posterior gallbladder wall often causes it to invaginate the gallbladder. Maximize your machine settings to visualize the posterior gallbladder wall separate from the duodenum and turn the patient to cause the duodenal contents to move.
- Other segments of fluid-containing gastrointestinal tract can also cause confusion (Fig. 2.33).

Stones that don't shadow

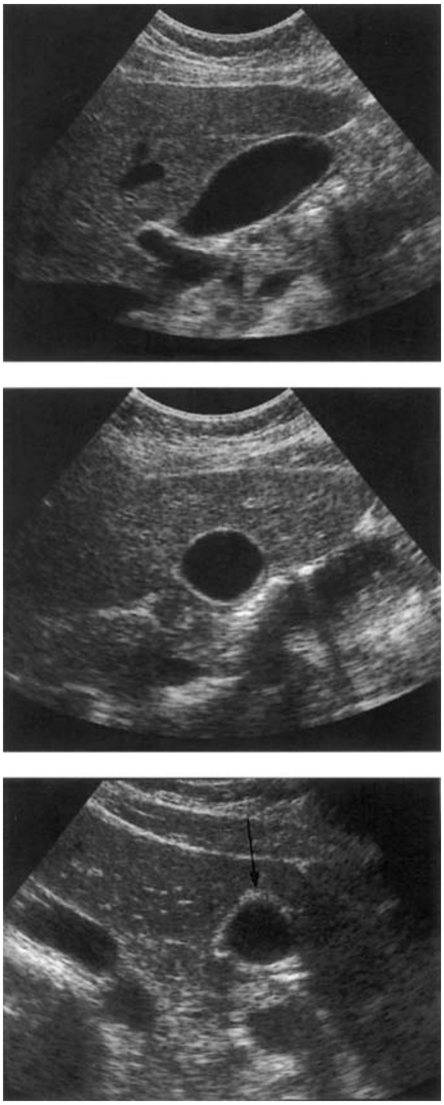
- Ensure they are stones and not polyps by standing the patient erect and watching them move with gravity. (Beware—polyps on long stalks also move around.)
- The stones may be smaller than the beam width, making the shadow difficult to display. Make sure the focal zone is set at the back of the gallbladder.
- Increase the line density, if possible, by reducing the field of view.
- Scan with the highest possible frequency to ensure the narrowest beam width.
- Reduce the TGC and/or power to make sure you have not saturated the echoes distal to the gallbladder (see Chapter 3).

Beware the folded gallbladder

- You may miss pathology if the gallbladder is folded and the fundus lies underneath bowel. Always try to unfold it by positioning the patient (Fig. 2.30).
- A fold in the gallbladder may mimic a septum. Septa are comparatively rare and have been over-reported in the past due to the presence of folding.

Pathology or artefact?

Sometimes the gallbladder may contain some echoes of doubtful significance, or be insufficiently distended to evaluate accurately. A rescan, after a meal followed by further fasting, can be useful.



A

B

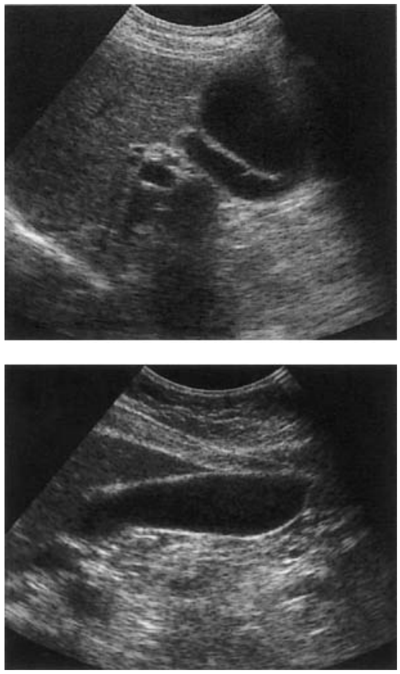
C

Figure 2.29 The gallbladder: (A) LS, (B) TS. (C) False appearance of wall thickening is produced (arrow) when the angle of scan is not perpendicular to the gallbladder wall in TS.

This can flush out sludge, redistending the gallbladder with clear bile. It may also help to clarify any confusing appearances of adjacent bowel loops.

BILE DUCTS

The common duct can be easily demonstrated in its intrahepatic portion just anterior and slightly to the right of the portal vein. A cross-section of the main hepatic artery can usually be seen passing between



A

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Figure 2.30 (A) A folded gallbladder is difficult to examine with the patient supine. (B) Turning the patient decubitus, right side raised, unfolds the gallbladder, enabling the lumen to be satisfactorily examined.

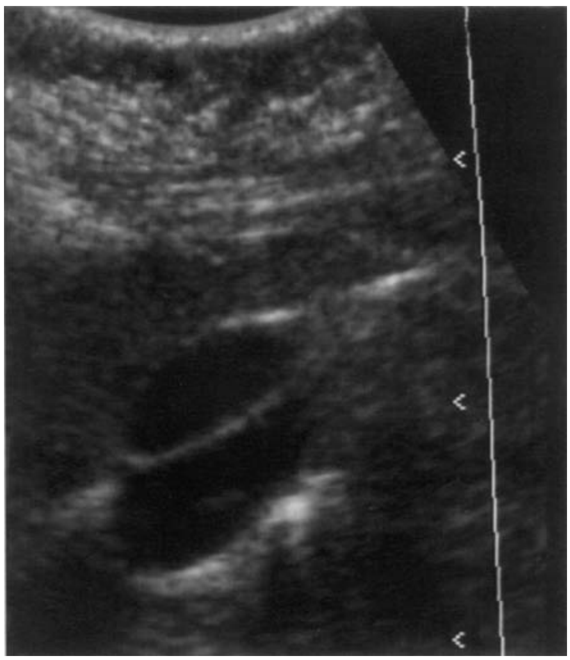


Figure 2.31 Double gallbladder—an incidental finding in a young woman.

Figure 2.32 A contracted, thick-walled gallbladder located in the gallbladder fossa on TS.

A

B

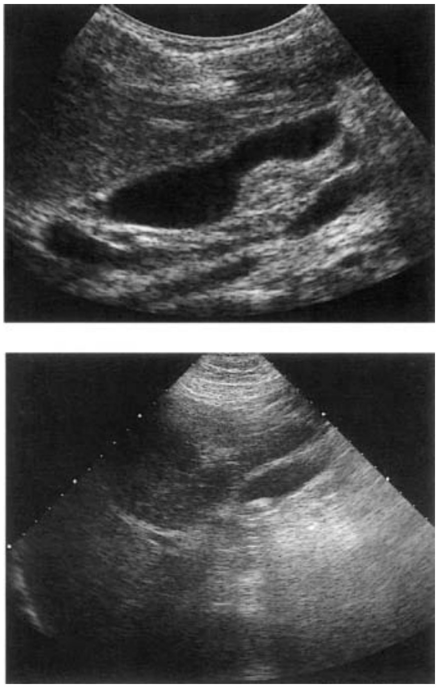


Figure 2.33 (A) The duodenum frequently invaginates the posterior wall of the gallbladder and may mimic pathology if the machine settings are not correctly manipulated. (B) Fluid-filled stomach near the gallbladder fossa mimics a gallbladder containing a stone. The real gallbladder was normal.

the vein and the duct (Figs 2.20A and 2.34), although a small proportion of hepatic arteries lie anterior to the duct (Fig. 2.20B). At this point it is usually referred to as the common duct, although it may, in fact, represent the right hepatic duct[7] rather than

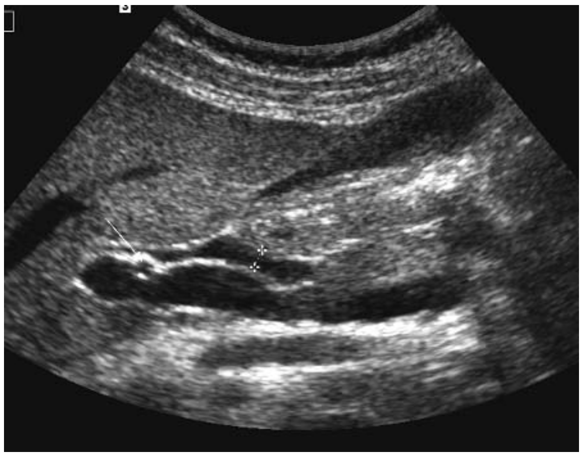


Figure 2.34 CBD at the porta hepatis. The lower end is frequently obscured by shadowing from the duodenum. The duct should be measured at its widest portion.

the common *bile* duct, because we can't tell at what point it is joined by the cystic duct.

The extrahepatic portion of the duct is less easy to see as it is often obscured by overlying duodenal gas. Good visualization of the duct usually requires perseverance on the part of the operator. It is insufficient just to visualize the intrahepatic portion of the duct, as early obstruction may be present with a normal-calibre intrahepatic duct and dilatation of the distal end. (Fig. 2.35).

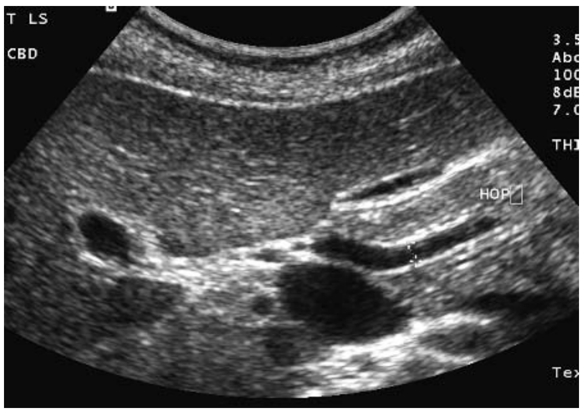


Figure 2.35 Visualization of the lower end of the duct often requires the operator to persevere with technique and patient positioning. The normal duct (calipers) is seen in the head of the pancreas.

Bile duct measurements

The internal diameter of the common duct is usually taken as 6 mm or less. It is age-dependent, however, and can be 8 or 9 mm in an elderly person, due to degeneration of the elastic fibre in the duct wall. Ensure this is not early obstruction by thoroughly examining the distal common bile duct or rescanning after a short time interval. The diameter can vary quite considerably, not only between subjects, but along an individual duct. The greatest measurement should be recorded, in longitudinal section. Never measure the duct in a transverse section (for example at the head of pancreas); it is invariably an oblique plane through the duct, which will overestimate the diameter. Intrahepatically, the duct diameter decreases. The right and left hepatic ducts are just visible, but more peripheral branches are usually too small to see.

Patients with a cholecystectomy who have had previous duct dilatation frequently also have a persistently dilated, but non-obstructed, duct (Fig. 2.36). Be suspicious of a diameter of 10 mm or more as this is associated with obstruction due to formation of stones in the duct.

Techniques

The main, right and left hepatic ducts tend to lie anterior to the portal vein branches; however as the biliary tree spreads out, the position of the duct relative to the portal branches is highly variable. Don't assume that a channel anterior to the PV branch is always a biliary duct—if in doubt, use colour Doppler to distinguish the bile duct from the portal vein or hepatic artery.

The proximal bile duct is best seen either with the patient supine, using an intercostal approach from the right, or turning the patient oblique, right side raised. This projects the duct over the portal vein, which is used as an anatomic marker.

Scanning the distal duct usually requires more effort. Right oblique or decubitus positions are useful. Gentle pressure to ease the duodenal gas away from the duct can also be successful. Sometimes, filling the stomach with water (which also helps to display the pancreas) and allowing it to trickle through the duodenum does the trick. Try also identifying the duct in the pancreatic head (Fig. 2.37) and then tracing it retrogradely towards the liver. Asking the patient to take deep breaths is occasionally successful, but may make matters worse by filling the stomach with air. It is definitely worth persevering with your technique, particularly in jaundiced patients.

SOME COMMON REFERRAL PATTERNS FOR HEPATOBILIARY ULTRASOUND

There is an almost infinite number of reasons for performing abdominal ultrasound. Some of the more common referrals are discussed below.

Figure 2.36 A persistently, mildly dilated duct postcholecystectomy (8.5 mm).

Figure 2.37 The common bile duct (arrow) seen on the head of pancreas on transverse section.

Jaundice

This symptom is a frequent cause of referral for abdominal ultrasound. It is therefore essential for the sonographer to have a basic understanding of the various mechanisms in order to maximize the diagnostic information from the ultrasound scan. The causes and ultrasound appearances of jaundice are dealt with more fully in Chapters 3 and 4; a brief overview is included here.

Jaundice, or *hyperbilirubinaemia*, is an elevated level of bilirubin in the blood. It is recognized by a characteristic yellow coloration of the skin and sclera of the eye, often accompanied by itching if prolonged.

Bilirubin is derived from the haem portion of haemoglobin. Red blood cells are broken down in the liver into haem and globin, releasing their bilirubin, which is non-soluble. This is termed *unconjugated bilirubin*. This is then taken up by the liver cells and converted to a water-soluble form, *conjugated bilirubin*, which is excreted via the biliary ducts into the duodenum to aid fat digestion.

By knowing which of these two types of bilirubin is present in the jaundiced patient, the clinician can narrow down the diagnostic possibilities. Ultrasound then further refines the diagnosis (Fig. 2.38).

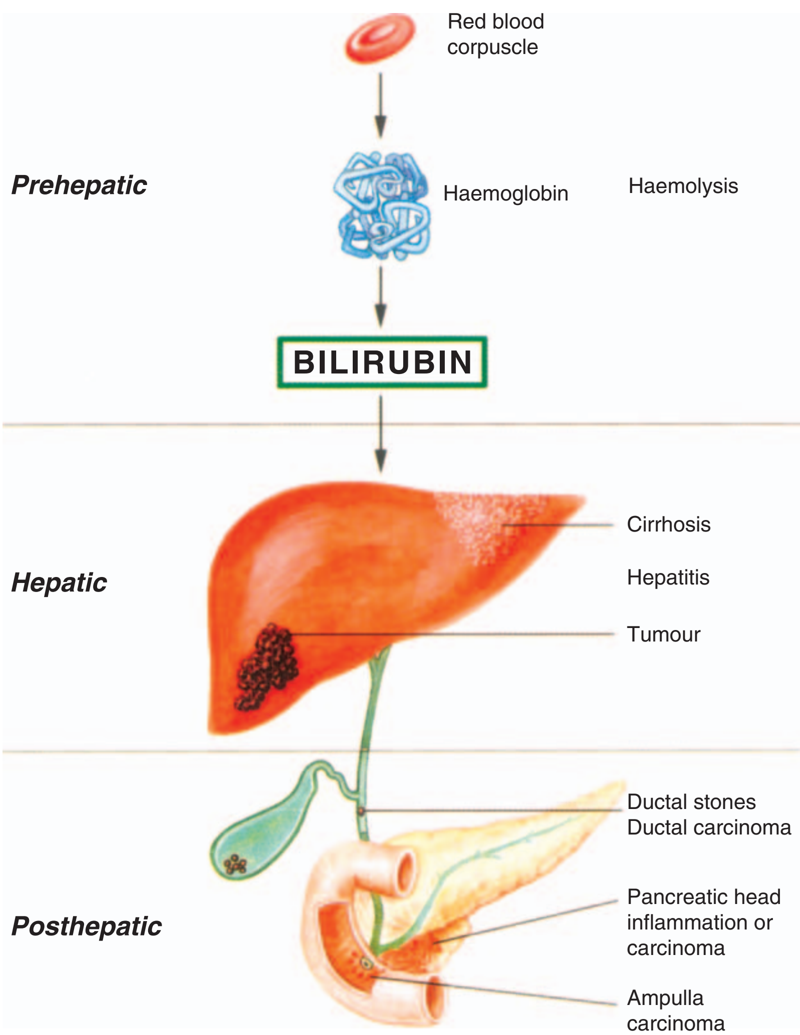


Figure 2.38 Some common causes of jaundice.

Jaundice can fall into one of two categories:

- *obstructive* (sometimes called posthepatic) in which the bile is prevented from draining out of the liver because of obstruction to the biliary duct(s)
- *non-obstructive* (prehepatic or hepatic) in which the elevated bilirubin level is due to haemolysis (the breakdown of the red blood cells) or a disturbance in the mechanism of the liver for uptake and storage of bilirubin, such as in inflammatory or metabolic liver diseases.

Naturally, the treatment of jaundice depends on its cause (Table 2.1). Ultrasound readily distinguishes obstructive jaundice, which demonstrates some degree of biliary duct dilatation, from non-obstructive, which does not.

Abnormal liver function tests

Altered or deranged liver function tests (LFTs) are another frequent cause of referral for abdominal ultrasound.

Biochemistry from a simple blood test is often a primary pointer to pathology and is invariably one of the first tests performed as it is quick and easily accessible. Most of these markers are highly unspecific, being associated with many types of diffuse and focal liver pathology. The most frequently encountered LFTs are listed in Table 2.2.

Other common reasons for referral

In some cases, the presenting symptoms may be organ-specific or even pathognomonic, simplifying the task of ultrasound diagnosis. Often, however,

Table 2.2 Common serum liver function tests

Test	Association with increased level
Bilirubin	Obstructive or non-obstructive jaundice. (Differentiation can be made between conjugated and unconjugated bilirubin)
Alkaline phosphatase (ALP) *(liver enzyme)*	Non-obstructive jaundice Metastases Other focal hepatic lesions
Alpha fetoprotein	Hepatocellular carcinoma (HCC)
Prothrombin time	Malignancy Diffuse liver disease (often with portal hypertension)
Gamma glutamyl transferase	Obstructive jaundice Alcoholic liver disease
Alanine amino-transferase (ALT)	Obstructive or non-obstructive jaundice
Aspartate amino-transferase (AST) *(liver enzymes)*	Hepatitis Viral infections Other organ failure (e.g. cardiac)
Protein (serum albumin)	Lack of protein is associated with numerous liver diseases. Low levels are associated with ascites, often due to portal hypertension

Table 2.1 Common causes of jaundice

Non-obstructive	Obstructive
Unconjugated hyperbilirubinaemia —haemolysis —haematoma —Gilbert's disease	*Conjugated hyperbilirubinaemia* —stones in the biliary duct —carcinoma of the duct, head of pancreas or ampulla —acute pancreatitis —other masses which compress the common bile duct (e.g. lymph node mass) —biliary atresia
Mixed hyperbilirubinaemia —hepatitis —alcoholic liver disease —cirrhosis of all types —multiple liver metastases —drug-induced liver disease	

(See Chapters 3 and 4 for further information.)

the symptoms are vague and non-specific, requiring the sonographer to perform a comprehensive and knowledgeable search. The non-invasive nature of ultrasound makes it ideal for the first-line investigation.

Upper abdominal pain

- Upper abdominal pain, the origin of which could be linked to any of the organs, is one of the most frequent causes of referral. The sonographer can narrow the possibilities down by taking a careful history (see Box 2.1).
- Is the pain focal? This may direct the sonographer to the relevant organ, for example a thick-walled gallbladder full of stones may be tender on gentle transducer pressure, pointing to acute or chronic cholecystitis, depending on the severity of the pain.
- Bear in mind that gallstones are a common incidental finding which may be a red herring. Always consider multiple pathologies.
- Is the pain related to any event which may give a clue? Fat intolerance might suggest a biliary cause, pain on micturition a urinary tract cause, for example.
- Is it accompanied by other symptoms such as a high temperature? This may be associated with an infective process such as an abscess.
- Could it be bowel-related? Generalized abdominal pain could be due to inflammatory or obstructive bowel conditions and knowledge of the patient's bowel habits is helpful.
- Has the patient had any previous surgery which could be significant?

