ARCHIVES OF ACOUSTICS
9, 1-2, 205-214 (1984)

PULSED AND CONTINUOUS WAVE DOPPLER IN HEART LESIONS

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Valvular obstructions and regurgitations can be diagnosed with either pulsed or CW Doppler. By recording the maximum velocities with CW Doppler the pressure drop across obstructions and across regurgitant valves can be obtained, permitting assessment of the severity of obstructions and providing information on the right heart pressures. Congenital lesions can be diagnosed, obstructions assessed and shunt size indicated.

1. Blood flow velocities

Flow velocity across the various valves in the heart can be recorded with Doppler when a small angle is obtained between ultrasound beam and velocity. With larger angles the velocity will be underestimated (at 25° the underestimation will be 9 per cent). With pulsed Doppler the velocities are recorded in a small area at a certain variable depth. The advantage is that a flow signal can be localized in depth, the drawback that there is a limit to the velocities that can be recorded. With continuous wave (CW) Doppler velocities are recorded all along the beam, a flow signal cannot be localized in depth, but there is no limit to the velocities that can be recorded.

The audio signal from the Doppler contains the frequency shifts from the blood flow that is recorded. The higher the velocities the larger the frequency shift will be and the higher frequency will be characteristic of the audio signal. The audio signal will also be of the higher frequency the smaller the angle to the velocity. The signal can therefore be used to find high velocities and the positions and beam directions with the smallest angle to flow.

Obstructions to flow cause an increase in the flow velocity across an obstruction. This increase in velocity is related to the pressure drop across the obstruction, and the relationship is described by the Bernoulli equation. By inserting the mass density for blood and conversion to mm Hg a simple formula is obtained where the pressure drop is calculated from 4 times the maximum velocity squared. From the maximum velocity recorded across obstructions, the pressure drop has been obtained in valve stenoses, across prosthetic valves and regurgitant valves [1—11]. In ventricular septal defects it can be used to obtain the pressure difference between the two ventricles [12].

In most cases the velocity prior to an obstruction is so low that it can be ignored in the calculation. But if it increases it should be considered, and the pressure drop is then obtained by subtracting the squared velocity prior to the obstruction from the velocity recorded past the obstruction squared.

When good Doppler signals with mostly high frequencies are obtained, the maximum velocity can be recorded either with a maximum frequency estimator or with spectral analysis. With the estimator the maximum velocity during systole or diastole is seen as a single line, with spectral display the various frequencies present in the Doppler signal at one time are shown. With weak Doppler signals or signals which contain only few high frequencies, these are more easily recorded with spectral analysis. Less than optimal Doppler signals can occur from large depths or when a high velocity jet is only partly recorded or in mild regurgitations. It is then more likely that the maximum velocity present will be recorded using a spectral display and underestimation of the maximum velocity and pressure drop less likely. The use of the audio signal to obtain a small angle to flow is therefore likely to cause less error than an attempt to correct for an assumed angle from the image.

The combination of Doppler with two-dimensional echo usually helps to make the examination quicker, and in some patients abnormal flow signals are more easily found. But the opposite also occurs, that these can be easier to find with a separate Doppler without imaging. This can partly be due to improved concentration and movement of the transducer when there is no image, and partly to better access and higher sensitivity with the smaller separate Doppler transducer.

2. Valvular obstructions

In mitral stenosis the increased flow velocity into the left ventricle in diastole is recorded toward the transducer at the apex, or flow direction may be slightly more medial. The velocity is highest in early diastole, it decreases more slowly than normal, and in sinus rhythm there is a second peak following the atrial contraction. The pressure drop can be calculated for 3-6 points during diastole, the course of the pressure drop can then be drawn and the mean pressure drop obtained. Fig. 1 shows mitral stenosis and mitral regurgitation in two patients, one in sinus rhythm and one in atrial fibrillation. The great variation in the mean pressure drop calculated with varying diastolic length can be seen, and this also illustrates the great variation in the pressure drop in mitral stenosis with changes in the heart rate.

When ultrasound and pressure measurements are carried out simultaneously, there is good correlation between the two methods [1, 2]. When optimum Doppler signals with a concentrated band of the highest frequencies are recorded, the calculated pressure drop can be almost identical to that recorded with pressure. In sinus rhythm the increase in velocity and pressure drop with atrial contraction may be more clearly seen in the velocity recording than in the pressure tracing, unless the left atrial, and not the pulmonary capillary venous pressure, is recorded [13].

