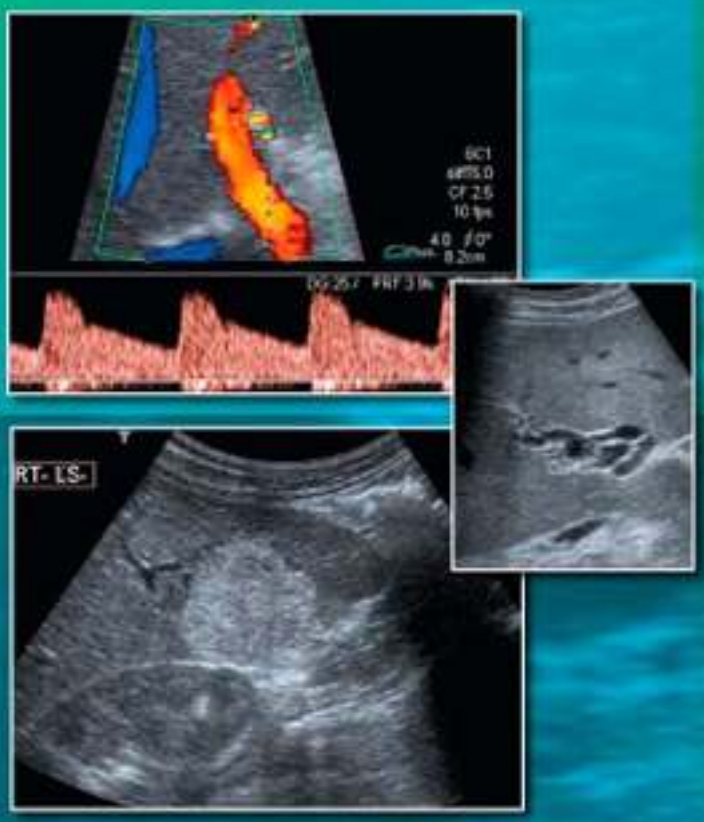
THIRD EDITION

Abdominal ULTRASOUND

HOW, WHY AND WHEN



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ABDOMINAL ULTRASOUND

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How, Why and When

Third Edition

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Preface

Ultrasound is one of the most important and most frequently used diagnostic tools at our disposal. It is used by a range of health professionals from various clinical backgrounds, and its contribution covers a broad spectrum from first-line triage to focused definitive diagnostic tool, from basic exclusion tool to guided interventional therapy. Ultrasound is operator dependent to a degree unrivalled by most diagnostic instruments, and, in the hands of the unwary operator, has the potential for great harm as well as good.

This book is intended as a practical, easily accessible guide to sonographer practitioners and those wishing to learn and develop in the field of ultrasound. It seeks to enable the operator to maximize the diagnostic information available and, most importantly, to recognize the limitations of the scan and to avoid diagnostic pitfalls.

Where possible it presents a wider, more holistic approach to the patient, including presenting symptoms, complementary imaging procedures and further management options. It does not aim to be in any way comprehensive, but is intended as a springboard from which practical skills and clinical knowledge can further develop.

The book seeks to increase the student's awareness of the contribution of ultrasound in patient management, and to encourage the sonographer to explore the enormous potential of diagnostic ultrasound in a properly supervised environment.

The author gratefully acknowledges the help and support of staff working in diagnostic ultrasound in Leeds.

Jane Bates
2010

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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 achieved
ALT	alanine aminotransferase
AML	angiomyolipomas
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
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
FDG-PET	$^{[18F]}$2-fluoro-2-deoxy-d-glucose positron emission tomography
FPS	frames per second
HA	hepatic artery
HCC	hepatocellular carcinoma
HELLP	haemolytic anaemia, elevated liver enzymes and low platelet count
HIDA	hepatic iminodiacetic acid
HOP	head of pancreas
HPS	hypertrophic pyloric stenosis
HV	hepatic vein
INR	international normalized ratio
IOUS	intraoperative ultrasound
IVC	inferior vein cava
IVU	intravenous urogram
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
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 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
TIPSS	transjugular intrahepatic portosystemic shunt
TIS	soft-tissue thermal index
TOP	tail of pancreas
TORCH	toxoplasmosis, rubella, cytomegalovirus and HIV
TS	transverse section
UTI	urinary tract infection
VHL	von Hippel–Lindau disease
VUJ	vesicouretic junction
WRMSD	work-related musculoskeletal disorders
XGP	xanthogranulomatous pyelonephritis

Optimizing the diagnostic information

1

CHAPTER CONTENTS

INTRODUCTION

Ultrasound is operator dependent to a greater degree than any other diagnostic imaging modality. The potential for misdiagnosis is significant, and the only acceptable way to undertake diagnostic ultrasound is:

1. After appropriate training – practical as well as theoretical
2. Preferably following independent assessment by a qualified ultrasound practitioner (as not everyone can reach the desired standard)
3. By continuing to develop your knowledge and technique with regular relevant practice
4. By employing audit of your practice, preferably within a team setting, as prolonged isolated practice is more likely to result in poor standards of diagnosis.

Importantly, the introduction of smaller, cheaper machines (increasingly hand-held) while improving accessibility to a valuable diagnostic technique on the one hand, has opened it up to potential abuse by untrained users on the other hand. This has focused attention on more rigorous quality control measures, and on the need for comprehensive practical training and competency assessment to supplement theoretical 'courses'.

TECHNIQUE

Ultrasound is devolving rapidly from radiology departments to other clinical environments, such as surgeries and clinics. The potential for ultrasound to be carried out by untrained personnel is therefore increasing. A lack of understanding by some has led to theoretical courses being considered as 'training'. This is very far from the case, and possibly one of the most dangerous legacies of this rapidly developing type of service provision.