Box 2.1

Always:
- take a verbal history from the patient—don't just rely on the request card
- obtain the results of any previous investigations, including previous radiology
- consider the possibility of multiple pathologies

Palpable right upper quadrant mass

A palpable right upper quadrant mass could be due to a renal, hepatobiliary, bowel-related or other cause. The sonographer should gently palpate to get an idea of the size and position of the mass and whether or not it is tender. Specifically targeting the relevant area may yield useful and unexpected results, for example a Reidel's lobe, colonic carcinoma or impacted faeces, which will help to guide the nature of further investigations.

APPENDIX: UPPER-ABDOMINAL ANATOMY

Diagrams of sectional upper-abdominal anatomy are reproduced here for quick reference. See Box 2.2 for the abbreviations used here.

Box 2.2 Abbreviations

AO	Aorta
CBD	Common bile duct
GB	Gallbladder
GDA	Gastroduodenal artery
HA	Hepatic artery
HOP	Head of pancreas
IVC	Inferior vena cava
LHV	Left hepatic vein
LL	Left lobe of liver
LPV	Left portal vein
LRV	Left renal vein
MHV	Middle hepatic vein
R Adr	Right adrenal gland
RHV	Right hepatic vein
RK	Right kidney
RL	Right lobe of liver
RPV	Right portal vein
RRA	Right renal artery
SA	Splenic artery
SMA	Superior mesenteric artery
SMV	Superior mesenteric vein
SPL	Spleen
ST	Stomach
SV	Splenic vein
TOP	Tail of pancreas

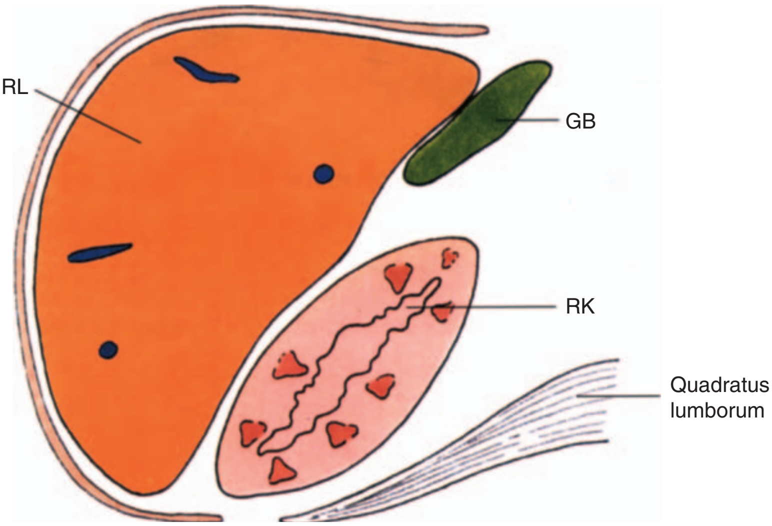


Figure 2A.1 LS through the right lobe of the liver.

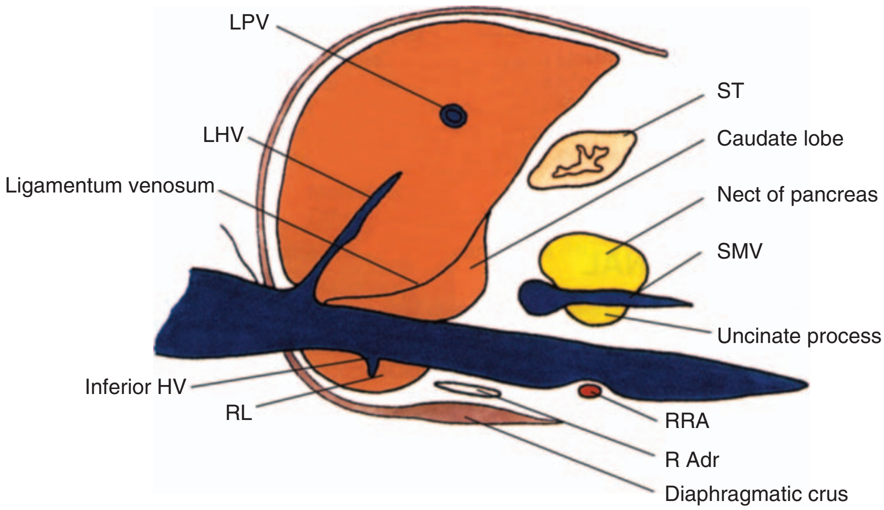


Figure 2A.2 LS through the IVC.

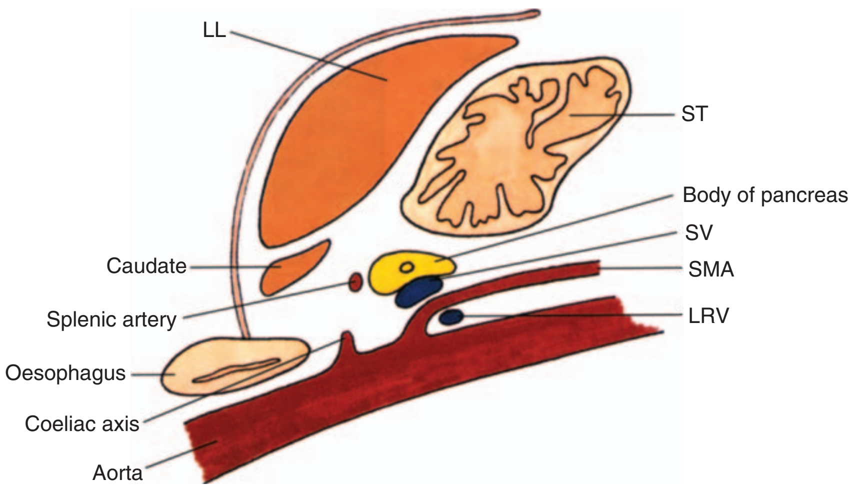


Figure 2A.3 LS through the midline, level of the aorta.

Figure 2A.4 Longitudinal oblique section through the CBD.

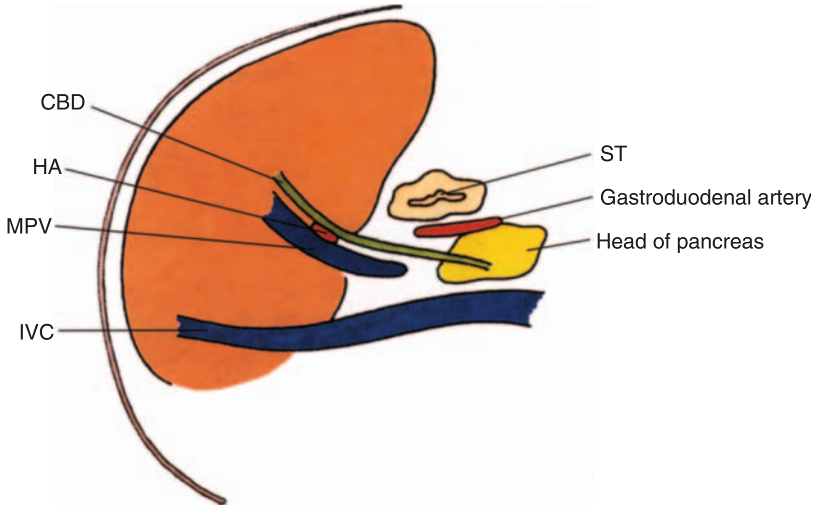
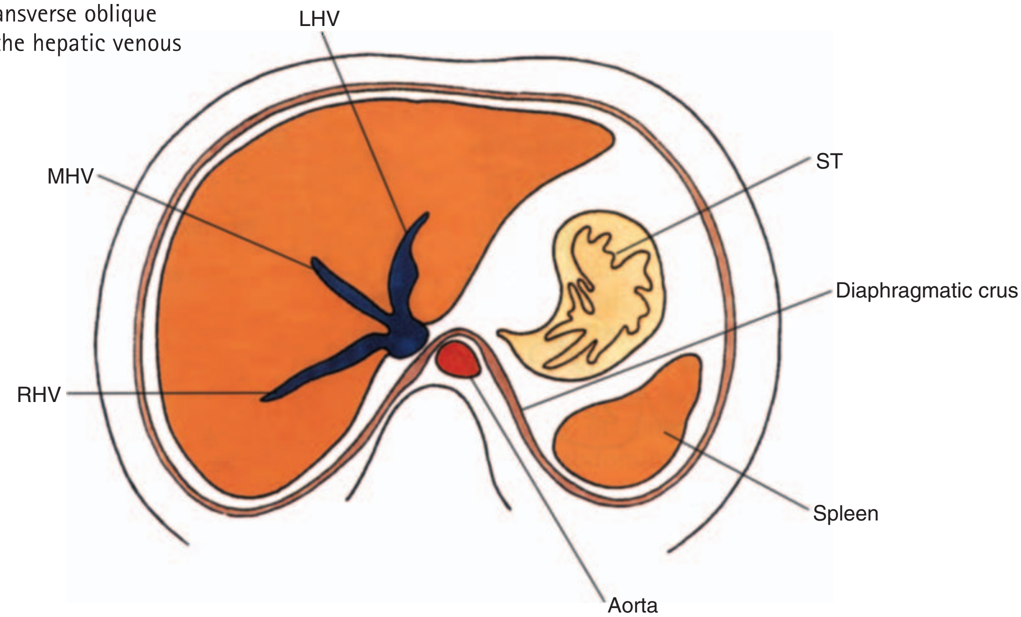


Figure 2A.5 Transverse oblique section through the hepatic venous confluence.



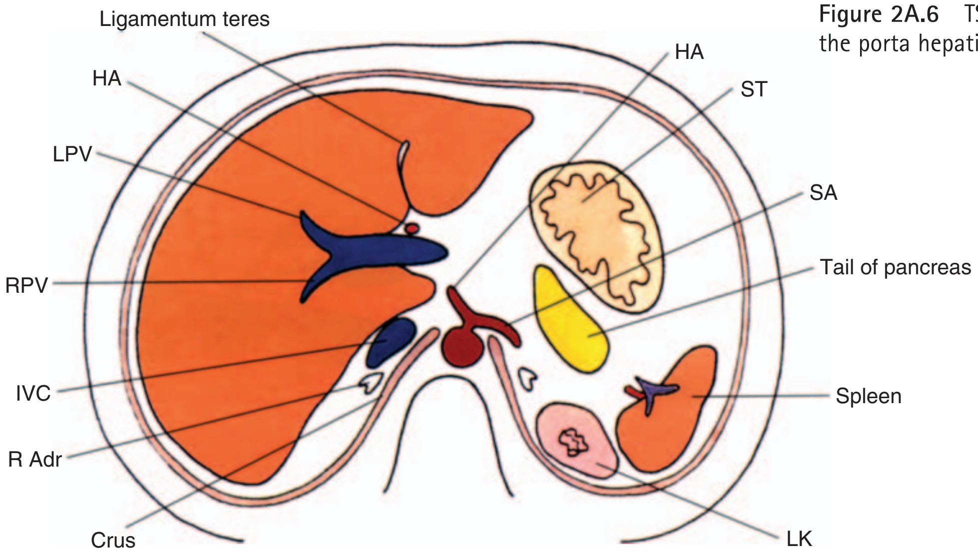


Figure 2A.6 TS through the level of the porta hepatis.

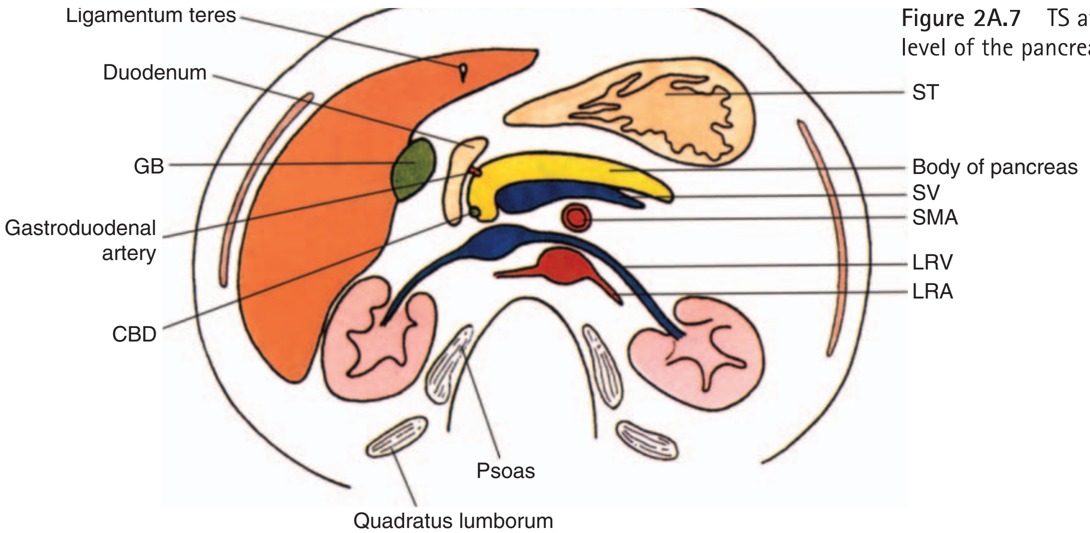


Figure 2A.7 TS at the level of the pancreas.

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Chapter 3

Pathology of the gallbladder and biliary tree

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Ultrasound is an essential first-line investigation in suspected gallbladder and biliary duct disease. It is highly sensitive, accurate and comparatively cheap and is the imaging modality of choice.[1] Gallbladder pathology is common and is asymptomatic in over 13% of the population.[2]

CHOLELITHIASIS

The most commonly and reliably identified gallbladder pathology is that of gallstones (see Table 3.1). More than 10% of the population of the UK have gallstones. Many of these are asymptomatic, which is an important point to remember. When

Table 3.1 Gallstones—clinical features

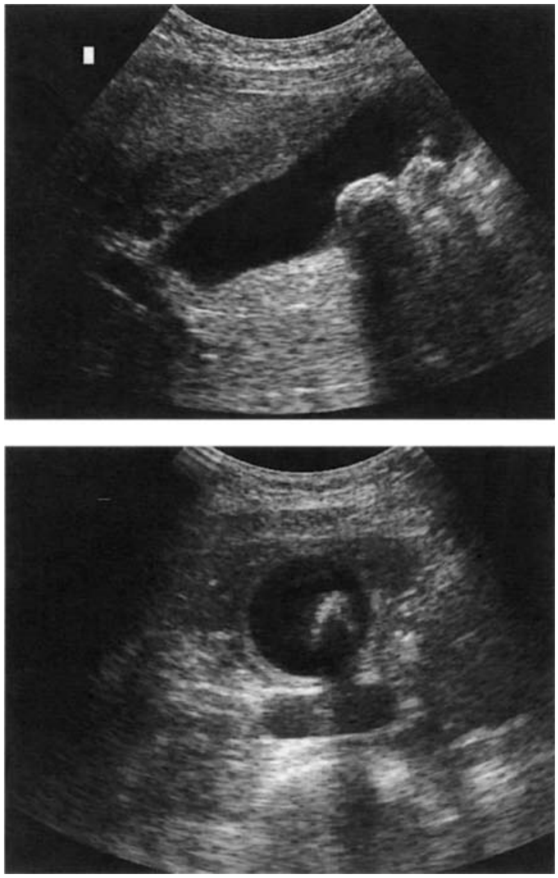
Often asymptomatic
Biliary colic—RUQ pain, fatty intolerance
+ve ultrasound Murphy's sign (if inflammation is present)
Recurring (RUQ) pain in chronic cholecystitis
Jaundice (depending on degree of obstruction)
Fluctuating fever (if infection is present)

RUQ=right upper quadrant.

scanning a patient with abdominal pain it should not automatically be assumed that, when gallstones are present, they are responsible for the pain. It is not uncommon to find further pathology in the presence of gallstones and a comprehensive upper-abdominal survey should always be carried out.

Gallstones are associated with a number of conditions. They occur when the normal ratio of components making up the bile is altered, most commonly when there is increased secretion of cholesterol in the bile. Conditions which are associated with increased cholesterol secretion, and therefore the formation of cholesterol stones, include obesity, diabetes, pregnancy and oestrogen therapy. The incidence of stones also rises with age, probably because the bile flow slows down.

An increased secretion of bilirubin in the bile, as in patients with cirrhosis for example, is associated with pigment (black or brown) stones.



A

B

Figure 3.1 (A) Longitudinal section and (B) transverse section images of the gallbladder containing stones with strong distal acoustic shadowing. Note the thickened gallbladder wall.

Ultrasound appearances

There are three classic acoustic properties associated with stones in the gallbladder; they are *highly reflective*, *mobile* and cast a *distal acoustic shadow*. In the majority of cases, all these properties are demonstrated (Figs 3.1–3.3).

Shadowing

The ability to display a shadow posterior to a stone depends upon several factors:

- The reflection and absorption of sound by the stone. This is fairly consistent, regardless of the composition of the stone.
- The size of the stone in relation to the beam width. A shadow will occur when the stone

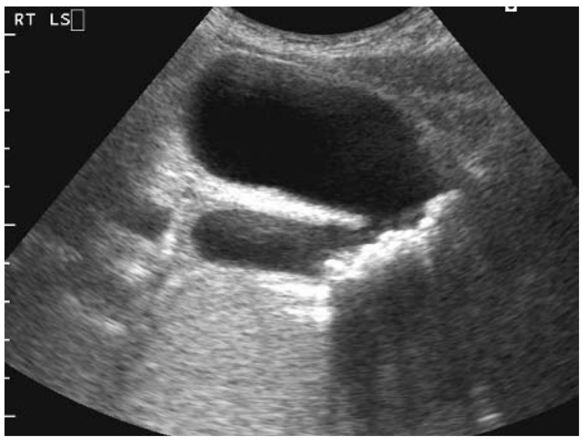


Figure 3.2 Multiple tiny stones combining to form a posterior band of shadow.

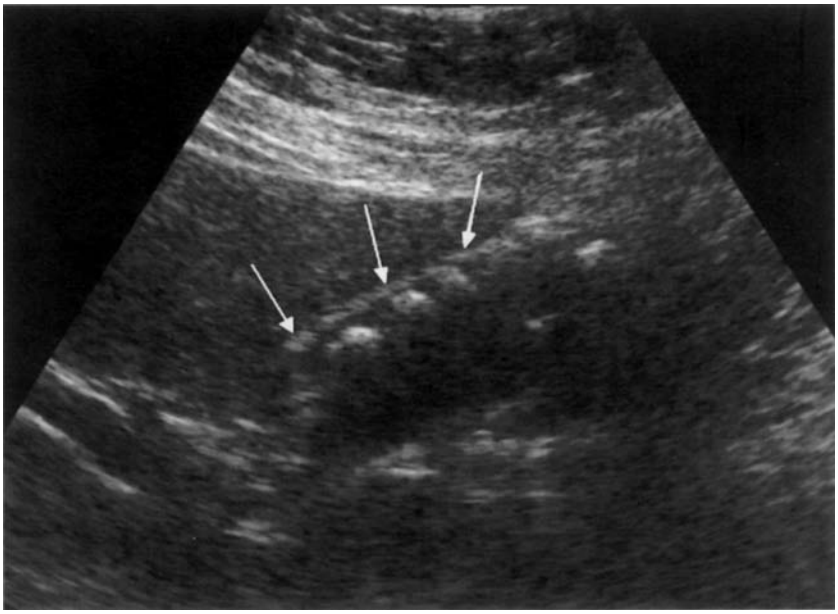


Figure 3.3 Floating stones just below the anterior gallbladder wall.

