

DOPPLER EVALUATION OF VALVULAR REGURGITATION #2

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INTRODUCTION

Some of the earliest uses for Doppler echocardiography were in detection of valvular insufficiencies. The first Doppler echocardiography studies of valvular regurgitation were, however, focused outside the heart. As early as 1971, it was demonstrated that retrograde blood flow could be detected during diastole in the subclavian arteries of patients with aortic insufficiency. At about the same time, certain abnormalities were detected in the jugular veins of patients with tricuspid insufficiency. Since then, there have been many studies using direct evaluation of the heart valves for insufficiency, and it is now becoming generally accepted that Doppler is a fairly sensitive and specific method for the detection of valvular insufficiency.

DOPPLER CHANGES IN VALVULAR REGURGITATION

Characteristics of Regurgitant Jets

Valvular regurgitation is defined as the presence of backwards, or retrograde, flow across a given closed cardiac valve. It should be realized by beginners that the terms "regurgitation" and "insufficiency" are synonyms and may be used interchangeably.

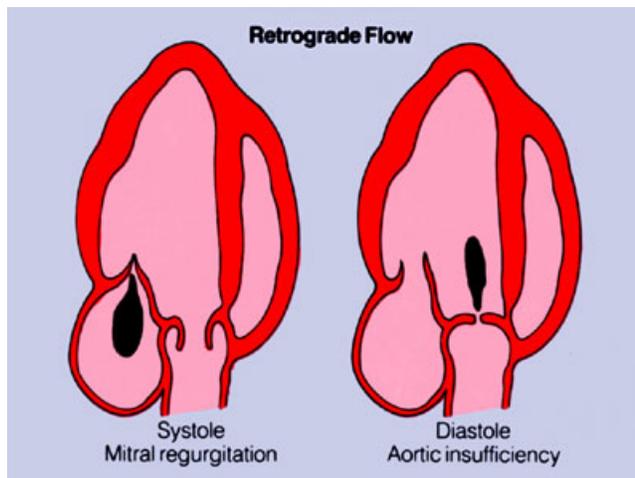


Figure 2.1 Valvular regurgitation is characterized by inappropriate retrograde flow during the cardiac cycle. The left panel demonstrates mitral regurgitation in systole, the right panel demonstrates inappropriate aortic insufficiency in diastole.

It is assumed that there is normally no flow backwards into the ventricles through the aortic or pulmonic valves in diastole. Similarly, there is no flow backwards into the atria across the mitral or tricuspid valves in systole. Thus, the first effect of regurgitation on blood flow through the heart is a change in direction.

Figure 2.1 demonstrates the abnormal direction of flow in the left heart for mitral and aortic regurgitation in systole and diastole respectively. Given the ability of Doppler echocardiography to detect the direction of blood flow, it seems ideally suited for assessment of valvular insufficiencies.

The second effect of regurgitation on cardiac blood flow is the creation of turbulence. Most valvular regurgitation is associated with some abnormality of leaflet coaptation. Regurgitant jets originate from small, irregular openings. They may be directed quite eccentrically and they are almost always turbulent. Regurgitant jets are made

up of many different velocities and complex flow patterns. These features are represented on the Doppler recording as spectral broadening, which is the graphic equivalent of turbulent flow.

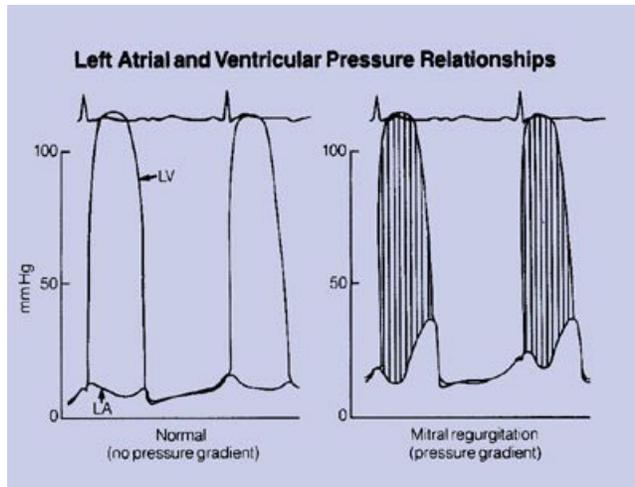


Figure 2.2 During systole, left ventricular pressure is greater than left atrial pressure (left panel). In the presence of mitral regurgitation, the flow communication between these chambers allows a high gradient to exist.

