Review

Doppler colour flow mapping: technology in search of an application?

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SUMMARY Although Doppler colour flow mapping may considerably reduce the need for conventional pulsed Doppler examination, quantitative flow measurements (particularly by continuous wave Doppler) are still essential in the evaluation of many conditions such as aortic stenosis. Doppler colour flow mapping is an important addition to the accurate non-invasive evaluation of several haemodynamic disorders of the heart and, as the technology improves, the range of applications will undoubtedly increase. Any technique that provides additional diagnostic information, makes an examination easier and quicker to perform, and at the same time provides data in a more comprehensible format has surely found a niche.

Since commercial colour flow mapping became available early in 1984, many have questioned its additional value over existing conventional Doppler echocardiography techniques. This scepticism has been fuelled by the knowledge that, unlike conventional echo and Doppler technology which evolved in university research departments, colour flow mapping was mainly developed by manufacturers before its likely clinical benefit was known. Colour flow mapping adds approximately £30,000 to the cost of an echo/Doppler instrument—the price of a small, conventional echo machine. The undoubted visual appeal of colour flow mapping must not be allowed to overshadow a consideration of its cost effectiveness.

The technology

The mean velocity and direction of blood flow in the scan plane are colour coded and these data are superimposed in real time on to the cross sectional ultrasound image to produce a spatially oriented map of blood flow. This can be correlated with the anatomical information from the conventional ultrasound image. The colour coded data on blood flow may also be superimposed on to an M mode ultrasound recording enabling flow to be temporally correlated with mechanical intracardiac events. By convention, blood flow away from the transducer is coloured blue with an increase in brightness or change in hue for the higher velocities. Flow towards the transducer is displayed as red with higher velocities being registered by increasing brightness or changing hue through to yellow. The exact colour system depends both on the map selected and the instrument used.

The technique uses a modification of pulsed Doppler technology—autocorrelation—to acquire data on mean blood velocity and direction down a selected number of image scan lines. The number of data points or sample volumes on each line, and hence the axial resolution of the instrument, can vary from under 100 to over 400 depending on the manufacturer. Figure 1 shows the autocorrelation principle.

Each line of Doppler data must be sampled several consecutive times to obtain data on flow and an image that are reliable. It is impossible to do this for each of the 100 or so lines in an image, to perform up to 400 flow calculations per line, and still achieve a frame rate which will produce a diagnostic moving image. This is a particular difficulty in infants and children in whom the heart rate may be very high. To achieve a compromise on the number of scan lines used for colour flow data, the width or sector angle of the

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colour image may be reduced to approximately 30° or 45° and flow data can be collected on alternate scan lines. Inevitably, this reduces the spatial resolution.

Ultra high-speed microprocessors have improved the processing speed of the flow calculations so that frame rates of, for example, 14 Hz at 16 cm over a 45° colour flow sector arc are now obtainable. Most conventional cross sectional images are displayed at 30 Hz over a 90° sector arc—more than double the colour flow frame rate. Again, some manufacturers have been more successful in achieving acceptable frame rates than others and this is an important factor in evaluating equipment. Low frame rates are distracting, causing flicker in a real time image so that important information may be missed.

Some manufacturers have incorporated a digital cine-loop image memory system into their instruments. This feature, which allows frame by frame replay and examination of high quality image data, is useful for analysing complicated or rapidly changing flow patterns or when copy of a precise flow event is required.

When conventional Doppler techniques are used, the presence of turbulent blood flow is inferred if there is “spectral broadening” in the flow signal. Since colour flow mapping is only capable of displaying the mean blood velocity at any point, turbulence may not be detected by the use of spectral broadening. An alternative method, that of “variance mapping”, is therefore used. For this technique, the spatial and temporal statistical variation in blood flow velocity and direction around every colour flow pixel is measured. If there is a high variance in the flow signals, then the blood flow at that point is assumed to be turbulent. The colour green is then added, at that point, to the other colours that would have been displayed. Variance or turbulence mapping is an option on most instruments and, when used, areas of turbulent flow are easily recognised by the presence of green. Theoretically, it is possible to quantify the amount of variance, and hence the turbulence, present in a flow jet. In the future this may have important applications including the serial monitoring of valve function.