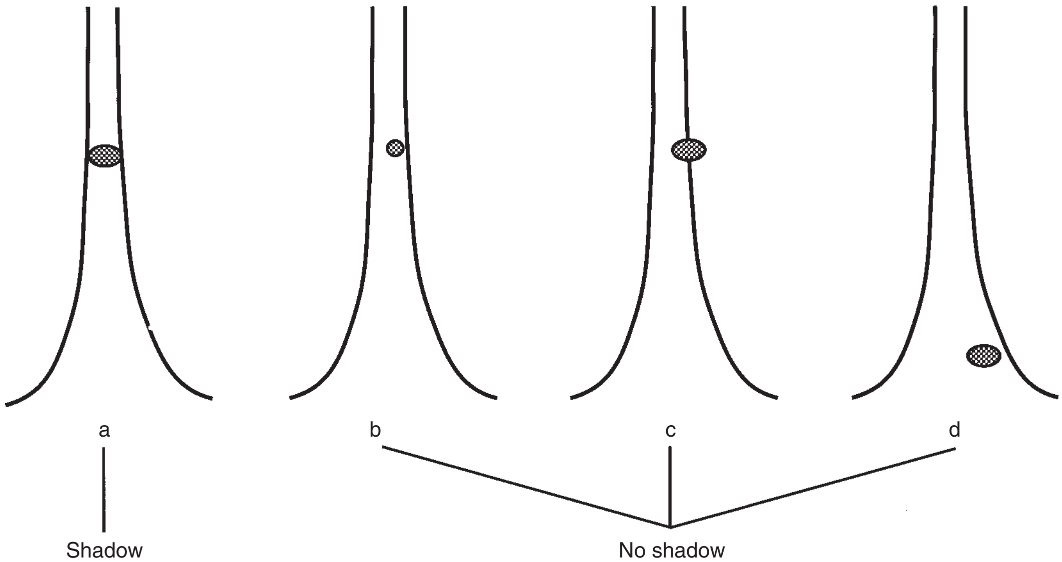


Figure 3.4 (a) A shadow will be displayed from the stone, which occupies the width of the beam. (b) The stone is smaller than the beam. (c) The stone is large, but just out of the beam. (d) The stone is large, but outside the focal zone, where the beam is wider.

fills the width of the beam (Fig. 3.4). This will happen easily with large stones, but a small stone may occupy less space than the beam, allowing sound to continue behind it, so a shadow is not seen. Small stones must therefore be within the focal zone (narrowest point) of the beam and in the centre of the beam to shadow (Fig. 3.5). Higher-frequency transducers have better resolution and are therefore more likely to display fine shadows than lower frequencies.

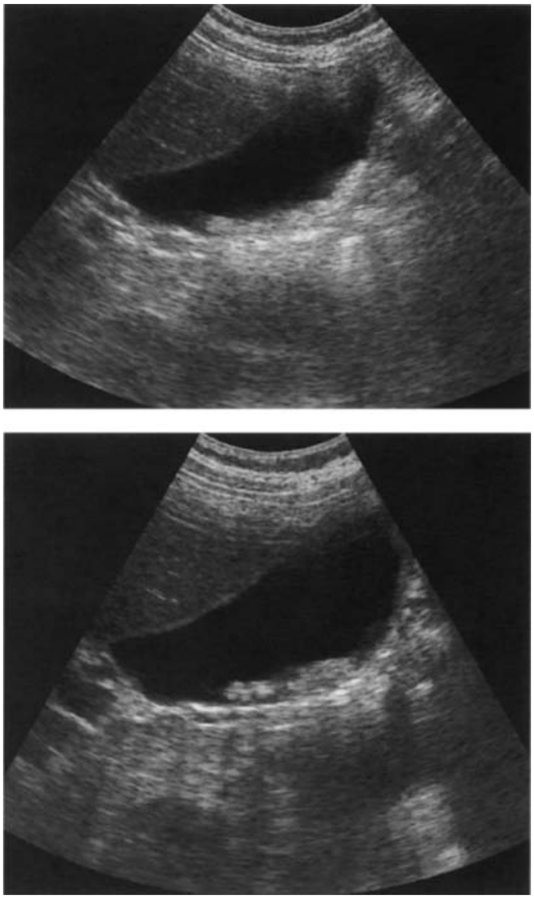


Figure 3.5 (A) The stones are outside the focal zone, and do not appear to shadow well. (B) The focal zone has been moved to the level of the stones, allowing the shadow to be displayed.

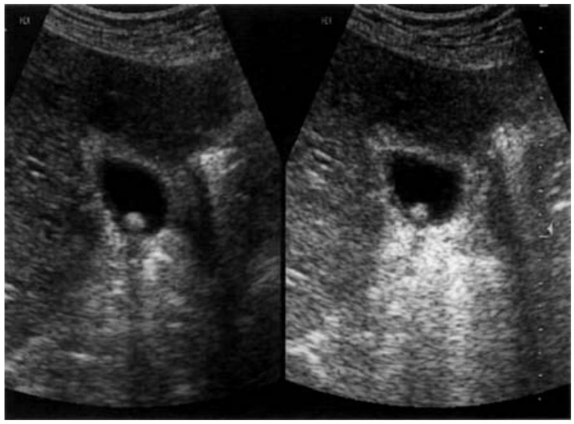


Figure 3.6 The shadow behind the gallstone (left image) is obscured if the time gain compensation is set too high behind the gallbladder (right image).

- The machine settings must be compatible with demonstrating narrow bands of shadowing. The fluid-filled gallbladder often displays posterior enhancement, or increased through-transmission. If the echoes posterior to the gallbladder are 'saturated' this will mask fine shadows. Turn the overall gain down to display this better (Fig. 3.6). Some image-processing options may reduce the contrast between the shadow and the surrounding tissue, so make sure a suitable dynamic range and image programme are used.
- Bowel posterior to the gallbladder may cast its own shadows from gas and other contents, which makes the gallstone shadow difficult to demonstrate (Fig. 3.7B). This is a particular problem with stones in the common bile duct (CBD). Try turning the patient to move the gallbladder away from the bowel. The shadow cast by gas in the duodenum, which contains reverberation, should usually be distinguishable from that cast by a gallstone, which is sharp and clean.

Reflectivity

The reflective nature of the stone is enhanced by its being surrounded by echo-free bile. In a contracted gallbladder the reflectivity of the stone is often not appreciated because the hyperechoic gallbladder wall is collapsed over it.

Some stones are only poorly reflective, but should still cause a distal acoustic shadow.

Mobility

Most stones are gravity-dependent and this may be demonstrated by scanning the patient in an erect position (Fig. 3.7), when a mobile calculus will drop from the neck or body of the gallbladder to lie in the fundus. Some stones will float, however, forming a reflective layer just beneath the anterior gallbladder wall with shadowing that obscures the rest of the lumen (Fig. 3.3).

When the gallbladder lumen is contracted, either due to physiological or pathological reasons,

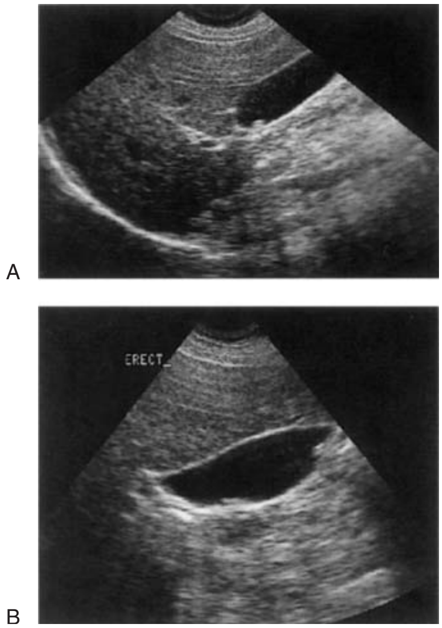


Figure 3.7 (A) Supine and (B) erect views demonstrating movement of the tiny stone into the fundus of the gallbladder. Note how duodenum posterior to the gallbladder masks the shadow in the erect state.

any stones present are unable to move and this is also the case in a gallbladder packed with stones.

Occasionally a stone may become impacted in the neck, and movement of the patient is unable to dislodge it. Stones lodged in the gallbladder neck or cystic duct may result in a permanently contracted gallbladder, a gallbladder full of fine echoes due to inspissated (thickened) bile (Fig. 3.8) or a distended gallbladder due to a mucocoele (see below).

Choledocholithiasis

Stones may pass from the gallbladder into the common duct, or may develop *de novo* within the common duct. Stones in the CBD may obstruct the drainage of bile from the liver, causing obstructive jaundice.

Due to shadowing from the duodenum, ductal stones are often not demonstrated with ultrasound without considerable effort. Usually they are accompanied by stones in the gallbladder and a degree of dilatation of the CBD. In these cases the operator can usually persevere and demonstrate the stone at the lower end of the duct. However, the duct may be dilated but empty, the stone having recently passed.

Stones may be seen to move up and down a dilated duct. This can create a ball-valve effect so that obstruction may be intermittent.

It is not unusual to demonstrate a stone in the CBD without stones in the gallbladder, a phenomenon which is also well-documented following cholecystectomy (Fig. 3.9). This may be due to a single calculus in the gallbladder having moved into the duct, or stone formation within the duct.

It is also important to remember that stones in the CBD may be present *without* duct dilatation and attempts to image the entire common duct

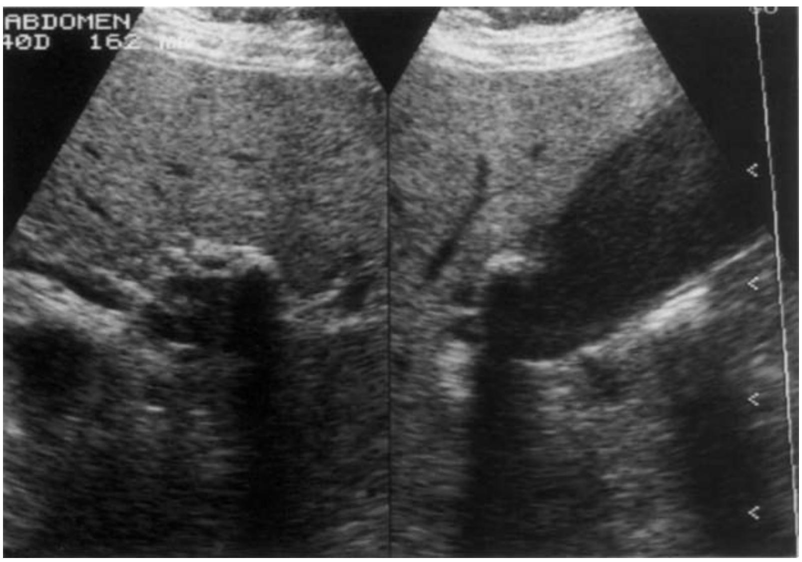
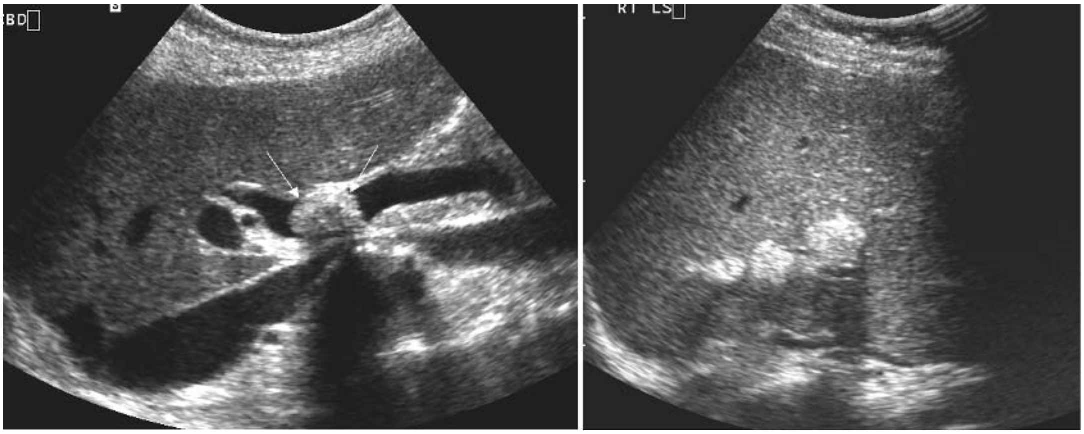
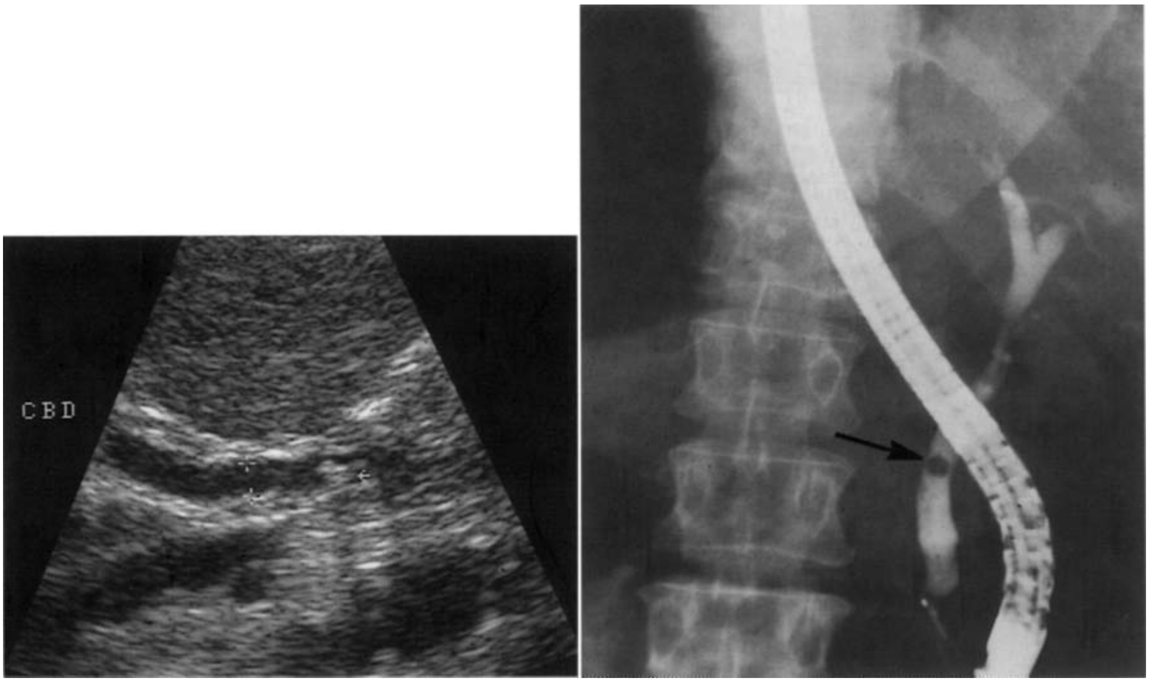


Figure 3.8 Stone impacted in the neck of the gallbladder. The left-hand image is a TS through the neck demonstrating the impacted stone. The right-hand image demonstrates the dilated gallbladder containing fine echoes from inspissated bile.



A B

Figure 3.9 (A) A stone in a dilated common bile duct (CBD) with posterior shadowing. The gallbladder was dilated but did not contain stones. (B) Stone formation in the intrahepatic ducts.



A B

Figure 3.10 (A) Small stone in the CBD causing intermittent obstruction. At the time of scanning, the CBD was normal in calibre at 5 mm. The duct walls are irregular, consistent with cholangitis. (B) Endoscopic cholangiopancreatography (ERCP) of a stone in a normal-calibre (5 mm) duct.

with ultrasound should *always* be made, even if it is of normal calibre at the porta (Fig. 3.10).

Other ultrasound signs to look for are shown in Table 3.2.

Possible complications of gallstones are outlined in Figure 3.11A. In rare cases, stones may perforate the inflamed gallbladder wall to form a fistula into the small intestine or colon. A large stone

Table 3.2 Gallstones—other ultrasound signs to look for

Acute or chronic cholecystitis
Complications of cholecystitis, e.g. pericholecystic collection
Stone impacted in the neck of gallbladder—mucocoele, hydrops
CBD stones
Biliary obstruction—dilatation of the CBD and/or intrahepatic ducts
Pancreatitis
Other causes of RUQ pain unrelated to stones

CBD = common bile duct.

passing into the small intestine may impact in the ileum, causing intestinal obstruction (Fig. 3.11B).

Biliary reflux and gallstone pancreatitis

A stone may become lodged in the distal common bile duct near the ampulla. If the main pancreatic duct joins the CBD proximal to this, bile and pancreatic fluid may reflux up the pancreatic duct, causing inflammation and severe pain.

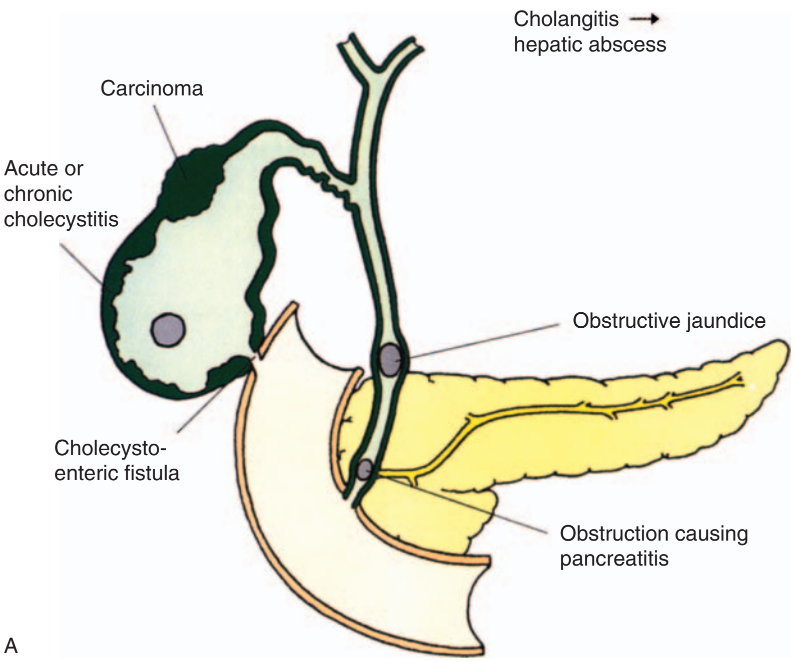
Reflux up the common bile duct may also result in ascending cholangitis, particularly if the obstruction is prolonged or repetitive. Cholangitis may result in dilated bile ducts with mural irregularity on ultrasound, but endoscopic retrograde cholangiopancreatography (ERCP) is usually superior in demonstrating intrahepatic ductal changes of this nature.

Bile reflux is also associated with anomalous cystic duct insertion (Fig. 3.12), which is more readily recognized on ERCP than ultrasound.

Further management of gallstones

ERCP demonstrates stones in the duct with greater accuracy than ultrasound, particularly at the lower end of the CBD, which may be obscured by duodenal gas and also allows for sphincterotomy and stone removal.