Whatever the limitations of your equipment, a comprehensive and properly executed technique is essential. This is not about taking pictures (unlike many other radiological imaging tests). It is about a comprehensive and confident evaluation of the organs (with representative images for audit and recording purposes). This can only be achieved with practical experience, closely supervised by qualified practitioners.

Knowing your own limitations, knowing when you have not been able to execute a satisfactory scan, and being able to request assistance from expert practitioners, is one of the most valuable lessons you will learn.

Although the dynamic nature of the scan is a huge advantage over other forms of imaging, the potential for misdiagnosis is significant. The skilled operator continuously adjusts his or her 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 serious misdiagnosis.

IMAGE OPTIMIZATION

Misinterpretation of ultrasound images is a significant risk in ultrasound diagnosis. The skill of effective scanning lies in the operator's ability to maximize the diagnostic information available, and in being able to properly interpret the appearances. This is dependent on:

- Technical skill – knowing how to interrogate the organ(s) fully, and obtain the most useful and relevant images
- Knowledge of how the sound interacts with tissue – recognizing and being able to avoid artefacts and the pitfalls of scanning
- 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
- Knowledge of the equipment being used, i.e. making the most of your machine Box 1.1).

There are numerous ways in which different manufacturers allow us to make compromises during the scanning process in order to maximize image quality and enhance diagnostic information.

BOX 1.1 Making the most of your equipment

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

The diagnostic 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)
- 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)
- Using 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 uses the second harmonic frequency using 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.

The bottom line is, 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

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, 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' 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). It has the advantage of a stronger signal, 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 – such as the inferior vena cava (IVC).

Pulsed Doppler uses pulses of Doppler from individual elements or small groups of elements within the array. This allows the operator to select

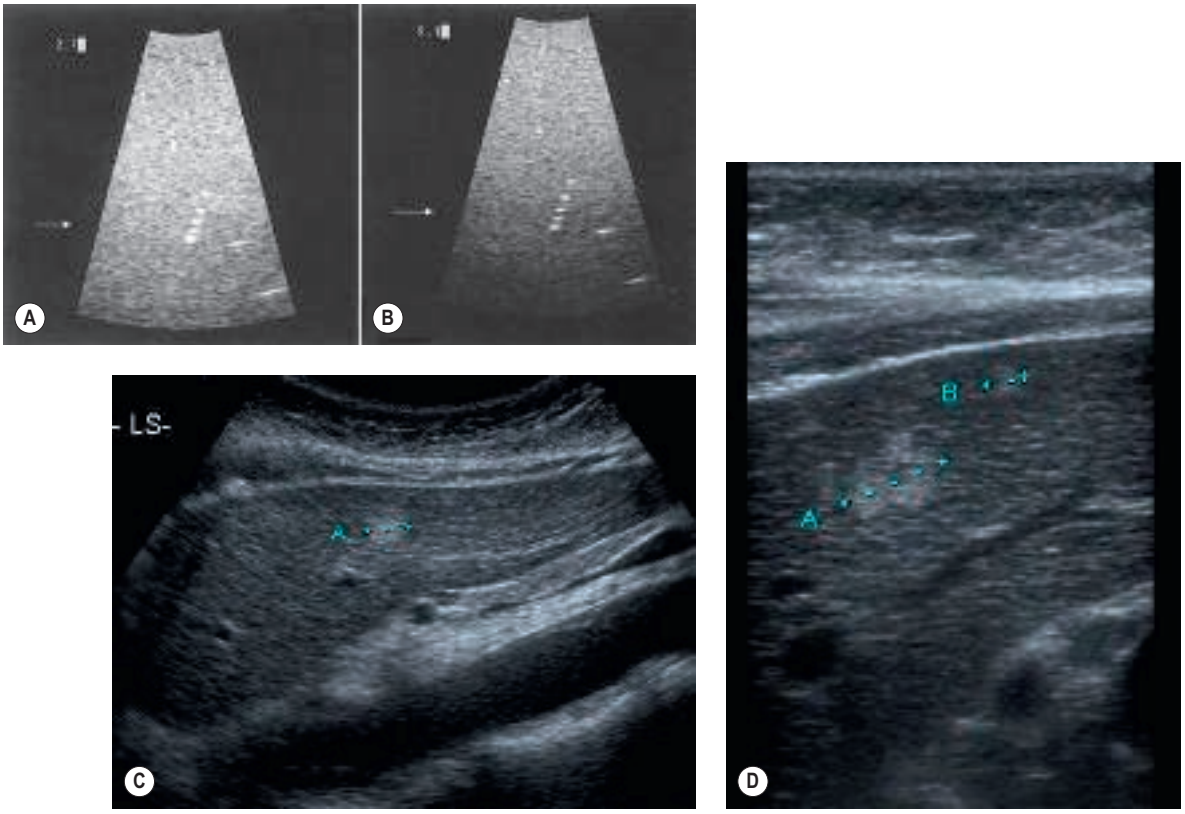

Fig. 1.1 • The effect of changing frequency. (A) At 2.7 MHz the wires are poorly resolved and the background 'texture' of the test object looks coarse. (B) The same transducer is switched to a resonant frequency of 5.1 MHz. Without changing any other settings, the six wires are now resolved and the background texture appears finer. (C) A small nodule in the anterior portion of the left lobe of liver demonstrated with a 5.0 MHz transducer. (D) Using 7.5 MHz, the nodule in (C) has improved detail, and a further small nodule (calipers B), not seen on the lower frequency, is detected near the anterior surface.