As with conventional cross sectional imaging, artefacts in colour flow images may arise as a result of poor insonation between the transducer and the heart. In about 20% of adults interference by the lungs and ribs may cause a “noisy” colour display that detracts from the image quality and the diagnostic information. A distracting artefact that is specific to some colour flow instruments is widespread coloration of tissue areas of the image. These areas should only be displayed in grey scale because they do not contain moving blood. However, if these tissue areas (valves, myocardium) are themselves moving, they may also generate a Doppler shift which the instrument then colour codes accordingly. This artefact has been reduced in some instruments by the use of a subtraction processing algorithm that only displays colour data in non-tissue areas and also by a filtering system based upon a “moving target indicator principle”.

Since colour flow mapping is essentially a pulsed Doppler system, it too is limited by the maximum flow velocity that can be detected without aliasing. In fact, the velocity at which aliasing occurs is usually considerably lower with colour flow mapping than with conventional pulsed Doppler. Aliasing causes the ambiguous display of multiple colours in the flow jet. This is often described as a mosaic appearance. In theory, the fact that aliasing occurs at relatively low blood velocities (in relation to the transducer) is a disadvantage. In practice, this phenomenon is quite useful. Aliasing is very easy to identify. The mosaic appearance draws the eye to areas of higher and possibly turbulent blood flow so that abnormalities are usually easy to detect. Figures 2 and 4 give examples of aliasing.

It is important that the instrument displays the velocity and direction of blood flow in relation to the transducer. For example, an aortic regurgitant jet may be moving slightly away from the transducer when viewed in the parasternal long axis view. It will therefore be coloured blue with some aliasing through to red, depending on the relative velocity (fig 2). If the same jet is viewed from an apical position it will now be moving towards the transducer with a

![Velocity sample points](image)

Fig 1 Autocorrelation method for flow estimation. Several points down selected scan lines are sampled and the received frequency waveform or phase shift is compared against a template of the transmitted frequency for each sample point. Frequency or phase shift templates for approximately 16 ranges of velocity and direction are stored within the instrument and the received data are matched to these templates to obtain an estimate of the mean flow velocity and direction. The mean flow velocity estimate is improved by increasing the number of times each scan line is sampled.
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Fig 2  Diastolic parasternal long axis colour flow image showing aortic regurgitation (AR). In this plane the regurgitant jet was directed inferiorly away from the transducer and was therefore mainly coded as blue. Because the relative flow velocity was high and the jet was turbulent there was some aliasing through to red and yellow. The jet was broad and extended past the mitral valve to the posterior left ventricular wall. This was graded as moderate aortic regurgitation. AO, aorta; LA, left atrium; LV, left ventricle; RVOT, right ventricular outflow tract.

Fig 3  Parasternal short axis image of flow through a small muscular ventricular septal defect (in the anterior septum) (IVS) into the right ventricle. The defect could not be visualised on cross sectional imaging without colour flow guidance, and the flow could not be readily detected by conventional Doppler. LVPW, left ventricular posterior wall. See legend to fig 2 for other abbreviations.
higher relative velocity. In this case the jet will be coloured red; however, there is likely to be multiple aliasing through to blue so that the flow jet will have a mosaic appearance. If a variance map is selected, then green will also be seen within the regurgitant jet (in either view) indicating that it is turbulent. This dependence on the relation between the direction of the flow jet and the transducer may be confusing at first. Future systems will evaluate the jet direction and display the flow colours that are dependent upon the true and not the relative blood velocity.

