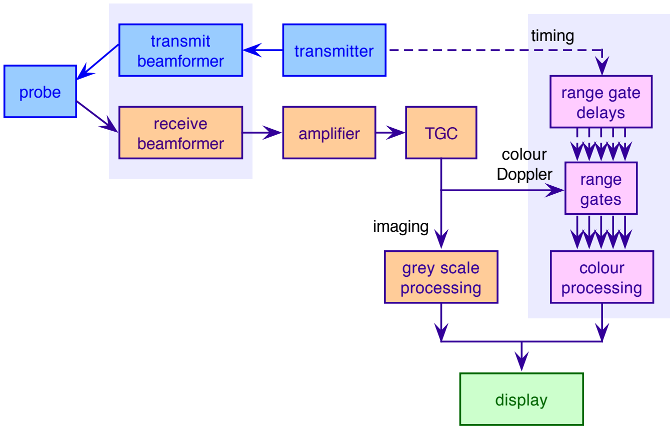

Figure 7.26 Block diagram showing colour Doppler processing incorporated into a grey scale imaging machine.

Note that there is no Doppler signal as such, and hence there is there is no audible output or spectral display.

We saw above that speed is essential for colour Doppler, both in acquiring the echo data and in processing and displaying it. Fast acquisition of the echo data is achieved by:

- using a small number of pulses (e.g. 8) for each line of sight,
- collecting echo information from many range gates at the same time,
- restricting the colour information to the colour box and
- making the colour box relatively narrow.

As discussed above, fast processing and display is achieved by calculating just three parameters for each sample volume. What do these three parameters mean and how are they used by the machine to determine what is displayed?

The mean (or average) Doppler shift is the most important as it determines the colour displayed at each point in the colour image. It is *proportional* to the mean blood velocity within the sample volume but it also depends on the Doppler angle at that point.

By convention, red colours are used when flow is towards the probe and blue when flow is away from the probe. As the colour bar on the machine's display shows (see Figure 7.27), the colour varies to indicate the amount of Doppler shift, ranging from dark shades of red and blue for low velocities to lighter shades for high velocities. Areas where flow is absent or too slow to be detected are black.

The range of Doppler shifts that can be measured and displayed is constrained by the Nyquist Limit (half the Doppler PRF), just as it is for spectral pulsed Doppler.

Figure 7.27 The colour bar shows the range of colours used to display the various Doppler shifts. Colours above the baseline correspond to flow towards the probe, as in the spectral display. Note also the grey scale bar to the left of the colour bar (arrow); this is related to the tissue/blood discrimination function.

Note that the velocity values displayed at the top and bottom of the colour bar indicate what the blood velocity *would be* at the Nyquist limits *if the Doppler angle was 0°*. It is important to recognise that these values are incorrect and of no real use if the Doppler angle is not 0°.

The second parameter, the "variance" of the Doppler signal, is a measure of spectral broadening. In most colour Doppler applications it is not displayed, although it is used in the tissue/blood discrimination function as discussed shortly. In echocardiography, on the other hand, areas of unusually large variance (i.e. areas with increased spectral broadening) are highlighted in the display using an additional colour, usually green (see Figure 7.28).

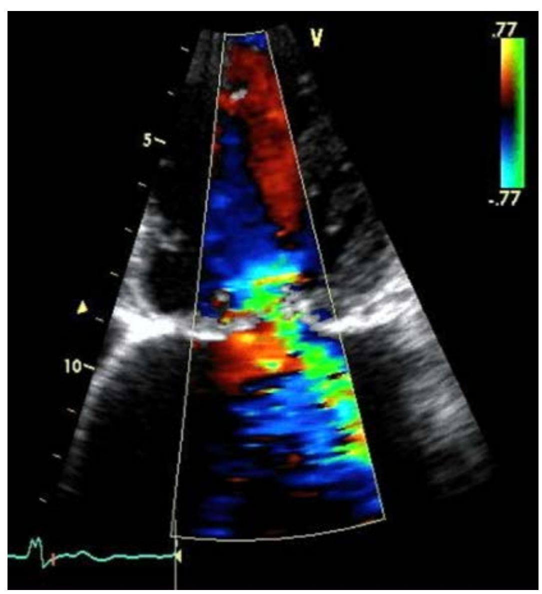

Figure 7.28 A colour Doppler image of the heart showing the use of variance (displayed in green) to highlight areas with increased spectral broadening. This is likely to be caused by turbulence.

The third parameter is the Doppler signal power. This is simply a measure of how strong the Doppler signal from each sample volume is. Like the variance, it is used in the tissue/blood discrimination function. In addition, the power is the parameter that is colour-coded and displayed in a specialised version of colour Doppler known as "power mode" colour Doppler. This will be discussed shortly.

Figure 7.29 is a block diagram showing the colour Doppler processing in more detail.