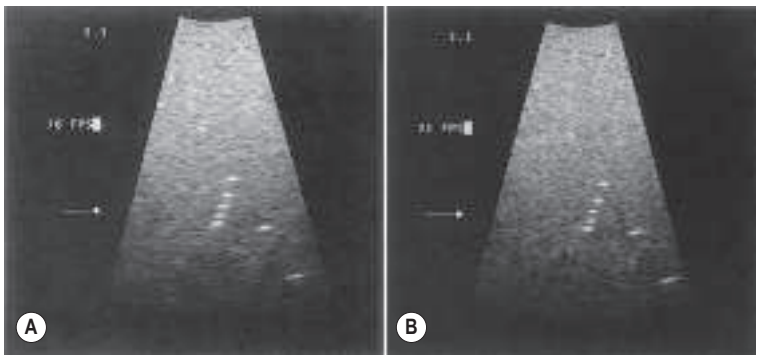

Fig. 1.2 • The effect of line density. (A) 76 frames per second (FPS). (B) 36 FPS – the resulting higher line density improves the image, making it sharper.

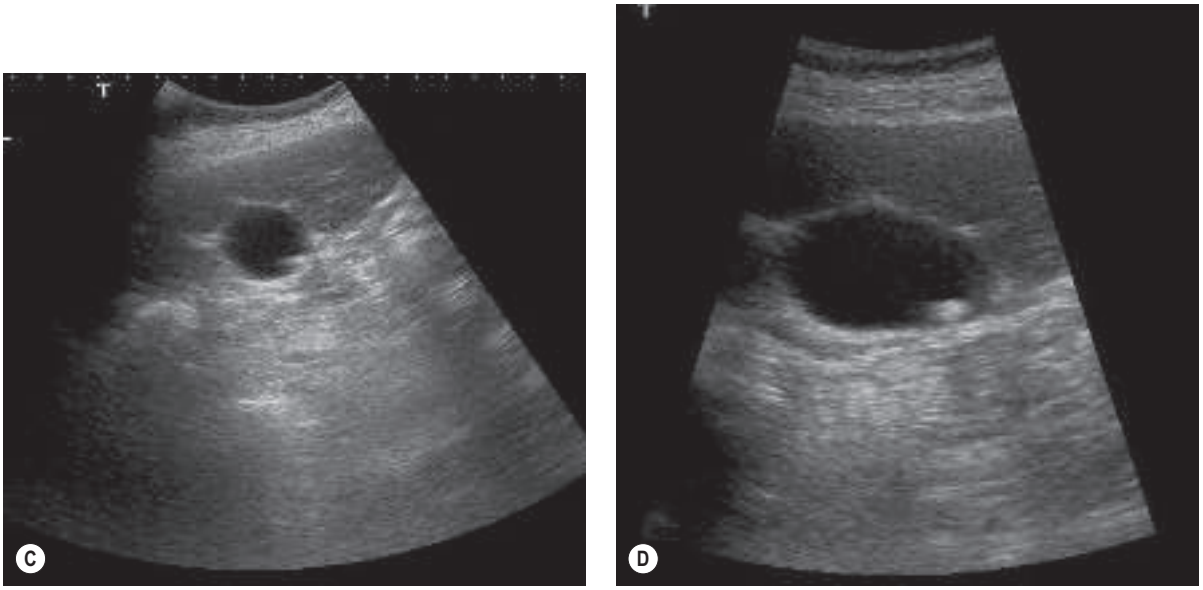

Fig. 1.2, cont'd • (C) The gallbladder is displayed with a low line density, as the scanning area is large. (D) By reducing the field of view, the line density is increased, clarifying the small stone in the gallbladder.