Applications

As with all Doppler techniques, colour flow mapping requires a good understanding of, and ability to perform, conventional ultrasound imaging. No real additional skill is required to obtain satisfactory colour flow images and the standard cross sectional imaging planes are used. The technique is at present qualitative rather than quantitative and it is unnecessary to "line up" with the flow as with conventional Doppler. Ease of use has been described as one of the advantages of this technique, though many manufacturers have made their colour flow instruments unnecessarily complicated and difficult to use. This may make this advantage difficult to realise. While there are many possible options for processing and display of colour flow data, in practice only a few of these are used and in many cases the instrument controls could be simplified. It would be more satisfactory for instruments to concentrate on those options that are known to be clinically useful.

The first commercial colour flow instruments were less sensitive than conventional Doppler technology. However, current instruments are just as sensitive. Continuous wave Doppler, with a dedicated Doppler transducer rather than an imaging transducer, remains the most sensitive technique. In practice, because colour flow mapping surveys the field of view, small elusive jets are comparatively easy to detect. These small jets may be missed by continuous or pulsed wave Doppler without detailed and time consuming searching.

In patients with multiple ventricular septal defects one or more of these may be missed by conventional Doppler. Because the eccentric jets of small ventricular septal defects are almost always of high velocity and turbulent, they are usually easy to find within the colour flow scan plane because they cause aliasing (mosaic pattern) and variance (green colour). Conventional continuous wave examination to record the jet velocity may then be performed, guided by the colour flow map. Figure 3 shows flow through a small muscular ventricular septal defect.

The situation may be similar in patients with prosthetic valves, where regurgitant jets (valvar or paravalvar) are often very eccentric and difficult to display by conventional Doppler ultrasonography. Confusing colour flow artefacts may arise from the opening and closing of the prosthesis and, in addition, shadowing by the prosthetic valve may make it difficult to detect regurgitant jets in some imaging planes. There are, however, encouraging reports suggesting that assessment of prosthetic valves is quicker and more accurate by colour flow mapping than by conventional pulsed Doppler.

Regurgitant lesions in native valves are easy to detect with colour flow mapping, and several studies have reported a high sensitivity and specificity. Measurement of severity, with angiography as the reference standard, has, however, been less successful. Superficially, angiography and colour flow mapping seem to provide similar types of flow images. The source data are, however, very different. With angiography, the severity of regurgitation is usually graded qualitatively by assessing the extent of opacification and clearance time of the contrast medium from the receiving chamber. Colour flow mapping on the other hand shows the spatial extent of the regurgitant jet velocities. Since the two techniques are measuring different variables, often under different physiological conditions, it is not surprising that the correlation is disappointing.

Several measurement techniques for colour flow have been proposed including planimetry of the area of the regurgitant jet, measurement of its length, and also the width near its origin. Unfortunately, all these variables are influenced by several factors including the sensitivity of the instrument, gain settings, view used, the driving pressure of the regurgitant jet, and the precise part of the cardiac cycle in which the measurements are made. Despite these problems, the technique is more sensitive than auscultation (not always an advantage), much easier to perform than angiography, and can usually grade regurgitant lesions into the clinically relevant categories of mild, moderate, or severe.

One of the major limitations of conventional Doppler is that it does not enable the spatial orientation of blood flow jets to be seen as colour flow mapping does. For example, in cases of combined mitral stenosis and aortic regurgitation it can be difficult to separate the two diastolic flow jets in the left ventricle by conventional Doppler ultrasonography. Also, in patients with prosthetic valves and after balloon dilatation of stenotic native valves the flow patterns may be very complex and will often consist of multiple jets that could not be discerned or evaluated by pulsed Doppler. Patients with congenital cardiac lesions may also have complex multiple intracardiac shunts. Figure 4 shows severe mitral regurgitation. The spatial extent of this regurgitant jet would have been very difficult to evaluate by
**Fig 4** Parasternal long axis systolic frame of severe mitral regurgitation (MR) secondary to rheumatic valve disease. The anterior mitral valve leaflet was prolapsing behind the immobile posterior leaflet. The jet was therefore directed posteriorly along the wall of the left atrium and bounced back anteriorly (off the posterior left atrial wall anterior to the descending aorta). In the short axis plane, this same jet fanned out along the left atrial wall both medially and laterally and was approximately 3 cm wide. The close proximity of this jet to the atrial wall and its complex shape would have been difficult to identify by conventional pulsed Doppler. Acceleration of blood within the left ventricular cavity (proximal to the regurgitant orifice) was indicated by aliasing of the colour through to yellow and red. The jet velocity within the left atrium was considerably higher and therefore caused multiple aliasing, with a mosaic of colours, as it travelled posteriorly. When the jet bounced anteriorly it had spread out, lost energy and velocity, and so aliasing was not as prominent. The jet was therefore coded mainly yellow and red as it moved back towards the transducer. See legend to fig 2 for abbreviations.