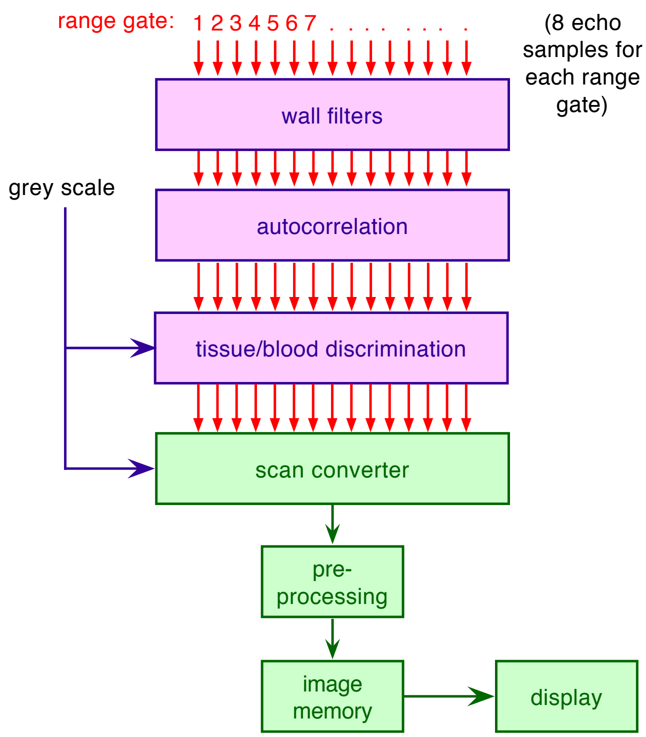

Figure 7.29 Block diagram showing in more detail the colour Doppler processing and image formation.

With reference to Figure 7.29, let us walk through the colour processing for a single range gate.

The 8 echo samples from the range gate are first wall-filtered to remove, as far as possible, any Doppler signals caused by moving tissues.

Unfortunately the colour Doppler wall filter is less effective than the pulsed Doppler wall filter because it has far less data to work with (just 8 samples). Thus Doppler signals from moving tissues will not be completely eliminated, and they will need to be suppressed later in the processing (specifically by the tissue/blood discrimination function).

Following the wall filter, the echoes are processed using the autocorrelation function to yield the three Doppler parameters discussed earlier – the mean Doppler shift, variance and power.

As with spectral Doppler, quadrature processing is used to determine whether flow is towards or away from the probe.

In the tissue/blood discrimination processor the machine analyses these three Doppler parameters, together with the grey scale echo amplitude at the same point, to determine whether the display should show grey scale (i.e. tissue) or colour (blood flow) at that point.

If the machine determines that the range gate has sampled moving blood and produced valid Doppler information then the mean Doppler shift will be displayed. If it does not, then the grey scale echo will be displayed in the normal way and the colour information for that point will be ignored.

How does the tissue/blood discrimination function work? First the machine assesses the strength of the grey scale echo. If it is stronger than a preset threshold value then the decision is made that tissue is present at that point in the image and so the grey scale information is displayed.

The threshold value for this "grey scale priority" (or "tissue priority") function is preset by the machine, but it can be adjusted by the user. Its value is displayed as a horizontal line on the grey scale bar located next to the colour bar, as shown in Figure 7.27. If the grey scale threshold is increased then stronger grey scale echoes will be required to override the display of colour. If it is decreased then lower level grey scale echoes will override the colour. If the grey scale echo is below the threshold value then the tissue/blood decision is based on the three measured Doppler parameters instead.

Before the colour image is stored in the memory the preprocessor fills any gaps and smooths the image. Persistence may also be used to improve the appearance of the colour image.

In summary, colour Doppler is a valuable and widely used modality. Its obvious strength is the two-dimensional display of Doppler information.

Its applications include:

- locating vessels;
- guiding the placement of the sample volume for a pulsed Doppler examination;
- identifying interconnections between vessels;
- mapping the relationship of vessels to organs;
- assessing the vascularity of a region (e.g. around a suspected malignancy);
- highlighting areas where the blood flow is potentially abnormal.

Colour Doppler also plays a major role in echocardiography.

However, we have seen that colour Doppler has a number of limitations, many of them related to the need to collect and process the echo data quickly for each colour image. The use of a small number of transmit pulses for each colour line of sight (e.g. 8) limits colour Doppler in a number of ways.

Compared with spectral pulsed Doppler, colour Doppler:

- is less able to detect slow-moving blood (so the velocity scale must be optimised at all times);
- is less successful in removing signals caused by moving tissues;
- measures the Doppler shift less accurately.

When the region of interest is relatively deep the colour Doppler frame rate may be quite low. This is clearly a disadvantage in a modality which we often use to assess highly dynamic cardiac and arterial blood flow. What can be done to improve the frame rate?