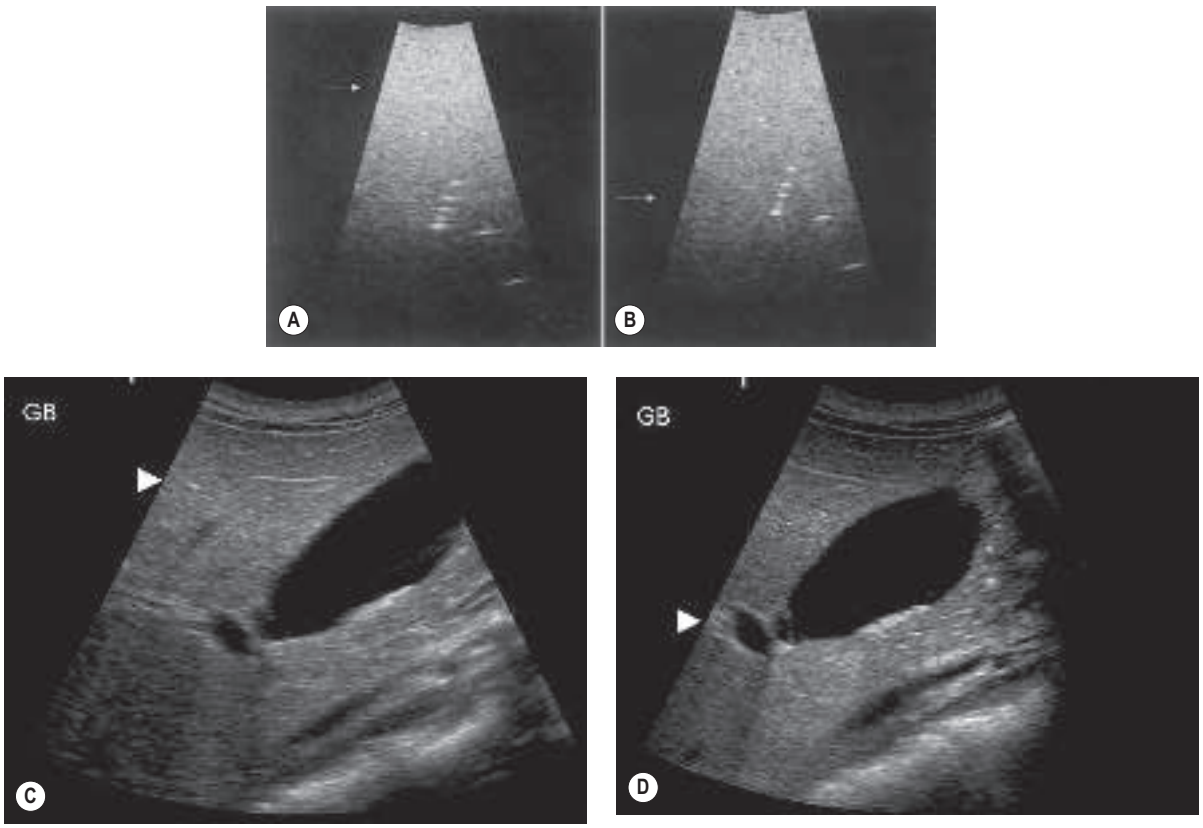

Fig. 1.3 • The effect of focal zone placement. (A) With the focal zone in the near field, structures in the far field are poorly resolved. (B) Correct focal zone placement improves both axial and lateral resolution of the wires. (C) The focal zone incorrectly set in the near field (arrowhead) makes it difficult to demonstrate small gallstones. (D) With the focal zone correctly set (arrowhead), the stones are resolved with a clear, diagnostic band of posterior shadowing.

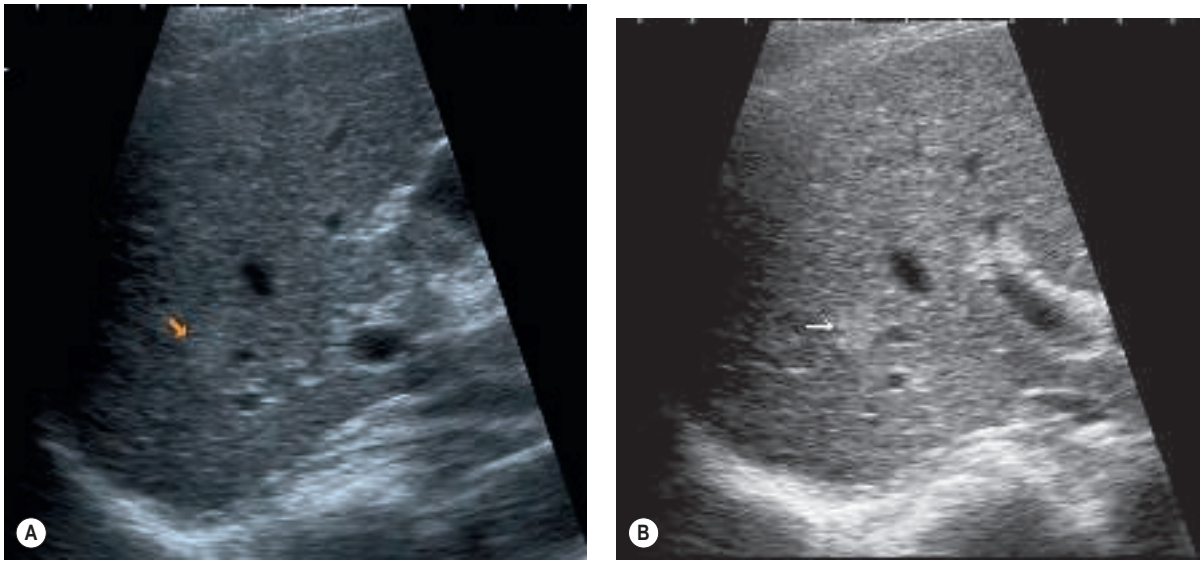

Fig. 1.4 • The effect of using post-processing options. (A) A small nodule in a cirrhotic liver merges into the background and is difficult to detect. (B) A post-processing option that allocates the range of grey shades in a non-linear manner enhances contrast resolution and improves the lesion's conspicuity.