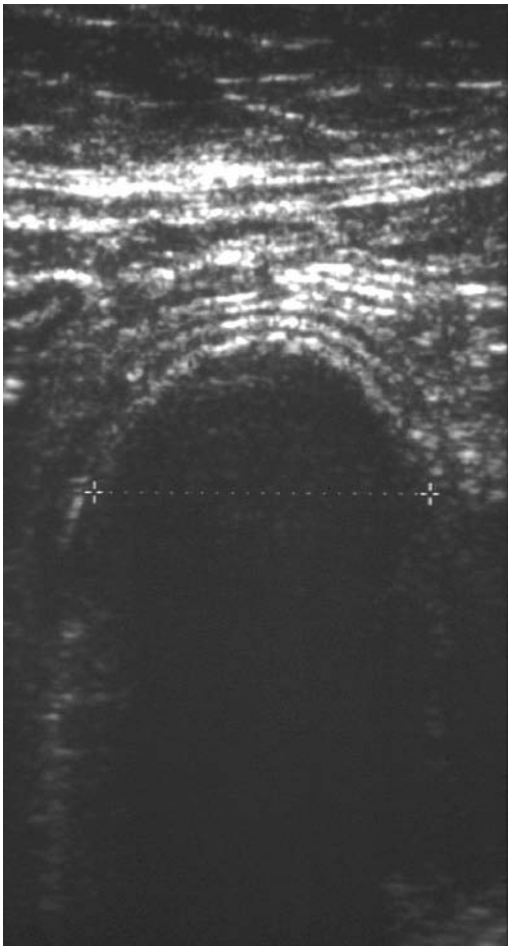
Laparoscopic cholecystectomy is the preferred method of treatment for symptomatic gallbladder disease in an elective setting and has well-recognized benefits over open surgery in experienced



A

Figure 3.11 (A) The possible complication of gallstones.

(Continued)



B

Figure 3.11 cont'd (B) Gallstone Ileus.

hands. Acute cholecystitis is also increasingly managed by early laparoscopic surgery, with a slightly higher rate of conversion to open surgery than elective cases.[3] Laparoscopic ultrasound may be used as a suitable alternative to operative cholangiography to examine the common duct for residual stones during surgery.[4] Both ultrasound and cholescintigraphy are used in monitoring postoperative biliary leaks or haematoma (Fig. 3.13).

Other, less common options include dissolution therapy and extracorporeal shock wave lithotripsy (ESWL). However, these treatments are often only partially successful, require careful patient selection and also run a significant risk of stone recurrence.[5]

ENLARGEMENT OF THE GALLBLADDER

Because of the enormous variation in size and shape of the normal gallbladder, it is not possible to diagnose pathological enlargement by simply using measurements. Three-dimensional techniques may prove useful in assessing gallbladder volume[6] but this is a technique which is only likely to be clinically useful in a minority of patients with impaired gallbladder emptying.

An enlarged gallbladder is frequently referred to as *hydropic*. It may be due to obstruction of the cystic duct (see below) or associated with numerous disease processes such as diabetes, primary sclerosing cholangitis, leptospirosis or in response to some types of drug.

A pathologically dilated gallbladder, as opposed to one which is physiologically dilated, usually assumes a more rounded, tense appearance.

Mucocoele of the gallbladder

If the cystic duct is obstructed, usually by a stone which has failed to pass through to the CBD, the normal flow of bile from the gallbladder is interrupted. Chronic cystic duct obstruction causes the bile to be replaced by mucus secreted by the lining of the gallbladder, resulting in a mucocoele. The biliary ducts remain normal in calibre.

If the gallbladder looks dilated, make a careful search for an obstructing lesion at the neck; a stone in the cystic duct is more difficult to identify on ultrasound as it is not surrounded by echo-free bile (Fig. 3.8).

Mirizzi syndrome

Mirizzi syndrome is a rare cause of biliary obstruction in which the cystic duct is obstructed by a stone, which in combination with a surrounding inflammatory process compresses and obstructs the common hepatic duct, causing distal biliary duct dilatation. This is associated with a low insertion of the cystic duct into the common hepatic duct. Occasionally a fistula forms between the hepatic duct and the gallbladder due to erosion of the duct wall by the stone. Ultimately this may lead to gallstone ileus—small-bowel obstruction resulting from migration of a large stone through

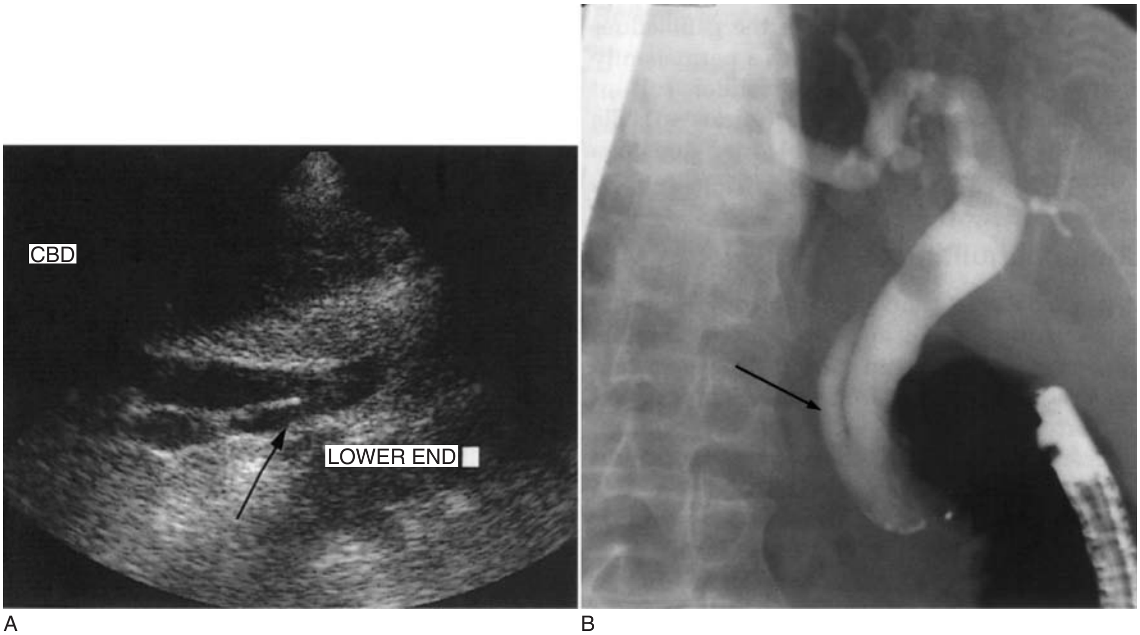


Figure 3.12 (A) Anomalous insertion of the cystic duct (arrow) into the lower end of the CBD. (B) Appearances of case in (A) are confirmed on ERCP. A stone is also present in the duct.

the cholecystoenteric fistula (Fig 3.11B). If the condition is not promptly diagnosed, recurring cholangitis leading to secondary biliary cirrhosis may result.

On ultrasound the gallbladder may be either enlarged or contracted and contain debris. A stone impacted at the neck may be demonstrated together with dilatation of the intrahepatic ducts with a normal-calibre lower common duct (Fig. 3.14). The diagnosis, however, is difficult, and ERCP is generally the most successful modality. Although rare, it is an important diagnosis as cholecystectomy in these cases has a higher rate of operative and post-operative complications.[7]

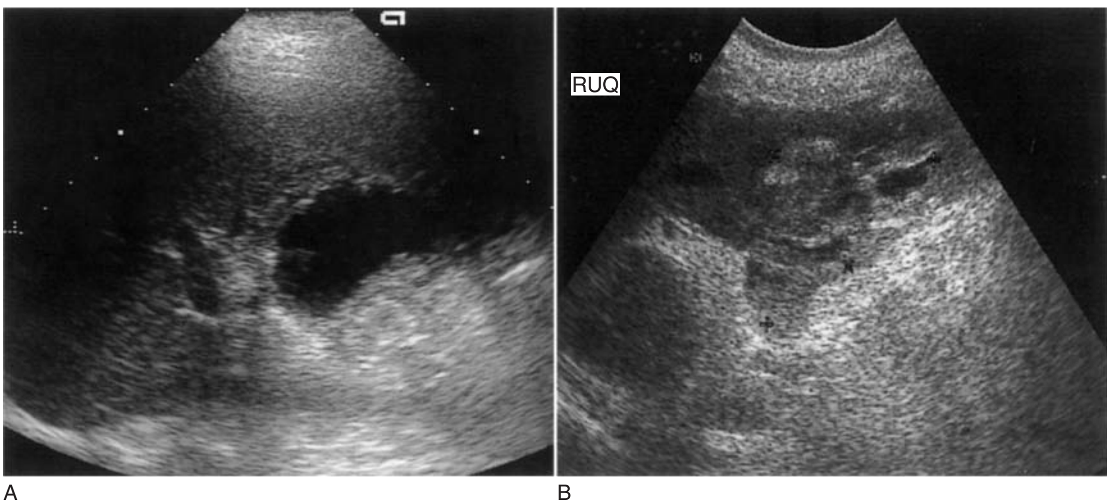


Figure 3.13 (A) Postoperative bile collection in the gallbladder bed. (B) Hyperechoic, irregular mass in the gallbladder bed which represents a resolving haematoma after laparoscopic cholecystectomy.

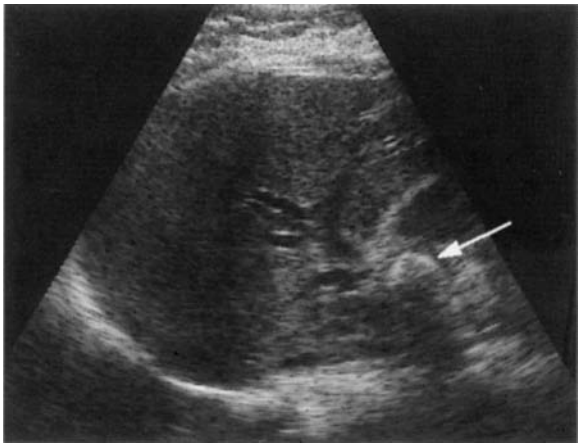


Figure 3.14 Mirizzi syndrome: a large stone in the neck of the gallbladder (arrow) is compressing the bile duct, causing intrahepatic duct dilatation. The lower end of the CBD remains normal in calibre.

Figure 3.15 Postprandial, contracted gallbladder, with consequently thickened wall.

THE CONTRACTED OR SMALL GALLBLADDER

Postprandial

The most likely cause is physiological and due to inadequate preparation. The normal gallbladder wall is thickened when contracted, and this must not be confused with a pathological process. Always enquire what the patient has recently eaten or drunk (Fig. 3.15).

Pathological causes of a small gallbladder

Most pathologically contracted gallbladders contain stones.

When the gallbladder cannot be identified, try scanning transversely through the gallbladder fossa, just caudal to the porta hepatis. Strong shadowing alerts the sonographer to the possibility of a contracted gallbladder full of stones. The reflective surface of the stones and distal shadowing are apparent and the anterior gallbladder wall can be demonstrated with correct focusing and good technique (Fig. 3.16).

Do not confuse the appearances of a previous cholecystectomy, when bowel in the gallbladder fossa casts a shadow, with a contracted, stone-filled gallbladder.

A less common cause of a small gallbladder is the *microgallbladder* associated with cystic fibrosis (Fig. 3.17). The gallbladder itself is abnormally small, rather than just contracted. Cystic fibrosis also carries an increased incidence of gallstones because of the altered composition of the bile and bile stasis and the wall might be thickened and fibrosed from cholecystitis.

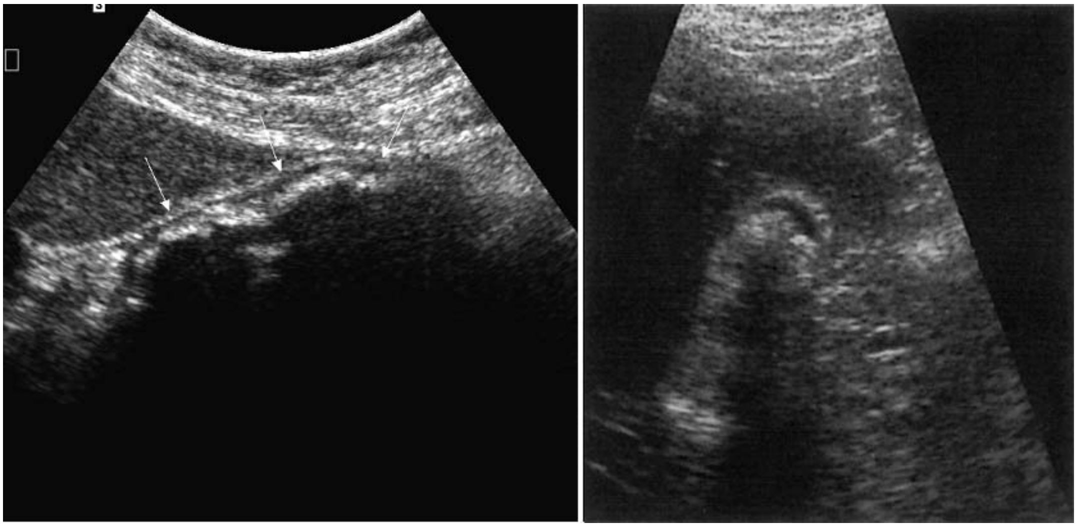
PORCELAIN GALLBLADDER

When the gallbladder wall becomes calcified the resulting appearance is of a solid reflective structure causing a distal shadow in the gallbladder fossa (Fig. 3.18). This can be distinguished from a gallbladder full of stones where the wall can usually be seen anterior to the shadowing (Fig 3.16).

A porcelain gallbladder probably results from a gallbladder mucocoele—a long-standing obstruction of the cystic duct, usually from a stone. The bile inside the non-functioning gallbladder is gradually replaced by watery fluid, the wall becomes fibrotic and thickened and ultimately calcifies.

There is an association between porcelain gallbladder and gallbladder carcinoma, so a prophylactic cholecystectomy is usually performed to pre-empt malignant development.[8]

The shadowing from the anterior gallbladder wall obscures the gallbladder contents, and can mimic bowel in the gallbladder fossa. A plain X-ray also clearly demonstrates the porcelain gallbladder.



A B

Figure 3.16 (A) The gallbladder lumen is filled with stones, causing dense shadowing in the gallbladder fossa. The thickened gallbladder wall can be demonstrated separately (arrows) from the reflective surface of the stones. (B) A small layer of bile is visible between the stones and the anterior gallbladder wall.

Figure 3.17 Microgallbladder in cystic fibrosis.

Figure 3.18 TS of a porcelain gallbladder demonstrating a calcified wall with strong acoustic shadowing.

HYPERPLASTIC CONDITIONS OF THE GALLBLADDER WALL

Adenomyomatosis

This is a non-inflammatory, hyperplastic condition which causes gallbladder wall thickening. It may be mistaken for chronic cholecystitis on ultrasound.

The epithelium which lines the gallbladder wall undergoes hyperplastic change, extending diverticula into the adjacent muscular layer of the wall. These diverticula, or sinuses (known as Rokitansky–Aschoff sinuses), are visible within the wall as fluid-filled spaces (Fig. 3.19), which can bulge eccentrically into the lumen, and may contain echogenic material or even (normally pigment) stones.

The wall thickening may be focal or diffuse, and the sinuses may be little more than hypoechoic 'spots' in the thickened wall, or may become quite large cavities in some cases.[9]

Deposits of crystals in the gallbladder wall frequently result in distinctive 'comet-tail' artefacts.

Often asymptomatic, this may present with biliary colic although it is unclear whether this is caused by co-existent stones. Its distinctive appearance allows the diagnosis to be made easily, whether or not stones are present.

Cholecystectomy is performed in symptomatic patients, usually those who also have stones. Although essentially a benign condition, a few cases of associated malignant transformation have been reported, usually in patients with asso-

Figure 3.19 Adenomyomatosis: (A) LS demonstrating a thickened gallbladder wall with a small Rokitansky-Aschoff sinus (arrow) at the fundus. (B) TS demonstrating a stone and comet-tail artifacts from within the wall due to crystal deposits. (C) TS through a more advanced case of adenomyomatosis with a large Rokitansky–Aschoff sinus, giving the appearance of a 'double lumen'.

ciated anomalous insertion of the pancreatic duct.[10]

Polyps

Gallbladder polyps are usually asymptomatic lesions which are incidental findings in up to 5% of the population. Occasionally they are the cause of biliary colic. The most common type are cholesterol polyps. These are reflective structures which project into the gallbladder lumen but do not cast an acoustic shadow. Unless on a long stalk they will remain fixed on turning the patient and are therefore distinguishable from stones (Fig. 3.20).

There is an association between larger adenomatous gallbladder polyps and subsequent carcinoma, especially in patients over 50 years of age, so cholecystectomy is often advised (Fig. 3.20C). Smaller polyps of less than 1 cm in diameter may be safely monitored with ultrasound.[11] In particular, gallbladder polyps in patients with primary sclerosing cholangitis have a much greater likelihood of malignancy (40–60%).[12]

Cholesterolosis

Also known as the 'strawberry gallbladder', this gets its name because of the multiple tiny nodules on the surface of the gallbladder mucosal lining.

Figure 3.20 (A) Small polyp in the gallbladder lumen—no posterior shadowing is evident. (B) A gallbladder polyp on a stalk moves with different patient positions. (C) Large, fleshy gallbladder polyp.

These nodules are the result of a build-up of lipids in the gallbladder wall and are not usually visible on ultrasound. However in some cases, multiple polyps also form on the inner surface, projecting into the lumen, and are clearly visible on ultrasound (Fig. 3.21). Cholesterolosis may be asymptomatic, or may be accompanied by stones and consequently requires surgery to alleviate symptoms of biliary colic.

INFLAMMATORY GALLBLADDER DISEASE

Cholecystitis is usually associated with gallstones; the frictional action of stones on the gallbladder wall causes some degree of inflammation in almost all cases. The inner mucosa of the wall is injured, allowing the access of enteric bacteria. The inflammatory process may be long-standing and chronic, acute or a combination of acute inflammation on a chronic background.

Acute cholecystitis

Acute inflammation of the gallbladder presents with severe RUQ pain localized to the gallbladder area. The pain can be elicited by (gently!) pressing the gallbladder with the ultrasound transducer—a positive ultrasound Murphy's sign. (This sign, although a useful pointer to acute inflammation, is not specific and can frequently be elicited in other conditions, such as chronic inflammatory cases.)

On ultrasound, the gallbladder wall is thickened greater than 2 mm. This is not in itself a specific sign (see Table 3.3), but characteristically the thickening in acute cholecystitis is symmetrical, affecting the entire wall, and there is an echo-poor 'halo' around the gallbladder as a result of oedematous changes (Fig. 3.22). This is not invariable, however, and focal thickening may be present, or the wall may be uniformly hyperechoic in some cases. Pericholecystic fluid may also be present, and the inflammatory process may spread to the adjacent liver.

Colour or power Doppler can be helpful in diagnosing acute cholecystitis and in differentiating it from other causes of gallbladder wall thickening. Hyperaemia in acute cholecystitis can be demonstrated on colour Doppler around the thickened wall[13] (Fig. 3.23). In a normal gallbladder, colour Doppler flow may be seen around the gallbladder neck in the region of the cystic artery but not elsewhere in the wall. The increased sensitivity of power Doppler, as opposed to colour

Figure 3.21 Cholesterolosis TS of the gallbladder demonstrating multiple tiny polyps in the gallbladder.