Generally the machine is designed to use a coarser "line density" (i.e. distance between lines of sight) when acquiring colour Doppler than for grey scale imaging. Some machines even offer the user a control allowing priority to be placed on either spatial resolution (finer line density) or frame rate (coarser line density).

Some machines have the capability to form several beams simultaneously, as discussed in chapter 12. If, for example, four beams are formed this will increase the frame rate by a factor of four.

Another parameter is the width of the colour box. The narrower it is the less lines of sight will be needed to create each image and so the frame rate will be higher.

What about the exposure of the patient's tissues to ultrasound? Colour Doppler exposures are generally somewhat higher than for grey scale imaging due to the increased transmit power needed to get adequate echoes from the blood. However, the exposure will be lower than for pulsed Doppler since the beam sweeps through a volume of tissue while in pulsed Doppler it is stationary. Note that when the colour box is made very narrow the exposure will be increased since it is concentrated in a smaller volume of tissue.

There are two further limitations of colour Doppler. First, it should be clear that colour Doppler is relatively complex and must be optimised for each examination.

While the machine's presets are often adequate, fine tuning of the controls is essential, especially in demanding situations (e.g. where the question is whether or not there is a trickle of blood flow through an occluded or nearly-occluded vessel.)

Secondly, the Doppler angle will usually vary throughout the image, making it virtually impossible to interpret the colours displayed except in a qualitative way. Figure 7.30 shows a dramatic example.

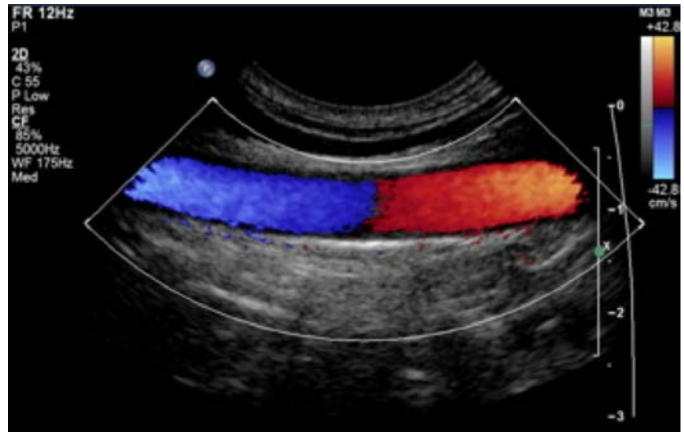

Figure 7.30 The colours vary continuously along the length of this straight vessel. The blood velocity is the same throughout; the changing colour is entirely due to the changing Doppler angle.

The inability to angle correct at each point and the other limitations of colour Doppler discussed above mean that as a modality it is complementary to spectral pulsed Doppler, not a substitute for it. When detailed information is needed (e.g. in an area identified on colour Doppler as being suspicious) pulsed Doppler must be used.

Power mode colour Doppler

The colour Doppler display can be complex and confusing at times due to the colour variations caused by changes in Doppler shift and flow direction (see Figures 7.30 and 7.31).

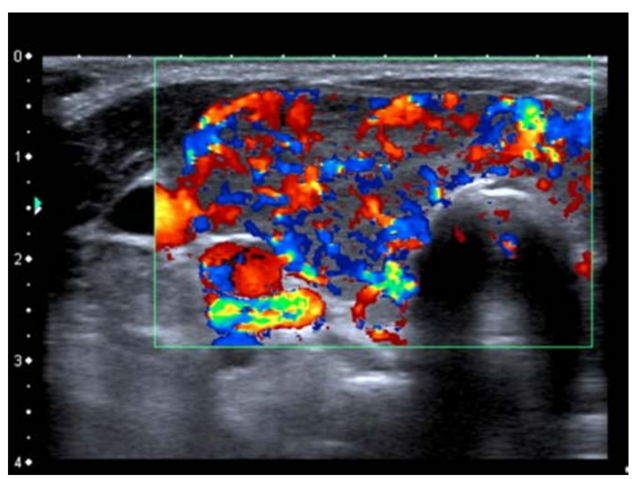

Figure 7.31 A colour Doppler image showing thyroid vascularity. Note how the variations in colour make it difficult to get an overall feel for the distribution and density of the vessels.

In some situations displaying the Doppler shift does not add value, in which case a simpler form of colour Doppler, "power mode" colour Doppler, can be more effective. Figure 7.32 shows two examples.