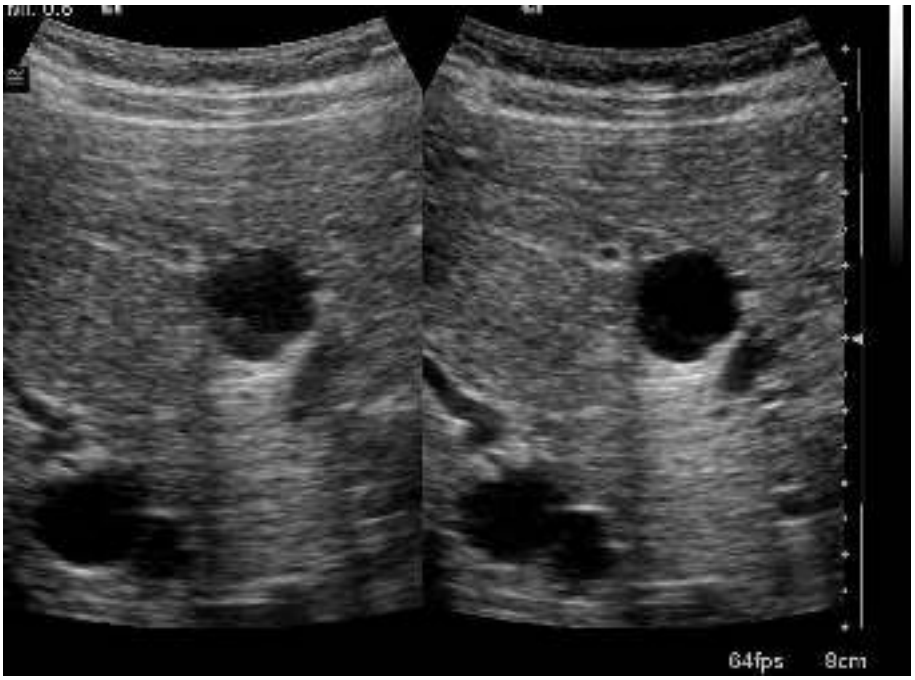

Fig. 1.5 • The effect of tissue harmonic imaging: the left image shows a liver containing cysts. The right image has tissue harmonic imaging applied, which reduces artefact and clarifies the structures.

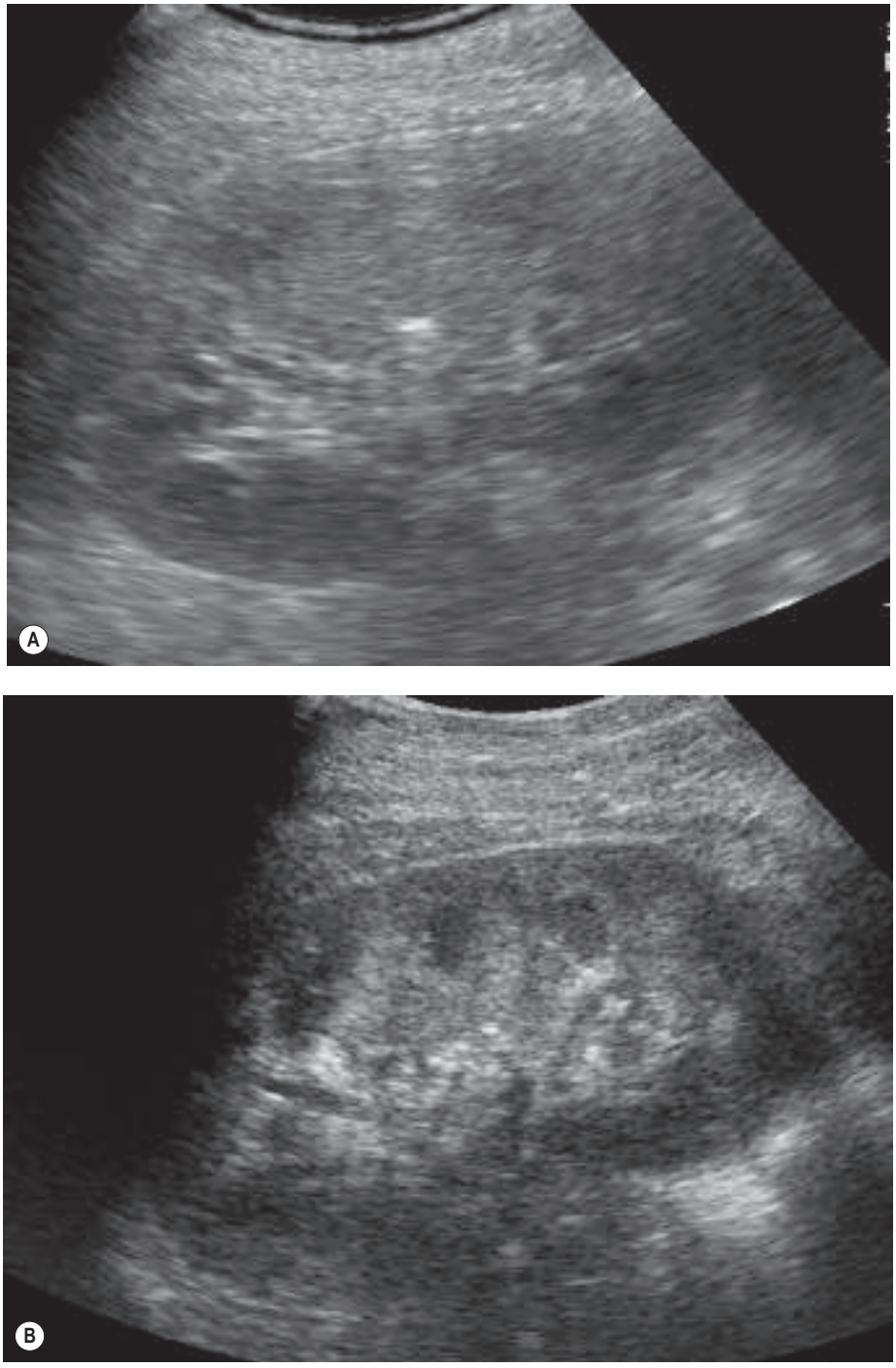

Fig. 1.6 • The importance of using correct equipment settings: (A) Incorrect use of equipment settings makes it difficult to appreciate the structures in the right kidney. (B) By increasing the resonant frequency, decreasing the frame rate (increasing line density) and adjusting the focal zone, structures in the kidney are clarified.