Table 3.3 Causes of a thickened gallbladder wall

Physiological
- —Postprandial

Inflammatory
- —Acute or chronic cholecystitis
- —Sclerosing cholangitis
- —Crohn's disease
- —AIDS

Adjacent inflammatory causes
- —Pancreatitis
- —Hepatitis
- —Pericholecystic abscesses

Non-inflammatory
- —Adenomyomatosis
- —Gallbladder carcinoma
- —Focal areas of thickening due to metastases or polyps
- —Leukaemia

Oedema
- —Ascites from a variety of causes, including organ failure, lymphatic obstruction and portal hypertension

Varices
- —Varices of the gallbladder wall in portal hypertension

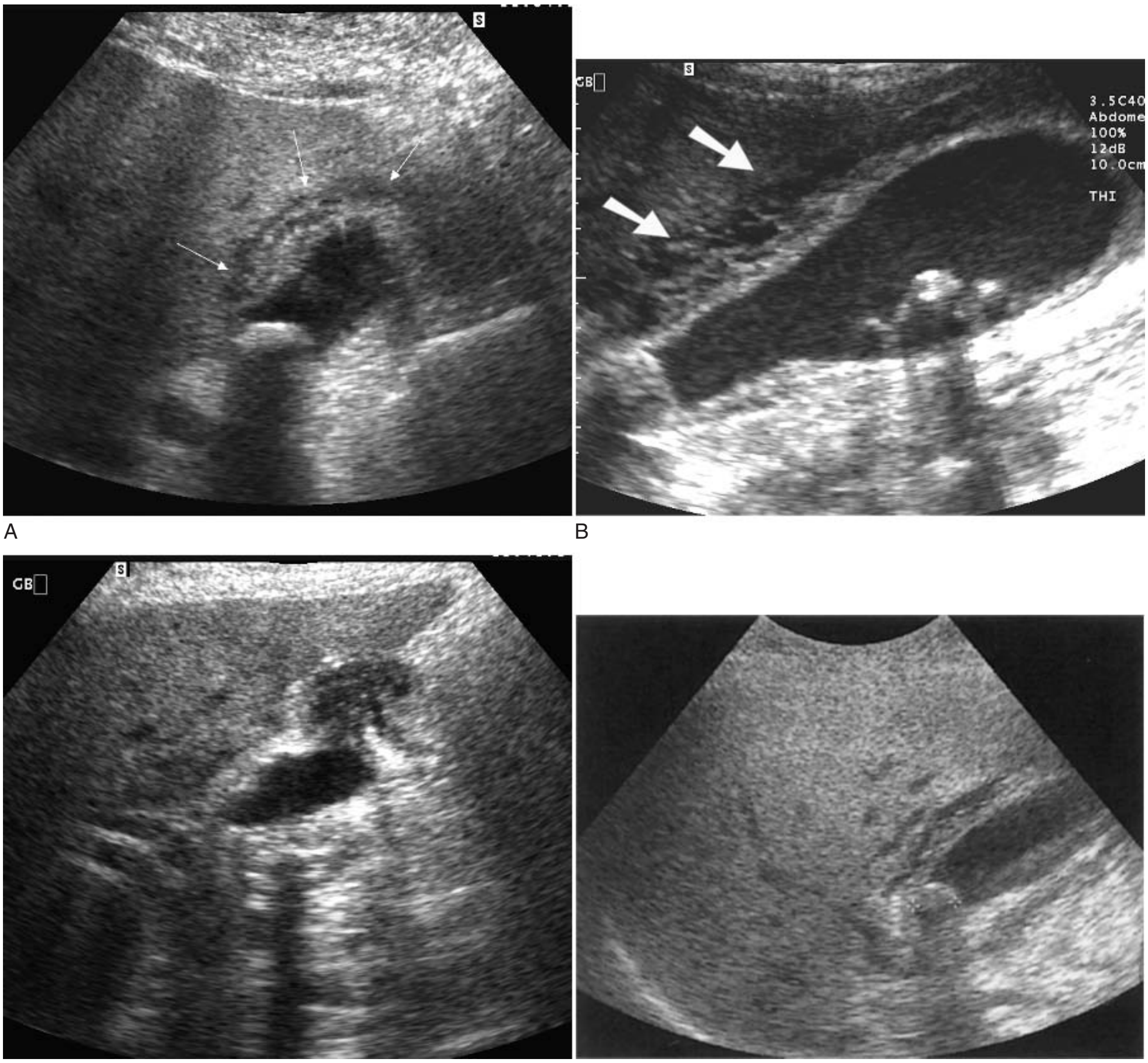
Doppler, does enable the operator to demonstrate vascularity in the normal gallbladder wall and the operator should be familiar with normal appearances for the machine in use when making the diagnosis of acute cholecystitis[14] (Fig. 3.24).

Doppler can potentially distinguish acute inflammation from chronic disease.[15] However, false-positive results can be found in cases of pancreatitis and gallbladder carcinoma and the technique does not add significantly to the grey-scale image.

Complications may occur if the acute inflammation progresses (see below) due to infection, pericholecystic abscesses and peritonitis.

Further management of acute cholecystitis

In an uncomplicated acute cholecystitis, analgesia to settle the patient in the short term is followed by the removal of the gallbladder. Open surgery, which is increasingly reserved for the more



A B C D

Figure 3.22 Acute cholecystitis: (A) TS of an oedematous, thickened gallbladder wall with a stone. (B) LS with a thickened wall (arrows). Stones and debris are present. (C) and (D) TS and LS demonstrating pericholecystic fluid.

(Continued)

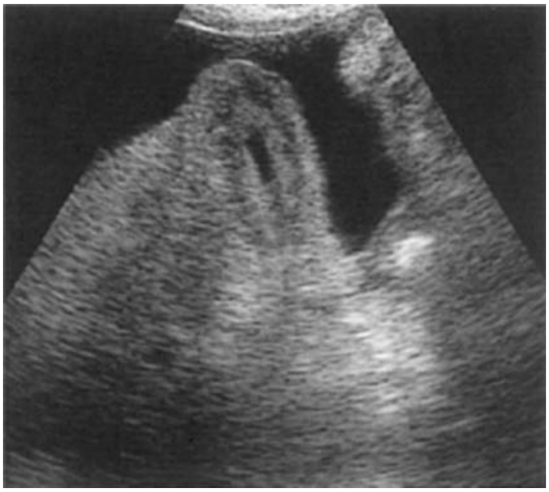


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Figure 3.22 cont'd (E) Normal gallbladder in the presence of ascites. Oedema may cause the wall to thicken, mimicking an inflammatory process.

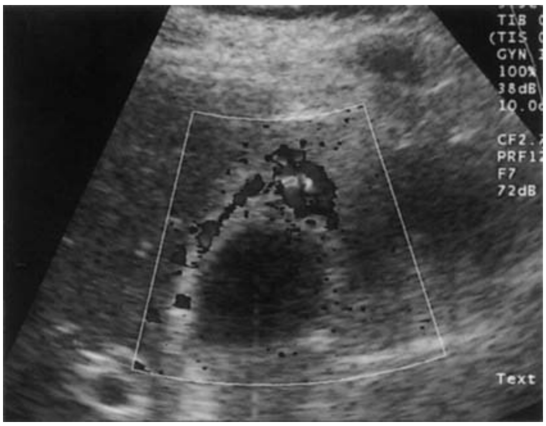


Figure 3.23 Colour Doppler demonstrates hyperaemia in the thickened gallbladder wall in acute cholecystitis.

complex cases, is giving way to the more frequent use of laparoscopic cholecystectomy.

If unsuitable for immediate surgery, for example in cases complicated by peritonitis, the patient is managed with antibiotics and/or percutaneous drainage of pericholecystic fluid or infected bile from the gallbladder, usually under ultrasound guidance. This allows the patient's symptoms to settle and reduces morbidity from the subsequent elective operation.[16]

Hepatobiliary scintigraphy has high sensitivity and specificity for evaluating patients with acute cholecystitis,[17] particularly if the ultrasound examination is technically difficult or equivocal and has the advantage of being able to demonstrate hepatobiliary drainage into the duodenum.

Plain X-ray is seldom used, but can confirm the presence of gas in the gallbladder.

Chronic cholecystitis

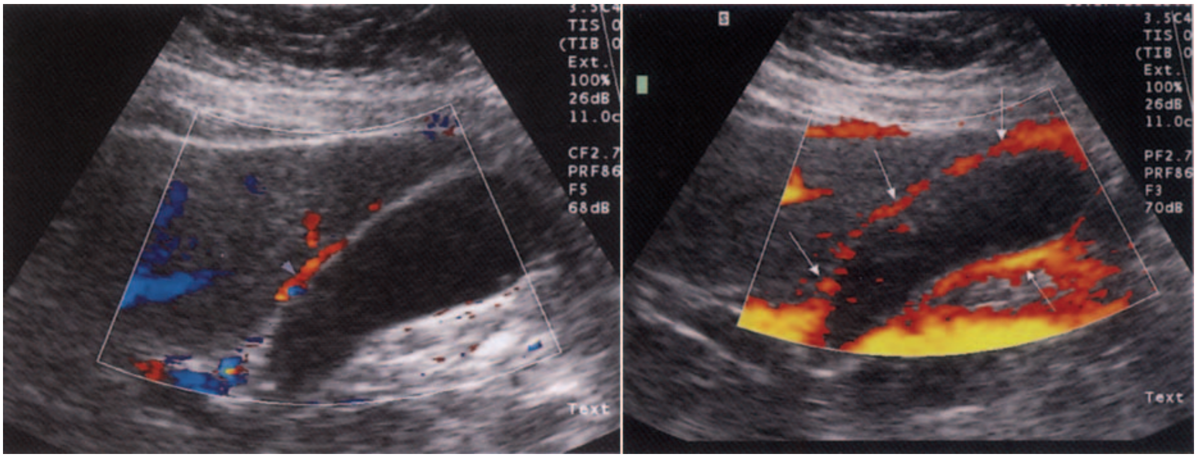
Usually associated with gallstones, chronic cholecystitis presents with lower-grade, recurring right upper quadrant pain. The action of stones on the wall causes it to become fibrosed and irregularly thickened, frequently appearing hyperechoic (Fig. 3.25). The gallbladder is often shrunken and contracted, having little or no recognizable lumen around the stones. Chronic cholecystitis may be complicated by episodes of acute inflammation on a background of the chronic condition.

Most gallbladders which contain stones show at least some histological degree of chronic cholecystitis, even if wall thickening is not apparent on ultrasound.

Acalculous cholecystitis

Inflammation of the gallbladder without stones is relatively uncommon. A thickened, tender gallbladder wall in the absence of any other obvious cause of thickening may be due to acalculous cholecystitis. This condition tends to be associated with patients who are already hospitalized and have been fasting, including post-trauma patients, those recovering from surgical procedures and diabetic patients. It is brought about by bile stasis leading to a distended gallbladder and subsequently decreased blood flow to the gallbladder. This, especially in the weakened postoperative state, can lead to infection. Because no stones are present, the diagnosis is more difficult and may be delayed. Patients with acalculous cholecystitis are therefore more likely to have severe pain and fever by the time the diagnosis is made, increasing the incidence of complications such as perforation.

The wall may appear normal on ultrasound in the early stages, but progressively thickens (Fig. 3.26). Biliary sludge is usually present and a



A B

Figure 3.24 Normal gallbladder wall vascularity. (A) In a normal gallbladder, colour Doppler can demonstrate the cystic artery (arrowhead) but does not demonstrate flow near the fundus. (B) Power Doppler is more sensitive and can demonstrate flow throughout the wall (arrows) in a normal gallbladder; this must not be mistaken for hyperaemia.

pericholecystic abscess may develop in the later stages. A positive Murphy's sign may help to focus on the diagnosis, but in unconscious patients the diagnosis is a particularly difficult one.

Because patients may already be critically ill with their presenting disease, or following surgery, there is a role for ultrasound in guiding percutaneous cholecystostomy at the bed-side to relieve the symptoms.[18]

Chronic acalculous cholecystitis implies a recurrent presentation with typical symptoms of biliary colic, but no evidence of stones on ultrasound. Patients may also demonstrate a low ejection fraction during a cholecystokinin-stimulated hepatic iminodiacetic acid (HIDA) scan. The symptoms are relieved by elective laparoscopic cholecystectomy in most patients, with similar results to those for gallstone disease[19] (although some are found to have biliary pathology at surgery, which might explain the symptoms, such as polyps, cholesterolosis or biliary crystals/tiny stones in addition to chronic inflamation).

Complications of cholecystitis

Acute-on-chronic cholecystitis

Patients with a long-standing history of chronic cholecystitis may suffer (sometimes repeated) attacks of acute inflammation. The gallbladder wall is thickened, as for chronic inflammation, and may become focally thickened with both hypo- and hyperechoic regions. Stones are usually present (Fig. 3.27).

Gangrenous cholecystitis

In a small percentage of patients, acute gallbladder inflammation progresses to gangrenous cholecystitis. Areas of necrosis develop within the gallbladder wall, the wall itself may bleed and small abscesses form (Fig. 3.28). This severe complication of the inflammatory process requires immediate cholecystectomy.

The gallbladder wall is friable and may rupture, causing a pericholecystic collection and possibly peritonitis. Inflammatory spread may be seen in the adjacent liver tissue as a hypoechoic, ill-defined area. Loops of adjacent bowel may become adherent to the necrotic wall, forming a cholecystoenteric fistula.

The wall is asymmetrically thickened and areas of abscess formation may be demonstrated. The damaged inner mucosa sloughs off, forming the appearance of membranes in the gallbladder lumen. The gallbladder frequently contains infected debris

The presence of a bile leak may also be demonstrated with hepatobiliary scintigraphy, using technetium[99], which is useful in identifying a bile

A

B

Figure 3.25 Chronic cholecystitis. (A) A hyperechoic, irregular, thickened wall. The gallbladder contains a small stone and thickened, echogenic bile. It was mildly tender on scanning. (B) The wall is focally thickened anteriorly, and the gallbladder contains a large stone and a polyp in the fundus.

collection which may otherwise be obscured by bowel on ultrasound.

Emphysematous cholecystitis

This is a form of acute gangrenous cholecystitis in which the inflamed gallbladder may become infected, particularly in diabetic patients, with gas-forming organisms. Both the lumen and the wall of the gallbladder may contain air, which is highly reflective, but which casts a 'noisy', less definite shadow than that from stones. Discrete gas bubbles have been reported on ultrasound within the gallbladder wall[20] and may also extend into the intrahepatic biliary ducts.[21]

The air rises to the anterior part of the gallbladder, obscuring the features behind it (Fig. 3.29). This effect may mimic air-filled bowel on ultrasound.

Emphysematous cholecystitis has traditionally had a much higher mortality rate than other forms of cholecystitis, requiring immediate cholecystectomy. However, improvements in ultrasound resolution, and in the early clinical recognition of this condition, suggest that it is now being diagnosed earlier and may be managed more conservatively. The gas in the gallbladder may be confirmed on a plain X-ray (Fig. 3.30), but ultrasound is more sensitive in demonstrating the earlier stages.

Gallbladder empyema

Empyema is a complication of cholecystitis in which the gallbladder becomes infected behind an obstructed cystic duct. Fine echoes caused by pus are present in the bile (Fig. 3.31). These patients are often very ill with a fever and acute pain. A pericholecystic gallbladder collection may result from leakage through the gallbladder wall with subsequent peritonitis. Ultrasound may be used to guide a bedside drainage in order to allow the patient's symptoms to settle before surgery is attempted.[22]

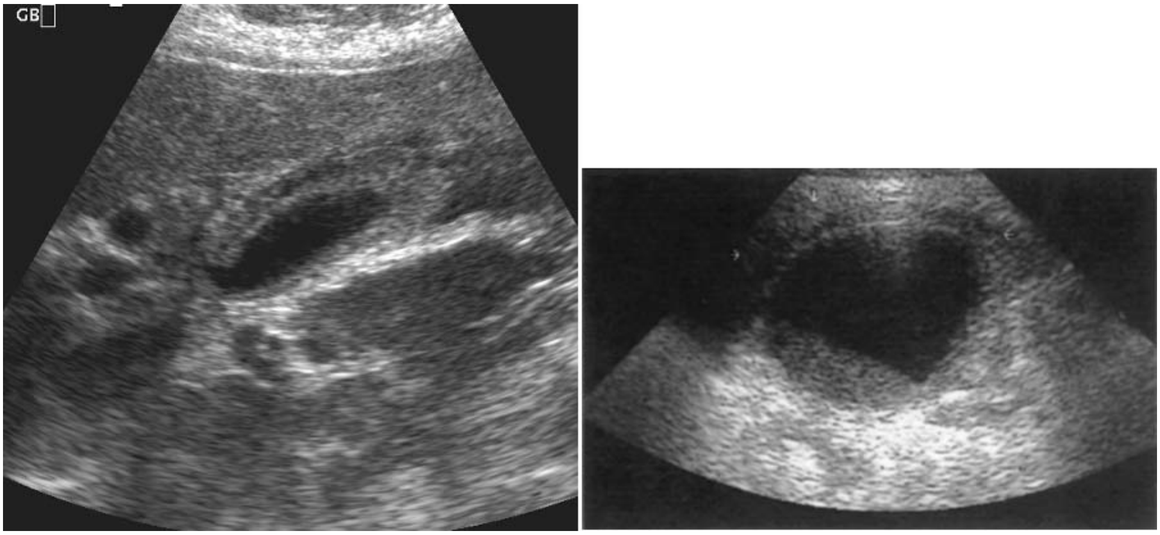
OBSTRUCTIVE JAUNDICE AND BILIARY DUCT DILATATION

Dilatation of all or part of the biliary tree is usually the result of proximal obstruction. Less commonly the biliary tree may be dilated but not obstructed (Table 3.4). The most common causes of obstruction are stones in the common duct or a neoplasm of the bile duct or head of pancreas.

The patient with obstructive jaundice may present with upper abdominal pain, abnormal liver function tests (LFTs) (see Chapter 2) and, if the obstruction is not intermittent, the sclera of the eye and the skin adopt a yellow tinge.

Assessment of the level of obstruction

It is possible for the sonographer to work out where the obstructing lesion is situated by observ-



A B

Figure 3.26 (A) Acalculous cholecystitis. The gallbladder wall is markedly thickened and tender on scanning. (B) Gravity-dependent sludge with a thick, oedematous wall. No stones were present.

Figure 3.27 Acute on chronic cholecystitis. A patient with known gallstones and chronic cholecystitis presents with an episode of acute gallbladder pain. The wall is considerably more thickened and hyperechoic than on previous scans.

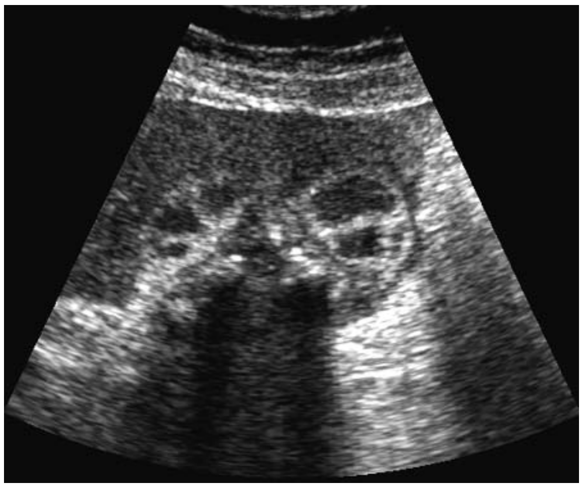


Figure 3.28 Gangrenous cholecystitis. The gallbladder wall is focally thickened and an intramural abscess has formed on the anterior aspect.

ing which parts of the biliary tree are dilated (Fig. 3.32):

- Dilatation of the common bile duct (that is, that portion of the duct below the cystic duct insertion) implies obstruction at its lower end.
- Dilatation of both biliary and pancreatic ducts implies obstruction distally, at the head of the pancreas or ampulla of Vater. This is more likely to be due to carcinoma of the head of pancreas, ampulla or acute pancreatitis than a stone. However, it is possible for a stone to be

A

B

C

Figure 3.29 Emphysematous cholecystitis. (A) and (B) TS and LS with gas and debris in the gallbladder lumen. (C) Gas in the gallbladder lumen completely obscures the contents.

lodged just distal to the confluence of the biliary and pancreatic ducts.