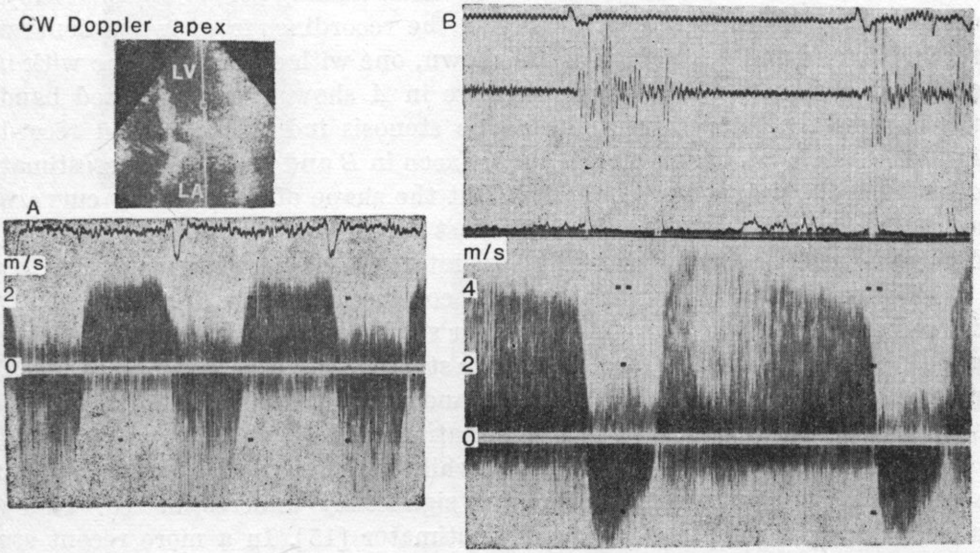

Fig. 1. When recording with CW Doppler from the apex the high velocity through the mitral orifice is recorded toward the transducer in diastole and mitral regurgitation away from the transducer in systole. In sinus rhythm there is a second peak following atrial contraction (*A*). In the patient with atrial fibrillation (*B*) there is still a pressure difference between the left atrium and ventricle even in a long diastole, indicating significant obstruction. The calculated mean pressure drop in *A* is 22 mm Hg, in *B* it varies with diastolic length, early diastolic pressure difference is 25 mm Hg and at end diastole it is 2 and 13 mm Hg for the two beats shown. Regurgitation is seen to start at mitral valve closure and it continues past aortic closure, lasting until the mitral valve opens again

The degree of obstruction at the mitral orifice also influences the course of the pressure difference during diastole. With more severe obstructions equalization of pressures occurs more slowly and this is seen as a slower decrease in velocity. The time it takes for the initial pressure drop to be reduced to half that value is easily measured directly from the velocity curve. Half the initial pressure drop will be where the maximum velocity is reduced to $v/\sqrt{2}$ or $v/1.4$. The pressure half-time increases with an increase in obstruction, it is less influenced by flow than the pressure drop is, and can therefore be used to assess the severity of obstruction, also when there is associated regurgitation [14].

The pressure half-time in normal subjects is less than 60 ms, in mild to moderate mitral stenosis from 100-200, and from 200 up to 5-600 with increasing severity of obstruction. It is especially helpful in patients with low pressure drop due to low cardiac output where a long pressure half-time will help to avoid underestimation of severity. Tricuspid stenosis can be diagnosed and assessed in the same way as mitral stenosis.

In aortic stenosis the best direction to the high velocity jet through the orifice can be from the suprasternal notch, the upper right sternal border or from the apex. The maximum velocity in the ascending aorta in normal subjects usually ranges from 1-1.7 m/s. In Fig. 2 the recordings from two patients with aortic stenosis and regurgitation are shown, one with severe and one with insignificant obstruction. The spectral curve in *A* shows a concentrated band of the highest frequencies from the aortic stenosis indicating a good recording from the aortic jet. This is not so clearly seen in *B* and possible underestimation of the velocity might be questioned. But the shape of the velocity curve with an early peak and low velocities in the last part of systole also indicates insignificant obstruction with practically no late systolic pressure difference.

The peak velocity gives the instantaneous peak pressure drop during systole. By calculating the pressure difference for some points during systole, the mean pressure drop can be obtained. In earlier studies good correlation with recorded pressure drops were found in children and young adults where good Doppler signals are easily obtained [4]. In older patients there was only moderate underestimation with good Doppler signals while with few high frequencies in the signal velocity and pressure drop was significally underestimated. This was a study using a maximum frequency estimator [15]. In a more recent study with the use of spectral display, correlation with recorded pressures was good also in older patients, there was a slight underestimation of the peak pressure drop and a moderate underestimation of the mean pressure drop [16]. The aortic jet could be reached in all, and the severity of obstruction was correctly assessed in all.