The third factor that characterizes the abnormal flow of a regurgitant jet is an increase in velocity, which is a result of a pressure gradient that exists across a regurgitant valve. For example, normal systolic pressure in the left ventricle is over 100 mmHg. At the same time, the pressure in the left atrium is very low and ranges from 2 to 12 mmHg. The left panel of **Figure 2.2** demonstrates these normal pressure relationships. Even though the pressure differences are great, no communication exists between the two chambers and no retrograde (or backwards) flow.

When mitral regurgitation is present, however, the abnormal communication between the left ventricle and left atrium in systole, and a pressure difference (or gradient) exists (**Fig. 2.2, right panel**). When the pressures within both the left atrium and ventricle are within normal ranges a gradient of 85 mmHg or more exists and produces retrograde flow into the left atrium. This flow takes the form of a high velocity regurgitant jet, as predicted by the Bernoulli equation described in detail in Unit 1.

As mitral insufficiency becomes worse and leads to chronic elevation of left atrial pressure, the systolic gradient between the left ventricle and the left atrium is reduced. In these cases, left atrial pressure may rise to very high levels.

Velocity Pressure Relationships

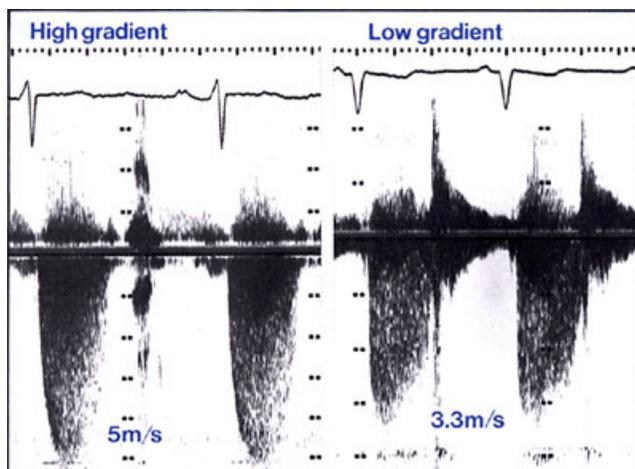


Figure 2.3 The gradient between the left ventricle and the left atrium in mitral insufficiency is reflected by the velocity of the Doppler spectral recording. A high gradient is seen in the left panel while a lower gradient is seen in the right panel. If systolic pressures are the same in both individuals, the recording on the right would suggest higher pressure within the left atrium.

Doppler echocardiographic findings are strongly influenced by the pressure gradients between chambers according to the Bernoulli equation. This relationship is simplified to:

$$p_2 - p_1 = 4V^2$$

and is very important to understand for further appreciation of the wealth of information available in the Doppler velocity spectral display. The Doppler spectral recordings from mild and severe mitral regurgitation are shown in **Figure 2.3** to illustrate this point further. As describes above, small degrees of mitral regurgitation produce very high pressure differences between the left ventricle and the left atrium. Minor degrees of regurgitation will, therefore, result in very high velocity jets as a consequence of these great pressure

differences. Severe mitral regurgitation results in relatively smaller differences between the two

chambers. These smaller pressure gradients result in relatively lower velocity jets. This, of course, assumes that the systolic pressures within the ventricles are similar in both situations.

Thus, the severity of valvular regurgitation is not reflected in an increase in the velocity of the regurgitant jet as detected by Doppler echocardiography. As will be demonstrated in more detail later, the inverse is usually the case. With greater degrees of regurgitation, pressures will rise in the chamber receiving the regurgitant volume leading to a general decrease in the velocity of the resultant Doppler spectral recording.