- Dilatation of the gallbladder alone (that is without ductal dilatation) is usually caused by, obstruction at the neck or cystic duct (Fig. 3.8).

To assess whether the gallbladder is pathologically dilated may be difficult on ultrasound. The sonographer should look at both the size and shape; the dilated gallbladder will have a rounded, bulging shape due to the increase in pressure inside it. A gallbladder whose wall has become fibrosed from chronic cholecystitis due to stones will often lose the ability to distend, so the biliary ducts can look grossly dilated despite the gallbladder remaining 'normal' in size, or contracted.

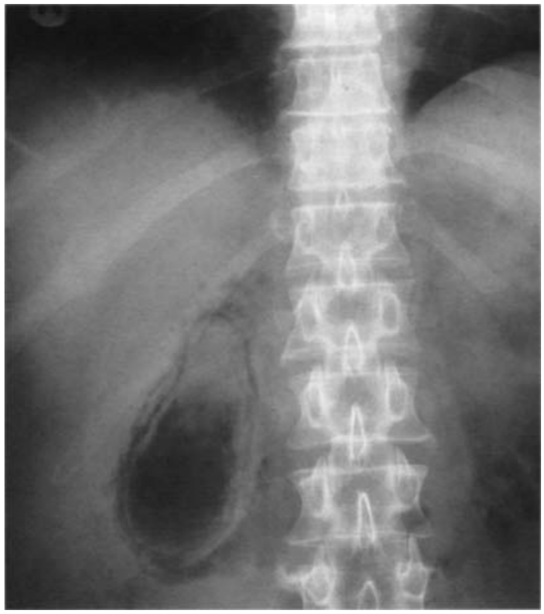


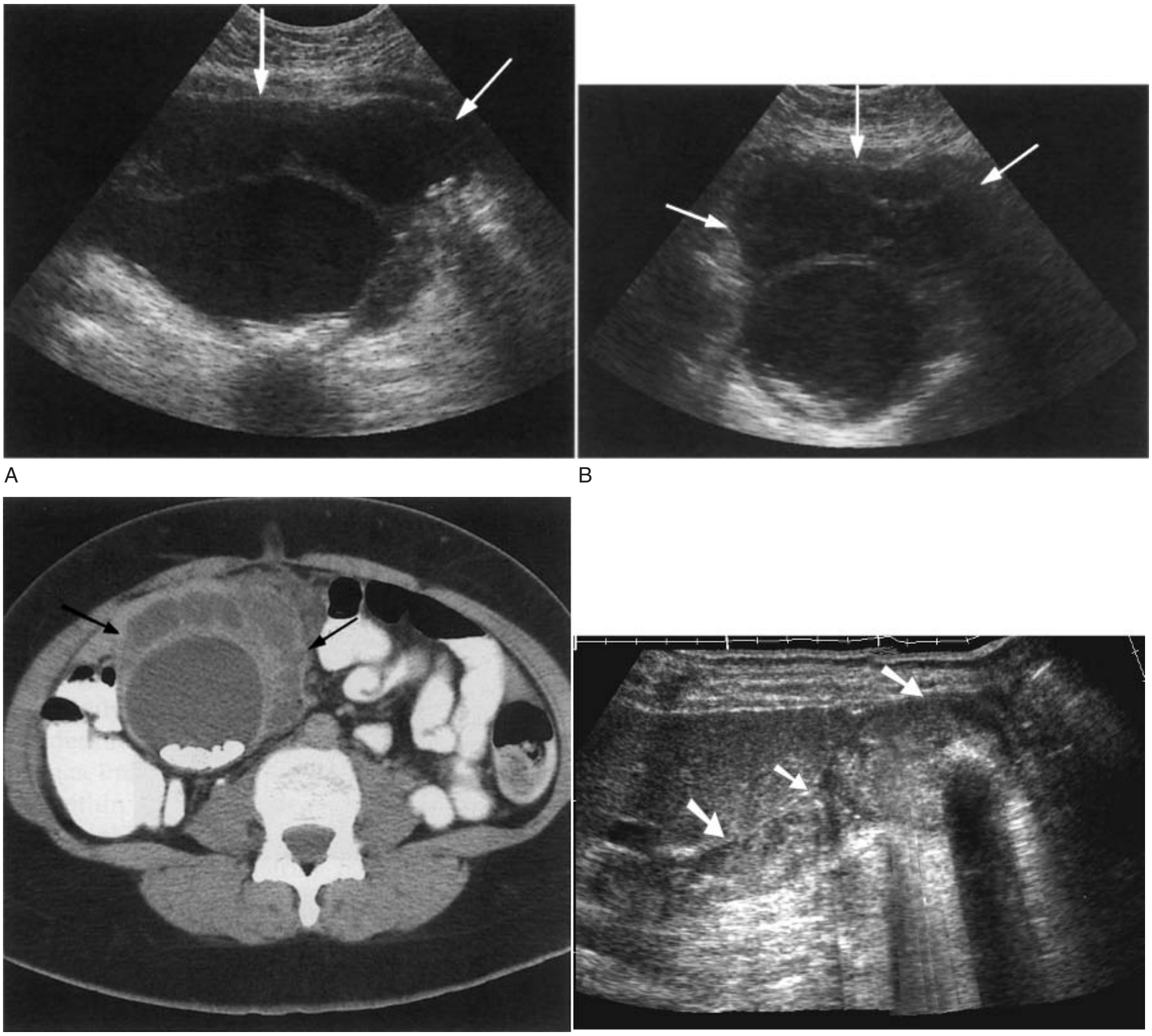
Figure 3.30 X-ray demonstrating gas in the gallbladder in emphysematous cholecystitis.

Early ductal obstruction

Beware very early common duct obstruction, before the duct becomes obviously dilated. The duct may be mildly dilated at the lower end, just proximal to a stone. Likewise intermittent obstruction by a small stone at the lower end of the duct may be non-dilated by the time the scan is performed (Fig. 3.10).

A significant ultrasound feature in the absence of any other identifiable findings is that of thickening of the wall of the bile duct. This represents an inflammatory process in the duct wall, which may be found in patients with small stones in a non-dilated duct, but is also associated with sclerosing cholangitis.[23]

It is sometimes technically difficult in some patients (particularly those with diffuse liver disease) to work out whether a tubular structure on



A B C D

Figure 3.31 Gallbladder empyema. (A) and (B) LS and TS of the same gallbladder. The gallbladder has ruptured, forming a cholecystoenteric fistula which had resealed at surgery. The gallbladder contains pus and stones, with several anterior septations, forming pockets of infected bile which also contained stones (arrows). (C) CT scan confirming the ultrasound appearances. (D) Gallbladder empyema demonstrating a large gallbladder full of pus and stones.

ultrasound represents a dilated duct or a blood vessel. Colour Doppler will differentiate the dilated bile duct from a branch of hepatic artery or portal vein (Fig. 3.33).

Assessment of the cause of obstruction

The numerous causes of biliary dilatation are summarized in Table 3.4. Frequently, ultrasound diagnoses obstruction but does not identify the cause. This is a good case for perseverance by the operator, as the lower end of the CBD is visible in the majority of cases once overlying duodenum has been moved away (Figs 3.9, 3.10 and 33.4). However, ultrasound is not generally regarded as a reliable tool for identifying ductal stones and is frequently unable to diagnose ductal strictures, especially those from benign causes.

Table 3.4 Causes of biliary duct dilatation

Intrinsic
—Stones
—Carcinoma of the ampulla of Vater
—Cholangiocarcinoma
—Stricture (associated with chronic pancreatitis)
—Biliary atresia/choledochal cyst
—Post-liver-transplantation bile duct stenosis (usually anastomotic)
—Parasites
—Age-related or post-surgical mild CBD dilatation
Extrinsic
—Carcinoma of the head of pancreas
—Acute pancreatitis
—Lymphadenopathy at the porta hepatis
—Other masses at the porta, e.g. hepatic artery aneurysm, gastrointestinal tract mass
—Intra-hepatic tumours (obstruct distal segments)
Diffuse hepatic conditions
—Sclerosing cholangitis
—Caroli's disease

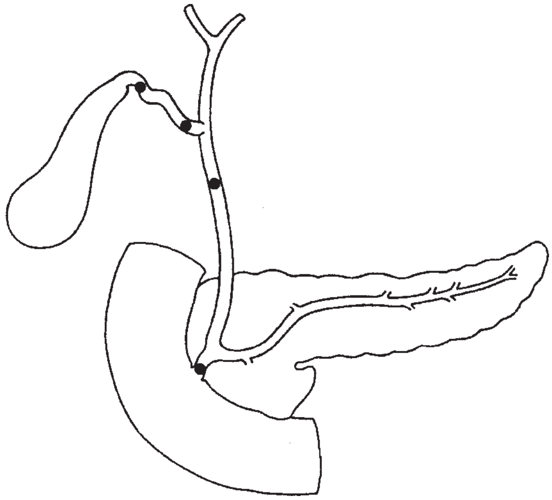


Figure 3.32 Sites of possible gallstone obstruction.

ERCP, although invasive, is a more accurate method of examining the CBD and will often identify strictures or small calculi not visible on ultrasound. It has the advantage of a therapeutic role in addition to its diagnostic capabilities, by allowing the extraction of stones at the time of diagnosis. It is associated with a small risk of complication, however, and its use is therefore increasingly limited in favour of the non-invasive magnetic resonance cholangiopancreatography (MRCP) (Fig. 3.34F). MRCP has been found to be highly effective in the diagnosis of CBD stones[24] and can potentially avoid the use of purely diagnostic ERCP.[25]

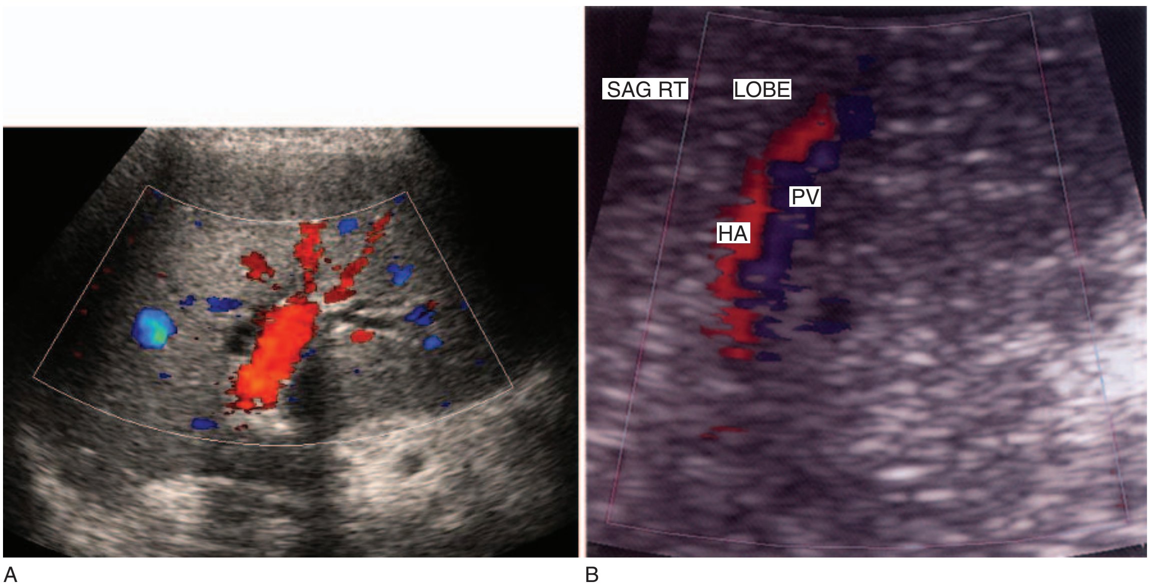
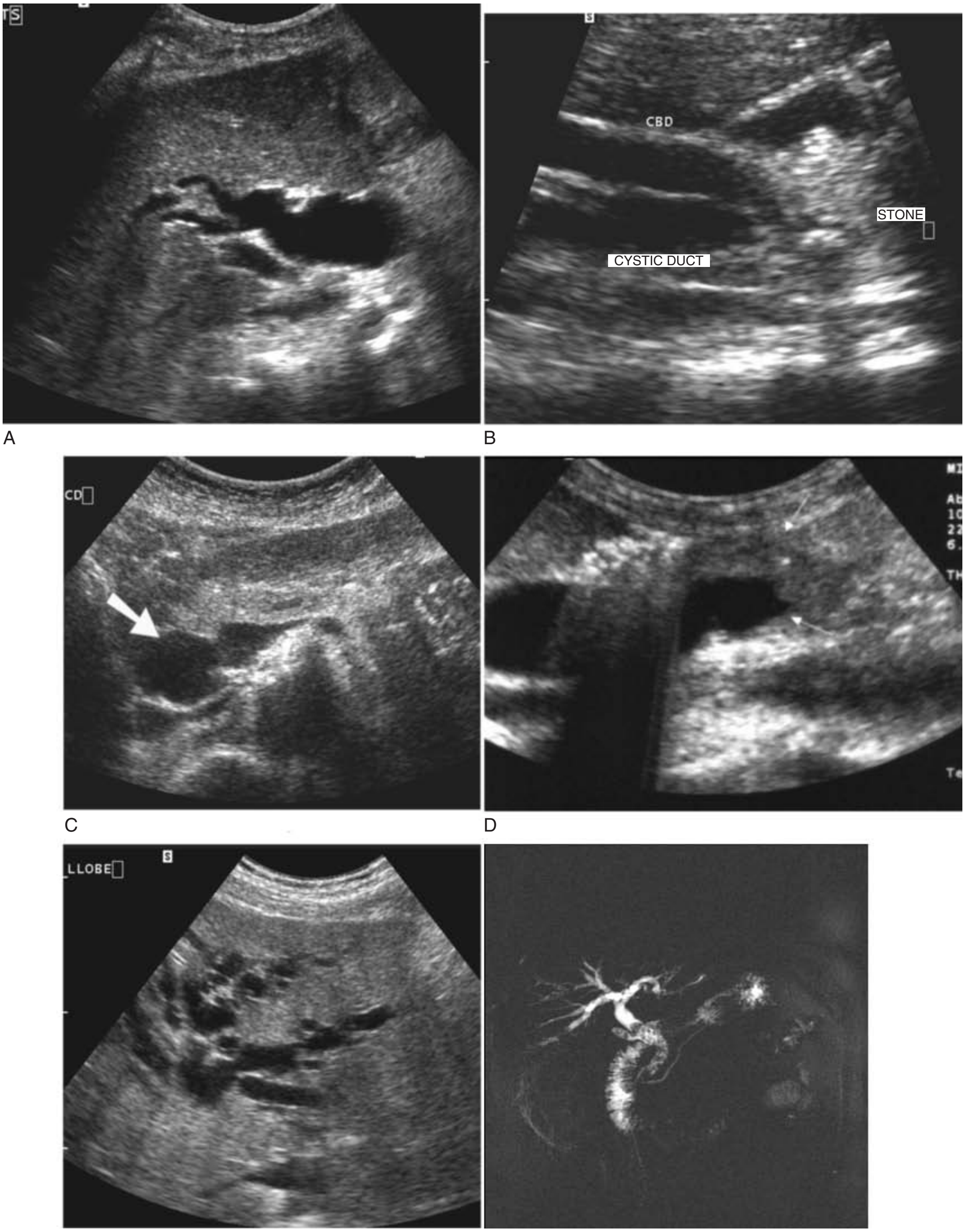


Figure 3.33 (A) Dilated biliary ducts do not demonstrate flow on colour Doppler, differentiating them from portal vessels. (B) Originally suspected as a dilated biliary tree, colour Doppler demonstrates that the 'extra tubes' are, in fact, dilated intrahepatic arteries in a patient with end-stage chronic liver disease with reversed portal venous flow.



A B C D E F

Figure 3.34 (A) Duodenal gas obscures the cause of obstruction at the lower end of this dilated CBD. (B) Patient positioning can move bowel gas away from the duct, demonstrating the cause of obstruction—a stone at the lower end. (C) TS of a dilated CBD in the head of the pancreas (arrow). (D) Dilated CBD with a hypoechoic ampullary carcinoma at the lower end (arrows). (E) Intrahepatic bile duct dilatation. (F) MRCP, post-cholecystectomy, showing stones in the CBD and cystic duct stump.

CT and MRI are useful for staging purposes if the obstructing lesion is malignant. Cholangiocarcinomas spread to the lymph nodes and to the liver and small liver deposits are particularly difficult to recognize on ultrasound if the intrahepatic biliary ducts are dilated.

In hepatobiliary scintigraphy, technetium^{99m}-labelled derivatives of iminodiacetic acid are excreted in the bile and may help to demonstrate sites of obstruction, for example in the cystic duct, or abnormal accumulations of bile, for example choledochal cysts.

Courvoisier's law, to which there are numerous exceptions, states that if the gallbladder is dilated in a jaundiced patient, then the cause is *not* due to a stone in the common duct. The reason for this is that, if stones are or had been present, then the gallbladder would have a degree of wall fibrosis from chronic cholecystitis which would prevent it from distending. In fact there are many exceptions to this 'law' which include the formation of stones in the duct, without gallbladder stones, and also obstruction by a pancreatic stone at the ampulla. Thus:

- Do not assume that obstructive jaundice in a patient with gallstones is due to a stone in the CBD. The jaundice may be attributable to other causes.
- Do not assume that obstructive jaundice cannot be due to a stone in the CBD if the gallbladder does not contain stones. A solitary stone can be passed into the duct from the gallbladder or stones can form within the duct.

Management of biliary obstruction

Management of biliary obstruction obviously depends on the cause and the severity of the condition. Removal of stones in the CBD may be performed by ERCP with sphincterotomy. Elective cholecystectomy may take place if gallstones are present in the gallbladder.

Laparoscopic ultrasound is a useful adjunct to surgical exploration of the biliary tree and its accuracy in experienced hands equals that of X-ray cholangiography. It is rapidly becoming the imaging modality of choice to examine the ducts during laparoscopic cholecystectomy.[26]

Endoscopic ultrasound can also be used to examine the CBD, avoiding the need for laparoscopic exploration of the duct when performed in the immediate preoperative stage.[27]

The treatment of malignant obstruction is determined by the stage of the disease. Accurate staging is best performed using CT and/or MRI. If surgical removal of the obstructing lesion is not a suitable option because of local or distant spread, palliative stenting may be performed endoscopically to relieve the obstruction and decompress the ducts (Fig. 3.35). The patency of the stent may be monitored with ultrasound scanning by assessing the degree of dilatation of the ducts.

Clinical suspicion of early obstruction should be raised if the serum alkaline phosphatase is elevated, (often more sensitive in the early stages than a raised serum bilirubin). In the presence of ductal dilatation on ultrasound, further imaging, such as CT or MRCP, may then refine the diagnosis.

Intrahepatic tumours causing biliary obstruction

Focal masses which cause segmental intrahepatic duct dilatation are usually intrinsic to the duct itself, for example cholangiocarcinoma.

It is also possible for a focal intrahepatic mass, whether benign or malignant, to compress an adjacent biliary duct, causing subsequent obstruction of that segment. This is not, however, a common cause of biliary dilatation and occurs most usually with hepatocellular carcinomas.[28] Most liver metastases deform rather than compress adjacent structures and biliary obstruction only occurs if the metastases are very large and/or invade the biliary tree. A hepatocellular carcinoma or metastatic deposit at the porta hepatis may obstruct the common duct by squeezing it against adjacent extrahepatic structures. Benign intrahepatic lesions rarely cause ductal dilatation, but occasionally their sheer size obstructs the biliary tree.