The shape of the velocity curve reflects the course of the pressure drop during systole and gives additional information about the severity of obstruction. In a study of more than 100 patients with aortic stenosis the time of the peak velocity in systole was early in all patients with mild obstruction, and when the time of the peak velocity was related to the left ventricular ejection time (LVET) a ratio of more than 0.54 was found in patients where surgery was indicated [15]. This was done using a maximum frequency estimator, with spectral display the peak velocity will be shown earlier in systole, due to less delay in the spectral recording. The severity of obstruction can therefore be assessed also if there are significant changes in flow accross the valve. With increased flow, as with associated regurgitation, there will be a relatively high velocity early in systole followed by a marked decrease, with severe obstruction and reduced flow the velocity may not be so high, but with less decrease during systole. The LVET is another useful indicator of the severity of aortic valve disease and it is easily measured from the amplitude of the Doppler signal (Fig. 2). By combining the pressure drop, the time of the peak velocity and the LVET a good assessment of the severity of aortic stenosis can be obtained [15].

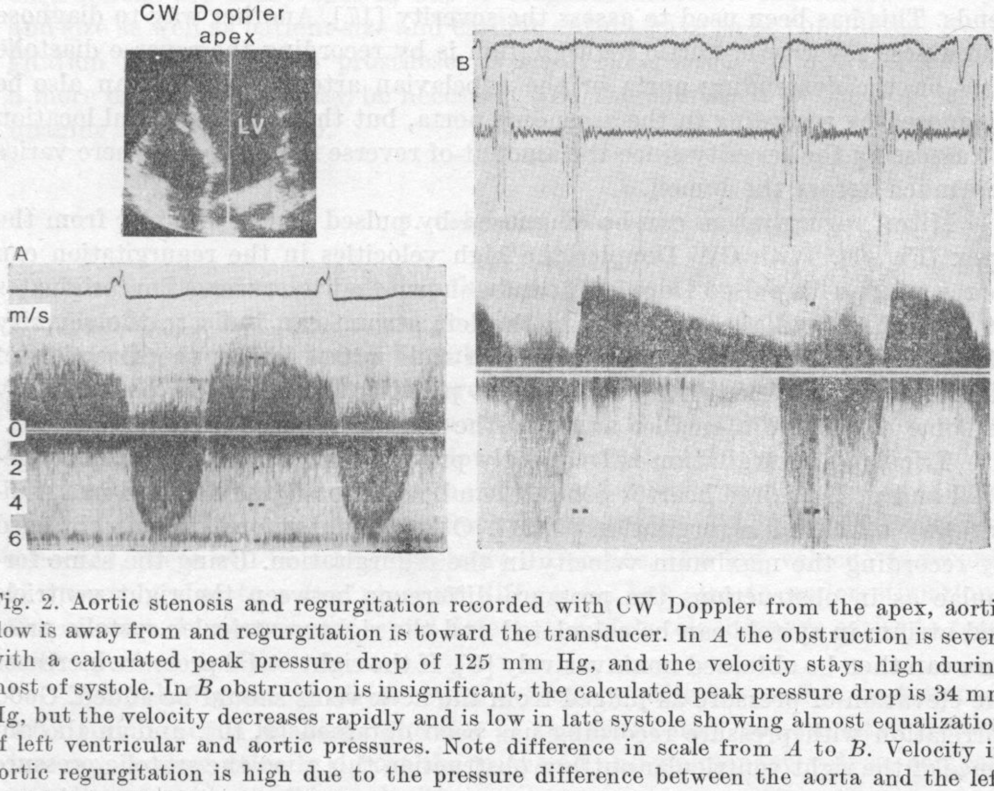

Fig. 2. Aortic stenosis and regurgitation recorded with CW Doppler from the apex, aortic flow is away from and regurgitation is toward the transducer. In *A* the obstruction is severe with a calculated peak pressure drop of 125 mm Hg, and the velocity stays high during most of systole. In *B* obstruction is insignificant, the calculated peak pressure drop is 34 mm Hg, but the velocity decreases rapidly and is low in late systole showing almost equalization of left ventricular and aortic pressures. Note difference in scale from *A* to *B*. Velocity in aortic regurgitation is high due to the pressure difference between the aorta and the left ventricle in diastole, and velocity decreases as aortic pressure falls. The amplitude curve below the phonocardiogram in *B* shows aortic valve opening and closure. Forward and regurgitant flows are continuous. Note the concentrated band of the high frequencies in the aortic stenosis in *A* which indicates that the jet is well recorded

3. Regurgitations

Doppler is a very sensitive method to diagnose regurgitations and this has clearly shown the lower sensitivity of the clinical diagnosis. Mild regurgitations cannot often be diagnosed clinically and even significant regurgitations can occasionally be present in the absence of a systolic or diastolic murmur.