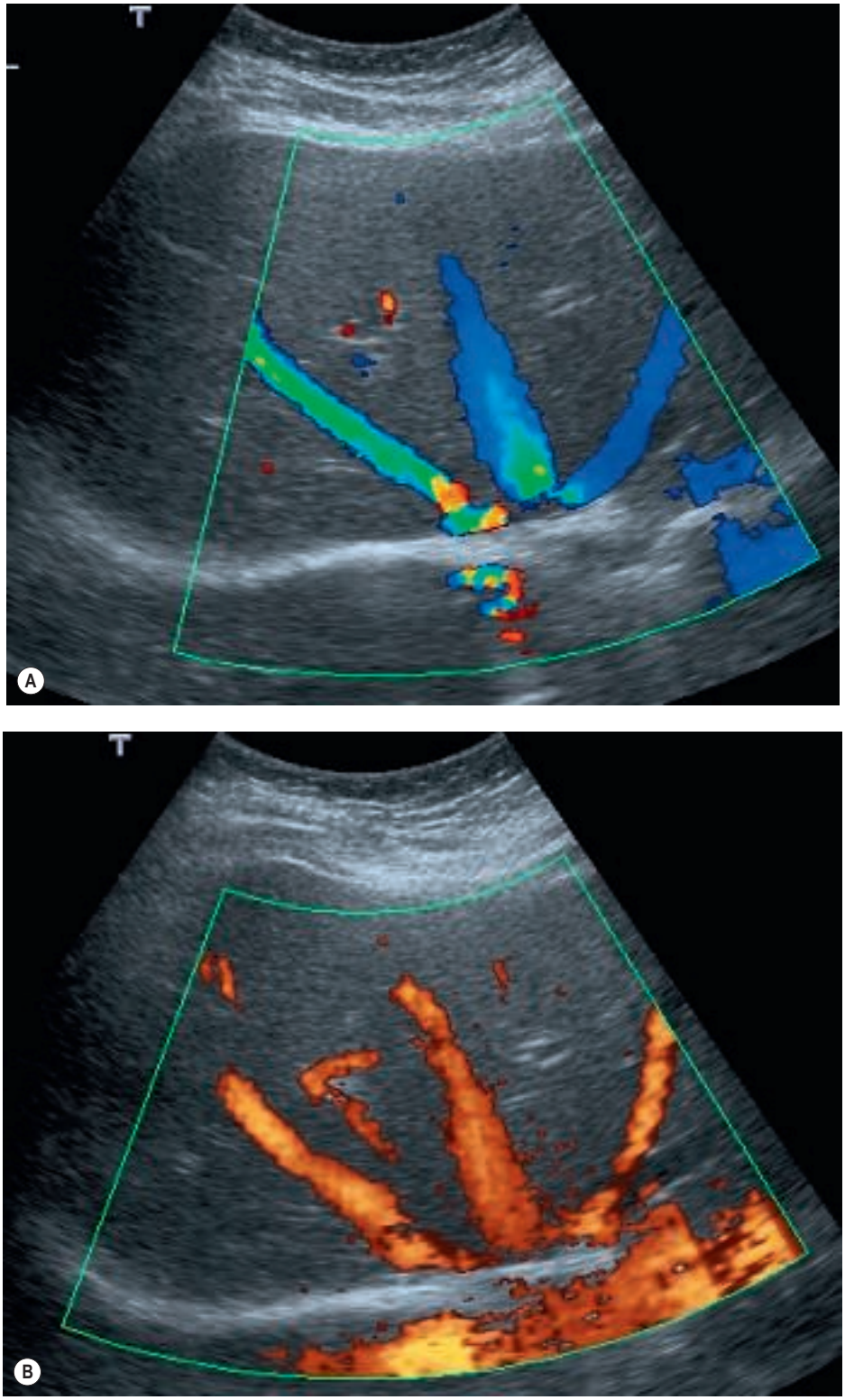

Fig. 1.7 • Colour Doppler of the hepatic vein confluence. Flow is coloured blue to indicate a direction away from the transducer.

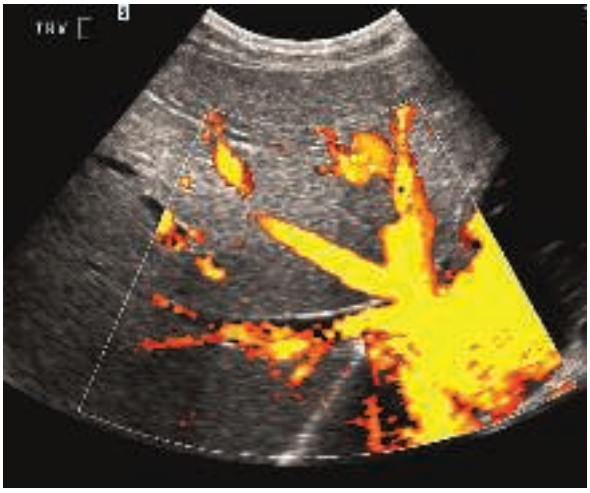

Fig. 1.8 • Power Doppler of the hepatic vein confluence. Directional information is lost, but power Doppler can be superior to colour in demonstrating low velocity flow.