Choledochal cysts

Most commonly found in children, this is associated with biliary atresia, in which the distal 'blind' end of the duct dilates into a rounded, cystic mass in response to raised intrahepatic pressure.

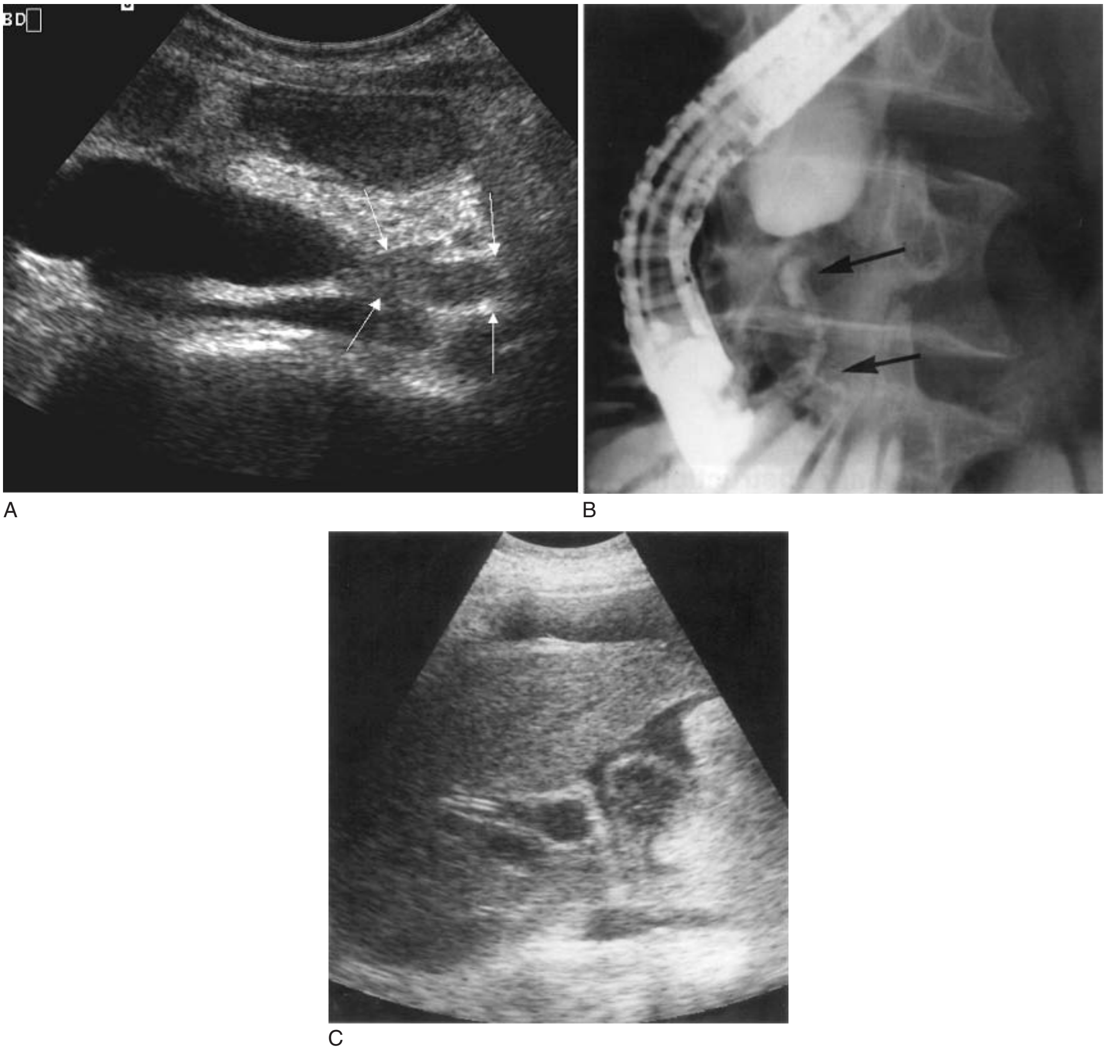


Figure 3.35 (A) This dilated CBD is obstructed by a mass (*arrows*) invading the lower end. (B) ERCP demonstrates a tight, malignant stricture, and can be used to position a palliative stent. (C) Stent in the CBD of a patient with a cholangiocarcinoma and malignant ascites. Decompression of the dilated biliary tree has been achieved, and ultrasound can be used to monitor the patency of the stent.

Choledochal cysts in adults are rare, and tend to be asymptomatic unless associated with stones or other biliary disease. They are sometimes associated with an anomalous insertion of the CBD into the pancreatic duct. The mechanism of the subsequent choledochal cyst formation is unclear, but it is thought that the common channel, which drains into the duodenum, is prone to reflux of pancreatic enzymes into the biliary duct. This can cause a biliary stricture, with subsequent proximal dilatation of the duct, forming a choledochal cyst[29] [Fig. 3.36].

Less commonly the dilatation is due to a non-obstructive cause in which the biliary ducts themselves become ectatic and can form diverticula. This may be due to a focal stricture of the duct which causes reflux and a localized enlargement of the duct proximal to the stricture. (See also *Caroli's disease*, below (Fig. 3.42.)

Figure 3.36 Choledochal cyst. (These can sometimes be difficult to distinguish from a gallbladder, particularly if large.)

Complications of choledochal cysts include cholangitis, formation of stones and progression of the condition to secondary biliary cirrhosis, which may be associated with portal hypertension.

It may be difficult to differentiate a choledochal cyst, particularly if solitary, from other causes of hepatic cysts. The connection between the choledochal cyst and the adjacent biliary duct may be demonstrated with careful scanning.

Cholangitis

Cholangitis is an inflammation of the biliary ducts, most commonly secondary to obstruction.

It is rarely possible to distinguish cholangitis from simple duct dilatation on ultrasound, although in severe cases the ductal walls appear irregular (Fig. 3.10A) and debris can be seen in the larger ducts (Fig. 3.37).

The walls of the ducts may appear thickened. Care should be taken to differentiate this appearance from tumour invasion and further imaging is often necessary to exclude malignancy.

Bacterial cholangitis is the most common form, due to bacterial infection which ascends the biliary tree. Bacterial cholangitis is also associated with biliary enteric anastomoses. It may be complicated by abscesses if the infection is progressive and untreated. Small abscesses may be difficult to diagnose on ultrasound, as they are frequently isoechoic and ill-defined in the early stages and biliary dilatation makes evaluation of the hepatic parenchyma notoriously difficult.

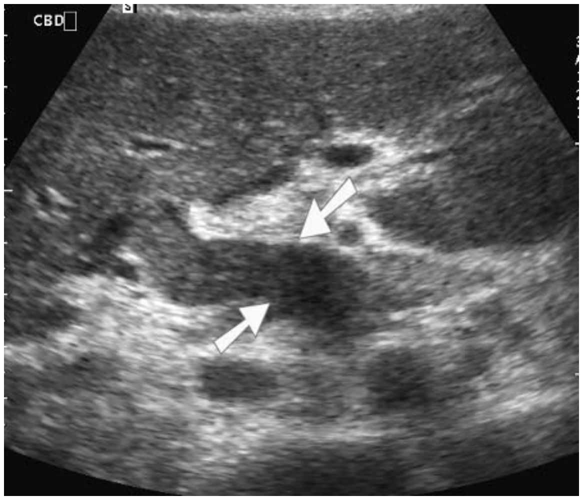


Figure 3.37 Cholangitis with debris present in the dilated CBD (*arrows*).

Contrast CT will often identify small abscesses not visible on ultrasound, and MRCP or ERCP demonstrates mural changes in the ducts.

Other forms of cholangitis include:

- Primary sclerosing cholangitis, a chronic, progressive cholestatic disease, which exhibits ductal thickening, focal dilatation and strictures (see p. 67).
- AIDS-related cholangitis which causes changes similar to that of primary sclerosing cholangitis.
- Recurrent pyogenic cholangitis (Oriental cholangiohepatitis) which is endemic in Southeast Asia and is associated with parasites and malnutrition. Intrahepatic biliary stones are also a feature of this condition.

BILIARY DILATATION WITHOUT JAUNDICE

Postsurgical CBD dilatation

In patients who have had cholecystectomy associated with previous dilatation of the CBD it is common to find a persistent (but non-significant) mild dilatation of the duct postoperatively. The serum alkaline phosphatase and bilirubin levels should be normal in the absence of pathology. Because stones may be found in the duct postoperatively, it is important to differentiate non-obstructive from truly obstructive dilatation in a symptomatic patient (Fig. 3.38). If in doubt, the patient may be rescanned at a suitable interval to assess any increase in ductal diameter.

Focal obstruction

Intrahepatic tumour, such as cholangiocarcinoma, may obstruct a segment of the biliary tree whilst the remainder of the liver and biliary tree appears normal. Focal duct dilatation should trigger the operator to examine the proximal area of dilatation for a possible mass. Such tumours may be present before jaundice is clinically apparent.

Pitfalls

Patients with cirrhosis and portal hypertension may have dilated hepatic arteries which can mimic the appearances of dilated ducts. Colour or power Doppler will readily differentiate between these, as the bile duct lacks a Doppler signal. Pneumobilia (air in the ducts) casts a distal acoustic shadow, and may therefore obscure ductal dilatation.

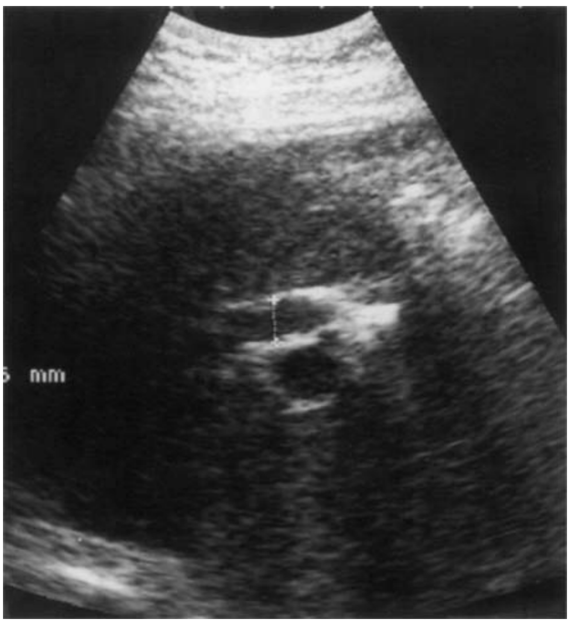


Figure 3.38 Biliary dilatation following laparoscopic cholecystectomy, due to a surgical clip across the CBD.

OBSTRUCTION WITHOUT BILIARY DILATATION

Early obstruction

It is possible to scan a patient at the time of recent onset of obstruction from a stone before the ducts have had time to dilate, leading to a false-negative diagnosis. If clinical suspicion persists, a rescan is frequently useful in these cases.

Occasionally, stones have a ball-valve effect in the duct, causing intermittent obstruction which may not demonstrate ductal dilatation on the ultrasound scan.

Fibrosis of the duct walls

There are a number of chronic pathological conditions which cause the walls of the ducts to become fibrotic and stiff. These include primary sclerosing cholangitis (see below), hepatitis and other chronic hepatic diseases leading to cirrhosis. The liver itself becomes rigid and this prevents biliary dilatation. In such cases the lack of dilated bile ducts does not necessarily imply an absence of obstruction.

OTHER BILIARY DISEASES

Primary sclerosing cholangitis (PSC)

PSC is a chronic hepatobiliary disease in which the walls of the bile ducts become inflamed, causing narrowing. It occurs predominantly in young men (with a 2:1 male to female ratio) and is characterized by multiple biliary strictures and bead-like dilatations of the ducts. The aetiology of PSC remains unclear but is associated with inflammatory bowel disorders or may be idiopathic.

Clinical features include jaundice, itching and fatigue. Some 25% of patients also have gallstones, which complicates the diagnosis. Approximately 70% of patients affected also have ulcerative colitis.

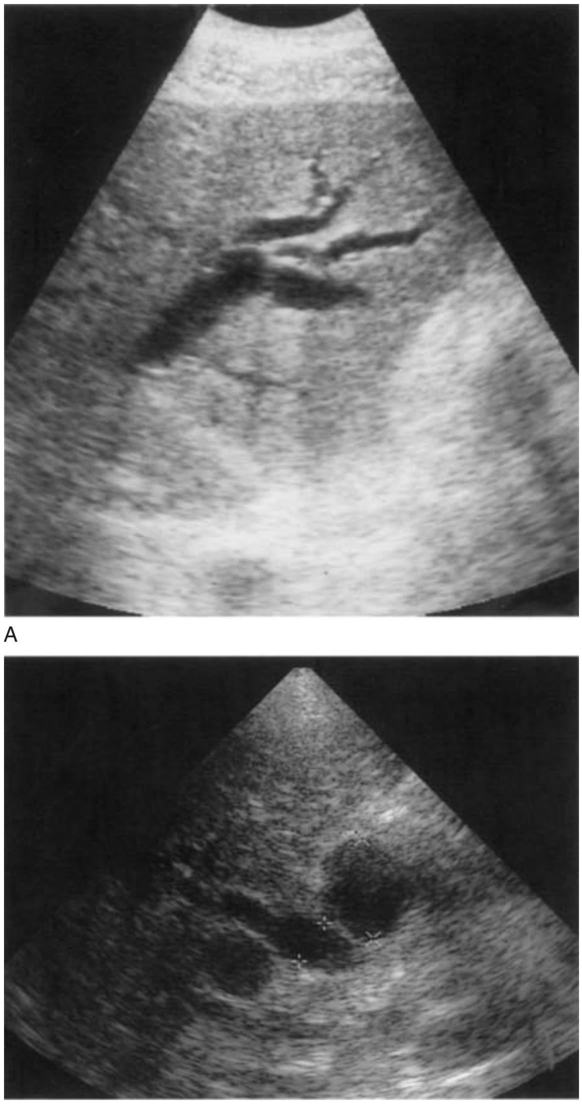
It is progressive gradual fibrosis which eventually obliterates the biliary tree. Untreated, this eventually leads to hepatic failure. PSC has a strong association with cholangiocarcinoma, and it is this, rather than hepatic failure, which may lead to death. In the absence of malignancy, however, hepatic transplant has a 70–90% 5-year survival rate.[30]

Ultrasound appearances

The ultrasound appearances in PSC may be normal or may demonstrate a coarse, hyperechoic texture throughout the liver. Ductal strictures may cause downstream dilatation in some segments (Fig. 3.39) and in some cases there is marked biliary dilatation, but in the majority of patients the biliary ducts are prevented from dilatation by the surrounding fibrosis and so appear unremarkable on ultrasound. MRCP is superior at demonstrating intrahepatic ductal strictures. Mural thickening, particularly in the CBD, may be demonstrated with careful, high-resolution scanning[31] (Fig. 3.40).

Ultrasound also demonstrates the effects of portal hypertension in advanced disease. The gallbladder may also have a thickened wall and can be dilated.[32]

Due to the association between PSC and cholangiocarcinoma, which may be multifocal, a careful search must be made for mass lesions. Because the ultrasound appearances may be those of a coarse, nodular liver texture, it is difficult to identify small cholangiocarcinomas and colour or power Doppler may be an advantage here (Fig. 3.41). This diagnosis is an important one, because the patient's prognosis and management are affected by the presence of cholangiocarcinomata. If no masses are identified, the prognosis is good and includes the endoscopic removal of stones to relieve symptoms, endoscopic stenting of main duct strictures to relieve jaundice and subsequent liver transplant to pre-empt the formation of carcinoma. However, if carcinoma is already present, 5-year survival falls to 10%.



A

B

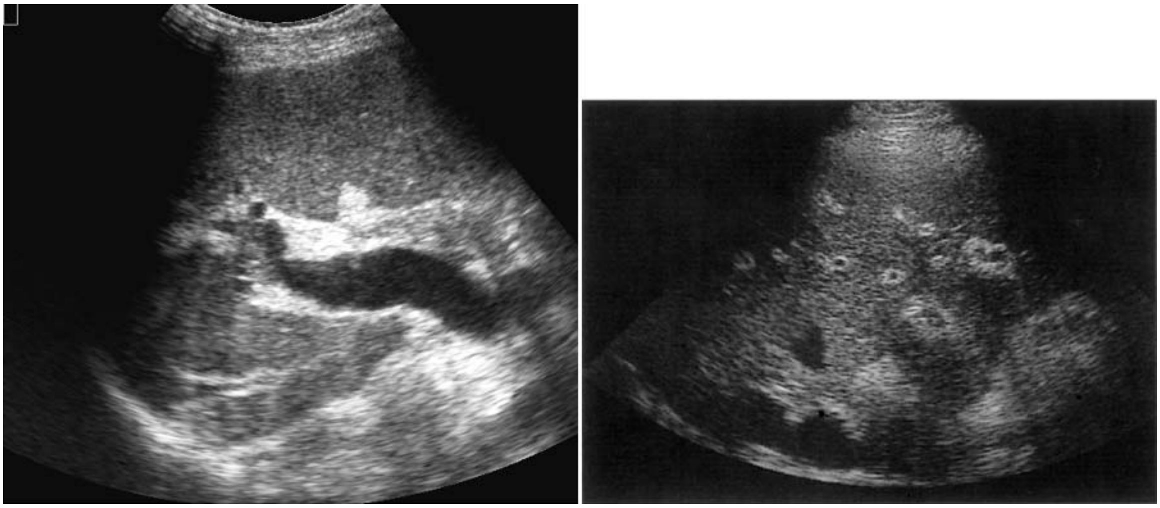
Figure 3.39 (A) Localized biliary dilatation due to a ductal stricture in a patient with primary sclerosing cholangitis (PSC). (B) Coarse-textured liver with a dilated CBD in PSC. A small choledochal cyst is present just anterior to the lower CBD.

Caroli's disease (congenital intrahepatic biliary dilatation)

This is a rare, congenital condition in which the bile ducts are irregularly dilated with diverticula-like projections. These diverticula may become infected and may separate off from the biliary duct, forming choledochal cysts (Fig. 3.42).

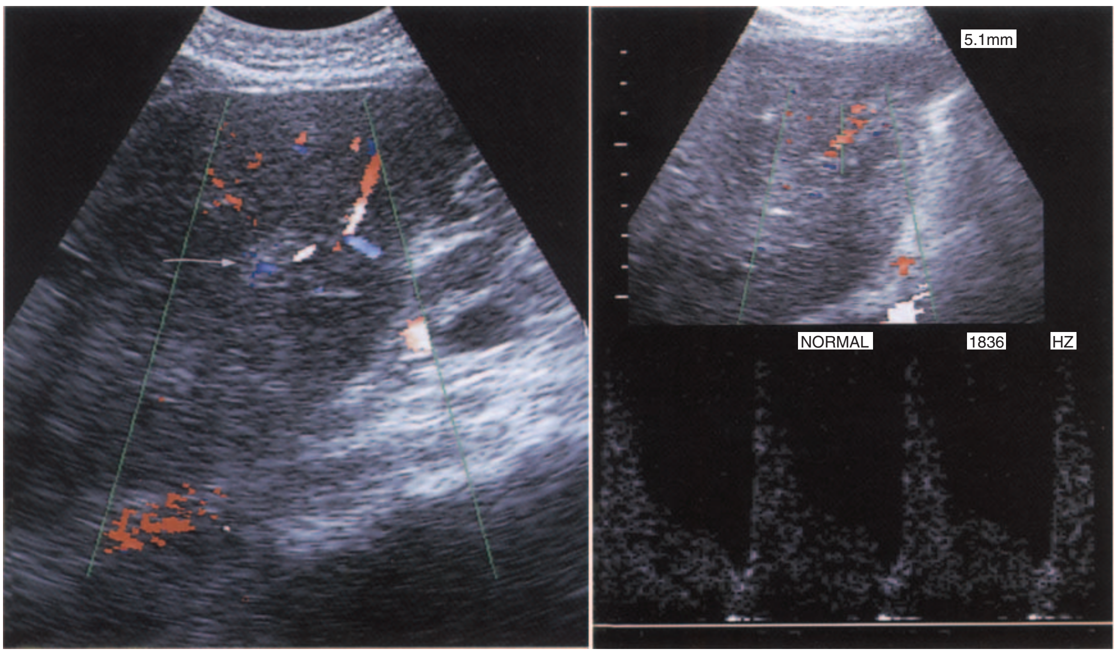
In most cases, the entire hepatobiliary system is affected to some degree. Sufferers may present in early childhood, with symptoms of portal hypertension, [33] or may remain well until adulthood, presenting with cholangitis. It is generally thought to be an autosomal recessive inherited condition and the prognosis is poor. Medical control of associated portal hypertension with varices can improve the quality of life.