The clinical diagnosis of mitral and tricuspid regurgitation can also be difficult when there is a systolic murmur due to another lesion.

Aortic regurgitation can be diagnosed by recording with CW Doppler toward the aortic valve, as shown in Fig. 2. With pulsed Doppler the high velocities in the regurgitation will not be recorded, there will be aliasing with the Doppler signal shown on both sides of the zero line [6], but the pulsed mode can be used to record how far down in the left ventricle the regurgitation extends. This has been used to assess the severity [17]. Another way to diagnose and assess severity of aortic regurgitation is by recording the reverse diastolic flow on the descending aorta or the subclavian arteries [18]. It can also be diagnosed by recording in the ascending aorta, but this is not a useful location for assessing the severity since the amount of reverse flow velocities here varies too much across the lumen.

Mitral regurgitation can be diagnosed by pulsed or CW Doppler from the apex (Fig. 1). With CW Doppler the high velocities in the regurgitation can be recorded, with pulsed Doppler it can be shown that the reverse flow originates at the orifice and the extension in the left atrium can indicate the severity [19, 20]. In the mitral valve prolapse or flail mitral leaflet the direction of the regurgitant jet may vary more and a parasternal transducer position may in some cases give a smaller angle to the regurgitation.

Tricuspid regurgitation is frequently present both in patients with congenital and with aquired heart lesions. It can be diagnosed and assessed in a simil ar way as mitral regurgitation [9, 21]. Other useful information is obtained by recording the maximum velocity in the regurgitation. Using the same formulae as in obstructions the pressure difference between the right ventricle and atrium in systole can be calculated and the right ventricular systolic pressure can then be obtained noninvasively [9]. If the right atrial pressure increases the elevation of pressure as judged from the neck veins should be added. Good correlation with pressure recording has been obtained [9, 10], and in the absence of the right ventricular outflow obstruction this gives the systolic pressure in the pulmonary artery.

Pulmonary regurgitation can also be more frequently recorded with Doppler than suspected from clinical findings, it is frequently present in patients with some degree of pulmonary hypertension, but also seen without this [22]. When there is no increase in diastolic pressure in the pulmonary artery velocity in the regurgitation is low, but it becomes higher when the pressure increases. From the maximum velocity in the regurgitation the pressure difference between the pulmonary artery and the right ventricle during diastole can be calculated and this is a sensitive method to detect increases in diastolic pressure in the pulmonary artery. In mild regurgitations the Doppler signal can be weak, and in mild tricuspid and pulmonary regurgitation the maximum velocities are far easier to record using spectral analysis than with a frequency estim ator

4. Prosthetic valves

Prosthetic valves usually cause some obstruction and Doppler can be used to assess this in the same way as for valvular obstructions. For both mitral and aortic valve prostheses both the course of the pressure difference and the mean pressure drop are useful to diagnose increased obstruction. Significant obstructions are easily shown, but to diagnose moderate increases valve type and size as well as patient size and cardiac output have to be considered. Regurgitation in aortic valve prostheses is easily diagnosed, in mitral prostheses a more careful search may be necessary and the combined use of Doppler and imaging can be of help.

5. Congenital lesions

The increased velocities in pulmonary stenosis can be recorded with CW Doppler from a low parasternal position in some cases, a higher one in others and in some from an apical or subcostal position. Calculated pressure drops correlate well with pressures recorded at catheterization [5, 6]. With pulsed Doppler the level of obstruction can be shown; if it is subvalvular the increase in velocity will be recorded below the valve.

In ventricular septal defects the maximum velocity can be used to calculate the pressure difference between the two ventricles. When a high velocity is recorded, there will be a large pressure difference. If a low velocity is recorded this may be due to a low pressure difference, but also to underestimation of the velocity. In ventricular septal defects the high velocities are easier to record with spectral analysis.

The velocity across atrial septal defects is quite low and is best recorded with simultaneous imaging. The size of the shunt may be estimated from the increase in flow velocity across the tricuspid and pulmonary valves, compared to mitral and aortic flow velocities.

The patent ductus arteriosus can be diagnosed either by recording flow into the pulmonary artery from a parasternal position, or reverse diastolic flow in the descending aorta below the level of the duct. When recording with CW Doppler up through the main pulmonary artery high velocities toward the transducer can be recorded throughout systole and diastole when there is no pulmonary hypertension. With pulmonary hypertension the velocity will be low and flow through the duct may be found only during part of the cardiac cycle.

In coarctations of the aorta increased velocity can be recorded with CW Doppler toward the descending aorta. The pressure drop can be obtained and is useful especially in the assessment following surgery.

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