**Fig 5** Considerable left to right shunting through a secundum atrial septal defect (ASD) seen in a modified apical four chamber view. As blood entered the left atrium from the superior pulmonary veins, traversed the atrial septum (and mitral valve), and crossed the tricuspid valve from the right atrium, it was moving towards the transducer and therefore was coloured red and yellow. The size of the shunt was assessed by examining the size of the flow jet within the right heart. The demonstration of transatrial shunting was so convincing that invasive investigations were not necessary before operation. In addition, it was possible to calculate the pulmonary artery systolic pressure from a tricuspid regurgitant jet and this confirmed the absence of important pulmonary hypertension. See legend to fig 2 for abbreviations.
conventional pulsed Doppler. Colour flow mapping may also assist and simplify quantitative measurements of flow velocity made with conventional Doppler. For example, it is very easy to identify the point of highest flow velocity on the colour flow map and then position the pulsed Doppler sample volume accordingly without making a search for the highest velocity point by repeatedly moving the pulsed Doppler sample volume in what amounts to a blind mapping procedure.

The spatial direction of a flow jet is almost impossible to predict accurately by imaging and conventional Doppler. However, if reliable quantitative measurements are to be made the jet direction must be known so that the Doppler beam can be orientated appropriately. There are many instances in which colour flow mapping may help to reduce the angle of incidence between the jet and the Doppler beam and therefore improve the accuracy of velocity and derived haemodynamic data. Examples include aortic stenosis, mitral stenosis, prosthetic mitral valves, ventricular septal defects, and tricuspid regurgitation. In tricuspid regurgitation the prediction of pulmonary artery systolic pressure can be improved if the continuous wave Doppler beam is aligned, with colour flow guidance along the direction of the tricuspid regurgitation. Some instruments, which have the facility to perform continuous wave Doppler and colour flow mapping using the same transducer, allow for the angle to be corrected. It must be remembered, however, that flow jets are three dimensional and correction is possible in one plane only. Therefore, it is better practice to minimise any angle of incidence by adjusting the position of the transducer and checking the jet direction in two orthogonal imaging planes.

Despite the advantages of colour flow Doppler, some experienced echocardiographers still feel that it provides them with little additional information over and above conventional Doppler. On the other hand, many of those who now perform routine Doppler examinations have restricted experience and find colour flow mapping easier to perform and understand. Cardiologists or surgeons who are unfamiliar with conventional Doppler spectral recordings find colour flow images easier to assess and so their use may reduce the need for invasive investigation of flow abnormalities before operation. Figure 5 shows a secundum atrial septal defect in which considerable left to right shunting was clearly seen and for which further investigations before surgical closure were deemed unnecessary.

Most centres that have experience of colour flow mapping agree that the technique is especially useful for rapid screening to establish normal flow and that it reduces the time spent on echocardiographic investigation. During the learning phase with colour Doppler we were able to increase the echocardiographic workload by 60% without an increase in staff. In busy departments, this advantage alone goes a long way towards justifying the use of the technique.

Transoesophageal echocardiography is a newer technique that is attracting much attention. When it is performed on conscious patients it is important to keep the examination time as short as possible. For this reason, colour flow mapping is now considered an essential adjunct to transoesophageal echocardiography.

References

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