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 Doppler controls is essential in order to avoid the pitfalls and increase confidence in the results. It is relatively straightforward 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 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. It is essential that the Doppler settings are sensitive enough to detect the velocity of flow in the vessel (Box 1.2). This means that the angle of insonation to the direction

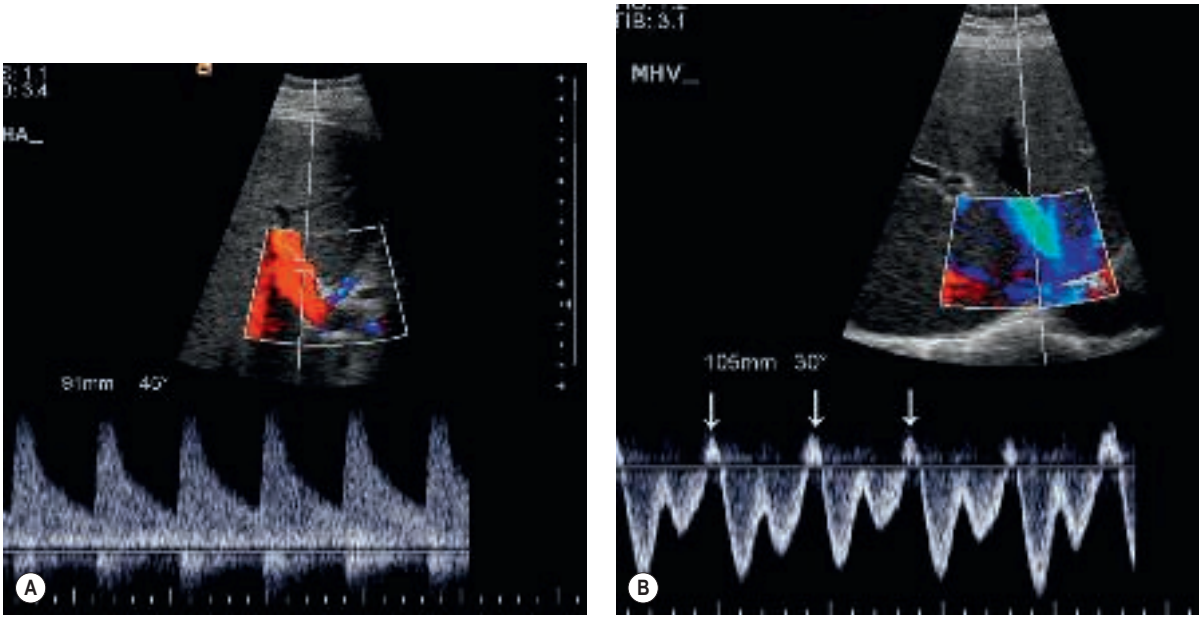

Fig. 1.9 • Flow velocity waveforms. (A) Low resistance flow towards the transducer from a normal hepatic artery. Good end diastolic flow throughout the cycle with a 'filled in' waveform indicating variance in flow. (B) In contrast, this hepatic vein trace with flow away from the transducer is triphasic, with a clear 'envelope' consistent with less variance. The pulsatile nature of the flow incorporates brief flow towards the transducer (arrows) at the end of each cycle.

of flow must be as close to 0° as possible (i.e. the vessel must be flowing towards or away from the beam, not perpendicular to it), the pulse repetition frequency (PRF) must be set to detect slow flow and the Doppler gain must be turned up sufficiently.

It is also possible to make mistakes if the settings are *too* sensitive, i.e. non-occlusive thrombus can be masked by too much colour flow, and a very low PRF can result in aliasing – giving a confusing picture if the operator is unaware (Fig. 1.10).