In a few cases, the disease is confined to one or two segments of the liver, in which case a cure can be effected with hepatic resection.[34] The extrahepatic biliary tree is often unaffected.



A B

Figure 3.40 PSC. Hyperechoic mural thickening of the biliary tree can be seen in (A) the CBD and (B) the intrahepatic ducts.



A B

Figure 3.41 PSC. (A) A tiny, suspicious, hyperechoic focal lesion (arrow) demonstrates increased flow on colour Doppler. (B) The spectral waveform confirms vigorous arterial flow in this small cholangiocarcinoma.

The ultrasound appearances are usually of widespread intrahepatic duct dilatation, with both saccular and fusiform biliary ectasia. Because it is also associated with biliary stone formation, the diagnosis is often not clear. The dilatation is also associated with cholangitis and signs of infection may be present in the form of debris within the ducts. Sometimes, frank choledocal cysts can be located.

Advanced disease is associated with portal hypertension and, in some cases, cholangiocarcinoma.[35]

Parasites

Parasitic organisms, such as the *Ascaris* worm and liver fluke, are extremely rare in the UK. However, they are a common cause of biliary colic in Africa,

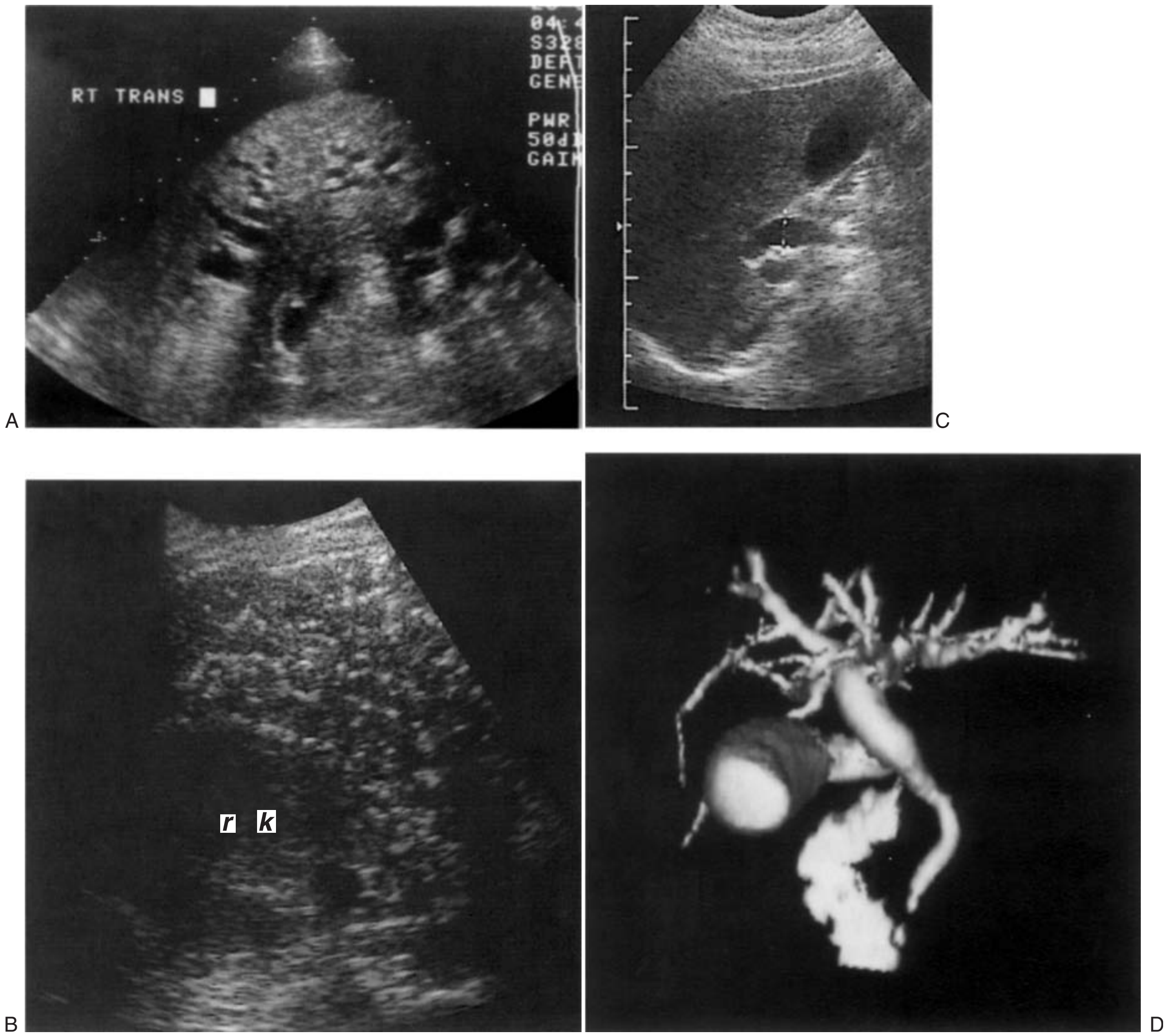


Figure 3.42 Caroli's disease. (A) Dilated biliary tree and ascites. (B) TS of a different patient with end-stage disease. The grossly abnormal liver texture contrasts with the right kidney. (C) A small section of focal CBD dilatation persisted in a symptomatic patient, with normal-calibre distal CBD. This was confirmed on ERCP and thought to be a dyskinetic segment, causing biliary reflux, but was later diagnosed as a mild form of Caroli's. (D) 3D CT reconstruction of the case in (C), confirming the ultrasound appearances. Note the tiny ectatic 'pouchings' of the intrahepatic ducts characteristic of Caroli's.

the Far East and South America. The hyperechoic linear structures in the gallbladder lumen should raise the sonographer's suspicion in patients native to, or who have visited these countries. Impacted worms in the biliary ducts may mimic other ductal masses.[36]

They are a rare cause of obstructive biliary dilatation (Fig. 3.43).

Patients may present with acute cholangitis or abdominal pain and vomiting. Endoscopic management is frequently highly effective.[37]

ECHOGENIC BILE

Biliary stasis

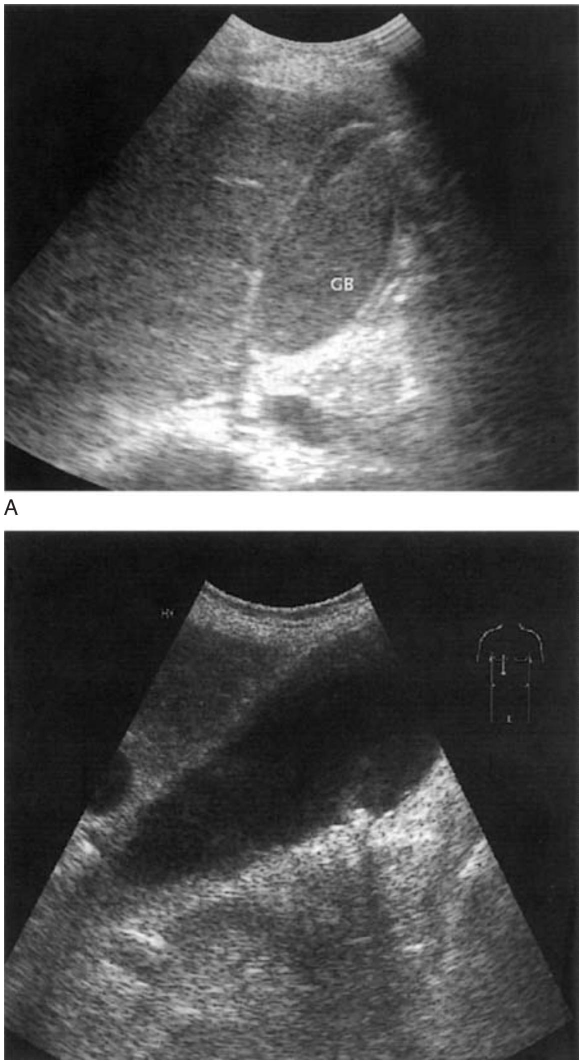
Fine echoes in the bile within the gallbladder are not uncommon on an ultrasound scan. This is commonly due to the inspissation of bile following prolonged starving, for example following surgery (Fig. 3.44). These appearances disappear after a normal diet is resumed and the gallbladder has emptied and refilled.

It occurs when the solutes in the bile precipitate, often due to hypomotility of the gallbladder, and can commonly be seen following bone marrow transplantation and in patients who have undergone prolonged periods (4–6 weeks) of total parenteral nutrition.[38]

Prolonged biliary stasis may lead to inflammation and/or infection, particularly in postoperative patients and those on immunosuppression (Fig. 3.44B). Its clinical course varies from complete resolution to progression to gallstones. However, following the resumption of oral feeding, the gallbladder may contract and empty the sludge into the biliary tree causing biliary colic, acute pancreatitis and/or acute cholecystitis.[39] For this reason, cholecystectomy may be considered in symptomatic patients with biliary sludge.

The fine echoes may form a gravity-dependent layer and may clump together, forming 'sludge balls'. To avoid misdiagnosing sludge balls as polyps, turn the patient to disperse the echoes or

Figure 3.43 *Ascaris* worm in the gallbladder.



A

B

Figure 3.44 (A) Inspissated bile in the normal gallbladder of a fasting patient. (B) Gravity-dependent biliary sludge with a small stone.

rescan after the patient has resumed a normal diet.

Biliary stasis is associated with an increased risk of stone formation.[40]

Biliary crystals

Occasionally, echogenic bile persists even with normal gallbladder function (Fig. 3.45). The significance of this is unclear. It has been suggested that there is a spectrum of biliary disease in which gallbladder dysmotility and subsequent saturation of the bile lead to the formation of crystals in the bile and also in the gallbladder wall, leading eventually to stone formation.[41] Pain and biliary colic may be present prior to stone formation and the presence of echogenic bile seems to correlate with the presence of biliary crystals.[42]

Biliary crystals, or 'microlithiasis' (usually calcium bilirubinate granules) have a strong association with acute pancreatitis[43] and its presence in patients who do not have gallstones is therefore highly significant.

Obstructive causes of biliary stasis

Pathological bile stasis in the gallbladder is due to obstruction of the cystic duct (from a stone, for example) and may be demonstrated in a normal-sized or dilated gallbladder. The bile becomes viscous and hyperechoic. The biliary ducts remain normal in calibre. Eventually the bile turns watery and appears echo-free on ultrasound; this is known as a mucocoele (see above) (Fig. 3.8).

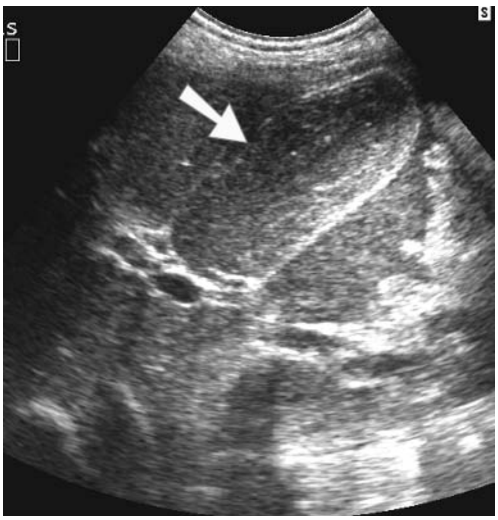


Figure 3.45 Biliary crystals.

Bile stasis within the ducts occurs either as a result of prolonged and/or repetitive obstruction or as a result of cholestatic disease such as primary biliary cirrhosis (PBC) (Chapter 4) or PSC. This can lead to cholangitis.

Haemobilia

Blood in the gallbladder can be the result of gastrointestinal bleeding or other damage to the gallbladder or bile duct wall, for example iatrogenic trauma from an endoscopic procedure.

The appearances depend upon the stage of evolution of the bleeding. Fresh blood appears as fine, low-level echoes. Blood clots appear as solid, non-shadowing structures and there may be hyperechoic, linear strands.[44]

The history of trauma will allow the sonographer to differentiate from other causes of haemobilia and echogenic bile, particularly those associated with gallbladder inflammation, and there may be other evidence of abdominal trauma on ultrasound such as a haemoperitoneum.

Pneumobilia

Air in the biliary tree is usually iatrogenic and is frequently seen following procedures such as ERCP, sphincterotomy or biliary surgery. Although it does not usually persist, the air can remain in the biliary tree for months or even years and is not significant.

It is characterized by highly reflective linear echoes (Fig. 3.46), which follow the course of the biliary ducts. The air usually casts a shadow which is different from that of stones, often having reverberative artefacts and being much less well-defined or clear. This shadowing obscures the lumen of the duct and can make evaluation of the hepatic parenchyma difficult.

Pneumobilia may also be present in emphysematous cholecystitis, an uncommon complication of cholecystitis in which gas-forming bacteria are present in the gallbladder (see above), or in cases where a necrotic gallbladder has formed a cholecystoenteric fistula.

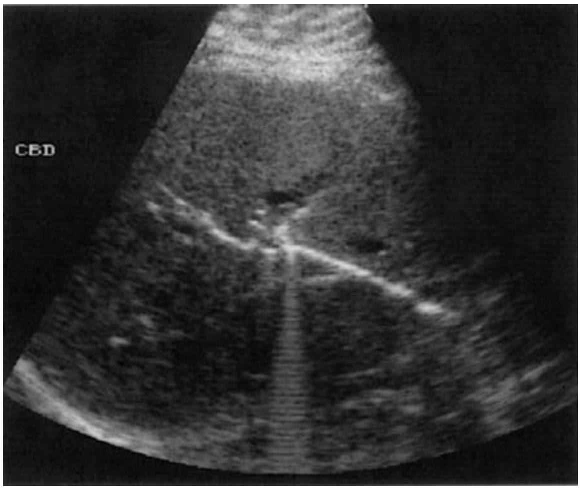


Figure 3.46 Air in the biliary tree following surgery. Note the 'reverberative' shadow.

Rarely, multiple biliary stones form within the ducts throughout the liver and can be confused with the appearances of air in the ducts.

MALIGNANT BILIARY DISEASE

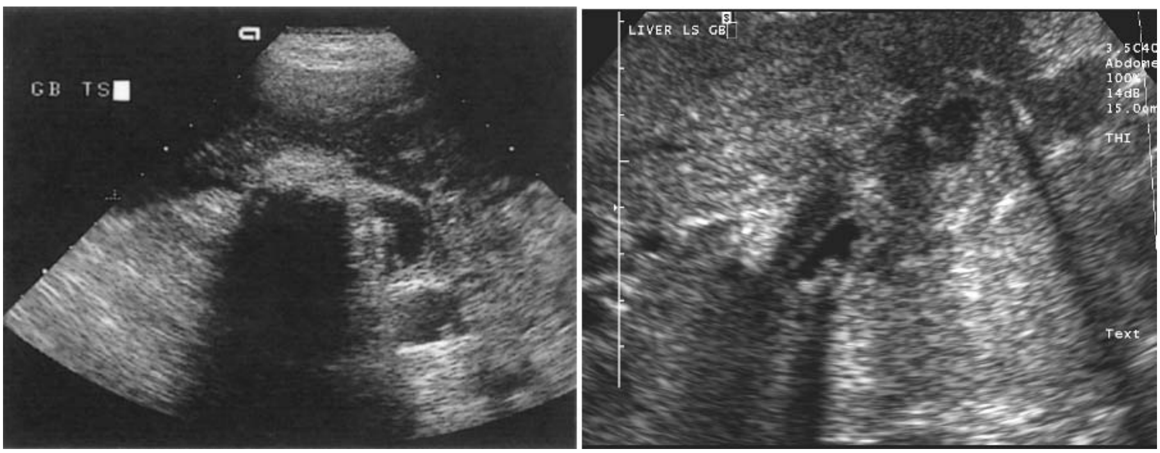
Primary gallbladder carcinoma

Cancer of the gallbladder is usually associated with gallstones and a history of cholecystitis. Most often, the gallbladder lumen is occupied by a solid mass which may have the appearance of a large polyp. The wall appears thickened and irregular and shadowing from the stones may obscure it posteriorly. A bile-filled lumen may be absent, further complicating the ultrasound diagnosis (Fig. 3.47). In a porcelain gallbladder (calcification of the gallbladder wall), which is associated with gallbladder carcinoma, the shadowing usually obscures any lesion in the lumen, making the detection of any lesion present almost impossible.

Particular risk factors for gallbladder carcinoma include large stones, polyps of over 1 cm in size, porcelain gallbladder and, occasionally, choledochal cyst due to anomalous junction of the pancreatobiliary ducts.[8]

The carcinoma itself is frequently asymptomatic in the early stages, and patients tend to present with symptoms relating to the stones. It is a highly malignant lesion which quickly metastasizes to the liver and portal nodes and has a very poor prognosis, with a curative surgical resection rate of around 15–20%.

Doppler may assist in differentiating carcinoma from other causes of gallbladder wall thickening,[45] but further staging with CT is usually necessary. Ultrasound may also demonstrate local spread into the adjacent liver.



A B

Figure 3.47 Gallbladder carcinoma. (A) TS, containing stones, debris and irregular wall thickening. (B) A different patient, demonstrating a grossly thickened hypoechoic wall with a contracted lumen.

Cholangiocarcinoma

This is a malignant lesion arising in the wall of the bile duct (Fig. 3.48). It is obviously easier to recognize from an ultrasound point of view when it occurs in and obstructs the common duct, as the subsequent dilatation outlines the proximal part of the tumour with bile. Cholangiocarcinoma may occur at any level along the biliary tree and is frequently multifocal.

A cholangiocarcinoma is referred to as a *Klatskin tumour* when it involves the confluence of the right and left hepatic ducts. These lesions are often difficult to detect on both ultrasound and CT. They are frequently isoechoic, and the only clue may be the proximal dilatation of the biliary ducts (Fig. 3.49).

Although rare, the incidence of cholangiocarcinoma seems to be increasing and it is strongly associated with PSC, a disease of the biliary ducts which predominantly affects young men (see above).

Multifocal cholangiocarcinoma may spread to the surrounding liver tissue and carries a very poor prognosis for long-term survival. In a liver whose texture is already altered by diffuse disease it may be almost impossible to identify these lesions before they become large. A pattern of dilated ducts distal to the lesion is a good clue (Figs 3.50 and 3.51).

Figure 3.48 The distal CBD has a thickened wall (arrowheads), and the lumen is filled with tumour at the lower end. (Gallbladder anterior.)

A B

Figure 3.49 Cholangiocarcinoma. (A) Irregular mass at the porta, causing biliary obstruction—a Klatskin tumour. (B) MRI of the same patient, confirming the mass at the porta.