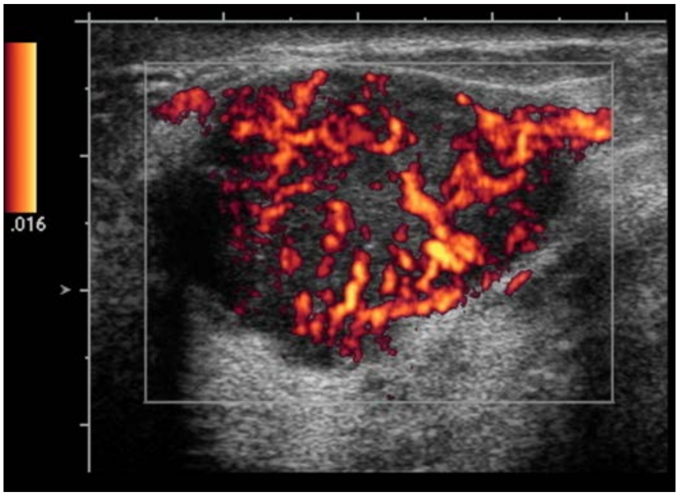

Figure 7.32 (a) A power mode colour Doppler image showing the vascularity in a breast mass. Compared to Figure 7.31 it is much easier to assess the distribution of the vessels in this image. Note the colour bar now shows how the colour varies with signal strength.

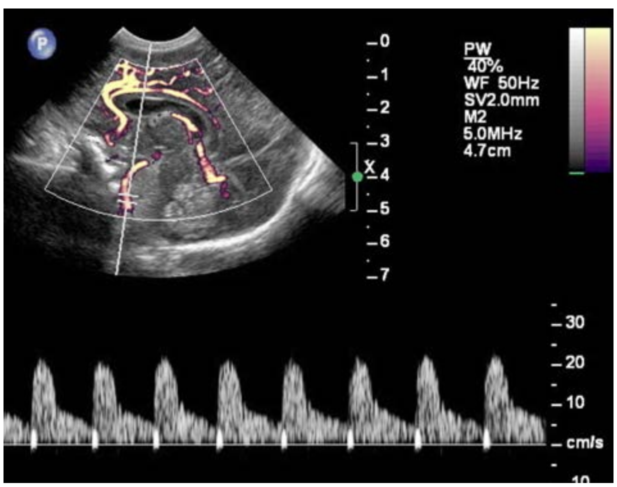

Figure 7.32 (b) Here a power mode colour Doppler image has been used to guide the placement of a pulsed Doppler sample volume in a neonatal brain.

How is the power mode colour Doppler image made? The processing is identical to that used for standard colour Doppler except that the colour displayed is determined by the Doppler signal power (i.e. how strong it is) rather than the mean Doppler shift.

In some machines it is possible to retain information about whether the flow is towards or away from the probe and so a directional power mode image can be displayed, as shown in Figure 7.33.

By good fortune, power mode colour Doppler has other advantages:

- Power mode colour Doppler is significantly more sensitive than standard colour Doppler, so it is the preferred mode when weak signals need to be detected and displayed. The reason for this is that it is easier for the machine to reliably determine the signal power than the mean Doppler shift when the echo signal is weak.
- With power mode colour Doppler, flow is detected and displayed even when the Doppler angle is 90° and there is no real Doppler shift. This is due to the presence of an artifact, "spectral mirror artifact", which will be discussed in chapter 8. Note that the flow would *not* be detected with conventional colour Doppler since the mean Doppler shift in this situation is zero.
- It is not affected by aliasing, except when the directional display is used.

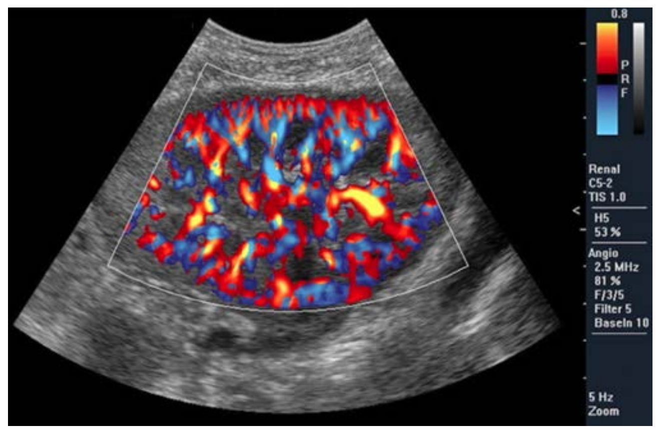

Figure 7.33 Directional power mode colour Doppler image showing the distribution of blood vessels in a transplant kidney.

Power mode colour Doppler is a specialised form of colour Doppler used in specific settings. Its advantages are that the display is simpler, the colour image does not drop out when the Doppler angle is 90° and it is possible to detect weak signals more reliably.

Doppler Tissue Imaging

Doppler Tissue Imaging (or DTI) is another specialised application of colour Doppler. The processing is identical to standard colour Doppler except that the wall filtering is reversed.

Doppler signals from moving tissue are retained and signals from moving blood are suppressed. The result is a colour coded image of moving tissues, as shown in Figure 7.34.