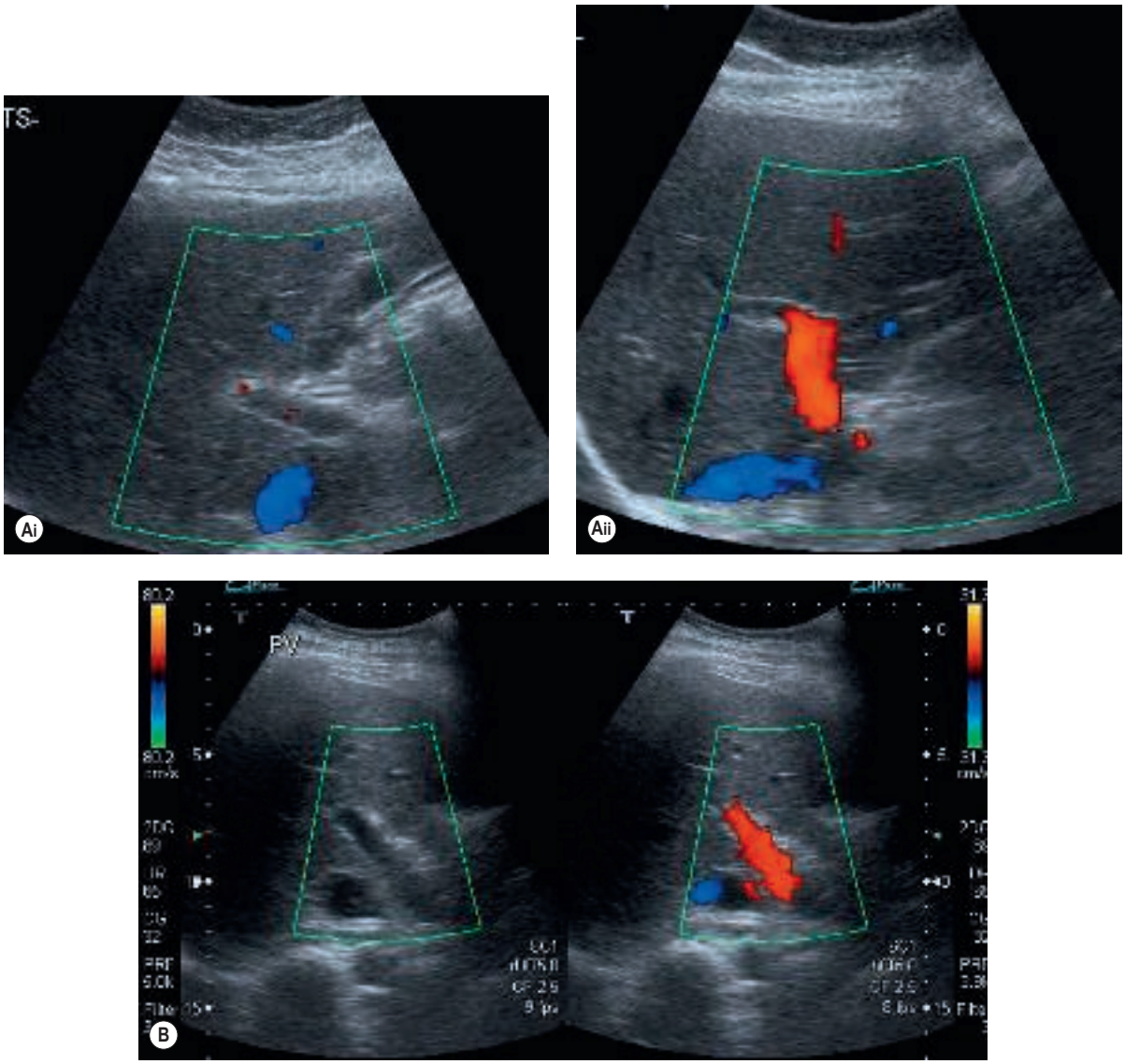

Fig. 1.10 • (Ai) The portal vein appears to have no flow when it lies at 90° to the beam – a possible misinterpretation for thrombosis. (Aii) When scanned intercostally, the vein is almost parallel to the beam and flow is easily demonstrated. (B) Too high a PRF results in the false appearances of no flow in the left image. Reducing the PRF demonstrates flow in the right portal vein (RPV) on the right image.

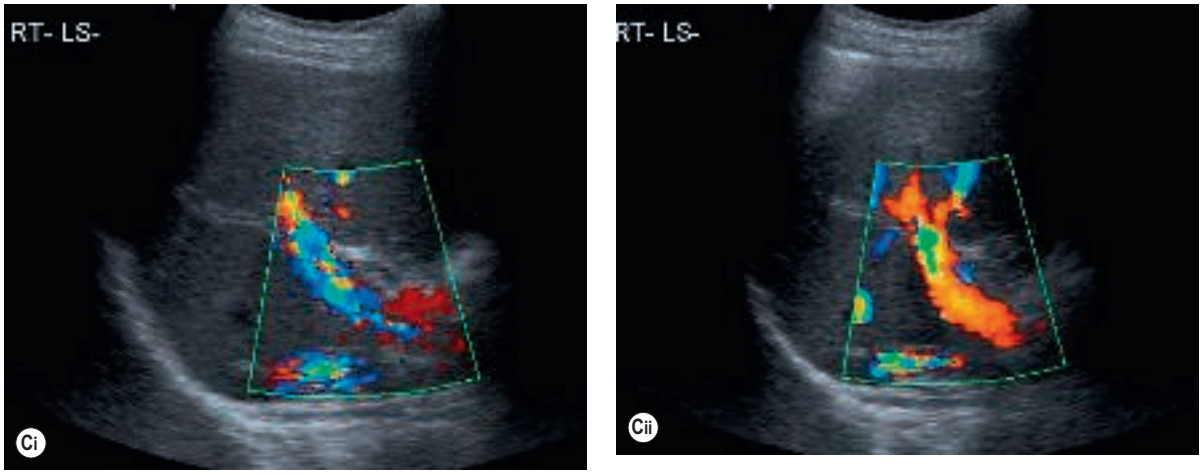

Fig. 1.10, cont'd • (Ci) This portal vein looks blue due to a low PRF and aliasing, which could be mistaken for reversed flow. (Cii) Reducing the PRF displays normal hepatopetal flow in red.

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

1. Ensure the angle of insonation between the vessel and the transducer is <60°. Colour and pulsed Doppler are highly angle dependent.
2. Ensure the Doppler gain is set at the correct level (colour and pulsed Doppler gain settings should be just below background noise level)
3. Ensure the Doppler power/output setting is sufficient
4. Ensure the PRF is set correctly. A low PRF ('range' or 'scale' setting) is required to pick up low velocity flow
5. Ensure the wall thump filter setting is low (if the setting is too high, real low velocity flow is filtered out)
6. Use power Doppler, which is more sensitive and is not angle dependent
7. Reduce the field of view and enlarge or zoom the vessel in question to give yourself the best chance of seeing and sampling flow from small vessels
8. Know the limitations of your machine. Machines differ in their ability to detect low velocity flow
9. If in doubt, test it on a reference vessel you know should contain flow

ADDITIONAL IMAGING MODES

Tissue harmonic imaging

Tissue harmonic imaging processes the harmonic frequency (usually twice the fundamental, transmitted frequency) by using pulse inversion. The reflected beam consists of the fundamental (transmitted) frequency together with diminishing amounts of harmonic frequencies. Using the harmonic has the effect of reducing artefact, improving spatial resolution and consequently the conspicuity of structures.[1,2] Different manufacturers have different ways of employing this mode, and therefore the results can differ from machine to machine. In some cases the dynamic range may be reduced, or the penetration impaired, so it is useful to be familiar with both fundamental and harmonic modes on your machine to get the best from the examination.

Compound imaging

There are two types of ultrasound compound imaging. The first, spatial compound imaging, insonates the tissues from several different angles. Theoretically, this enables the beam to be perpendicular to the various reflective surfaces for a greater proportion of the image, thus improving the definition around lesions and reducing artefact due to edge attenuation. It has been shown to improve