Another important implication of the increase in velocity in regurgitant jets is that almost all degrees of valvular regurgitation result in a velocity increase above 1.5 m/sec. The practical effect of these higher velocities on Doppler recordings is that aliasing is almost always produced in pulsed wave Doppler interrogations of valvular regurgitation. This results in the fact that pulsed Doppler echocardiography may be used for detection of the location of the turbulence (or area of the jet) but not its peak velocity.

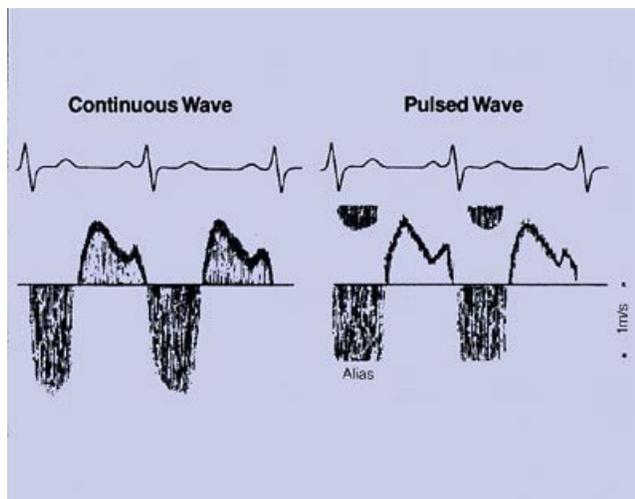


Figure 2.4 Schematic diagram of a mitral regurgitant jet recorded from the apex. Most regurgitant jets result in velocities that exceed 1.5 m/sec and require CW Doppler to record the full spectral velocity profile (left panel). PW Doppler recordings of mitral regurgitation are always aliased (right panel).

This is demonstrated in the idealized drawing of spectral recordings resulting from a mitral insufficiency jet shown in **Figure 2.4**. The left panel shows systolic turbulent flow moving away from a transducer positioned at the apex. The full profile is recorded by CW Doppler. When the same jet is interrogated by PW Doppler, aliasing occurs.

The Spatial Location of Abnormal Jets

Appreciation of the three main features of regurgitant jets described above (i.e., abnormal direction, turbulence, high velocity) is crucial to the success of the Doppler beginner. In addition, it is important to realize that a regurgitant jet may be directed anywhere within the spatial volume of the receiving chamber (**Fig. 2.5**). The jet may also vary in size from small to large.

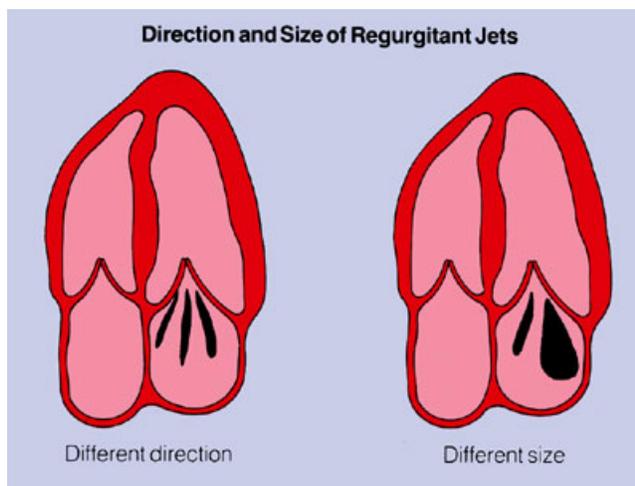


Figure 2.5 Left panel demonstrates that regurgitant jets may be directed in just about any direction; right panel shows that the area of the jets may also be widely different, from very small to very large. A complete PW Doppler examination requires tedious mapping throughout the image for detection of abnormal flow.

The spatial location and general size of a jet is best assessed using PW Doppler echocardiography, even though aliasing invariably occurs as a result of the high velocities encountered (**Fig. 2.6**). This makes recognition of the complete abnormal flow profile of a regurgitant jet almost impossible by PW Doppler alone. In the pulsed spectral tracing of aortic insufficiency shown, the spectral recording is filled from top to bottom in diastole and recognition of the complete spectral profile is quite difficult. Thus, CW

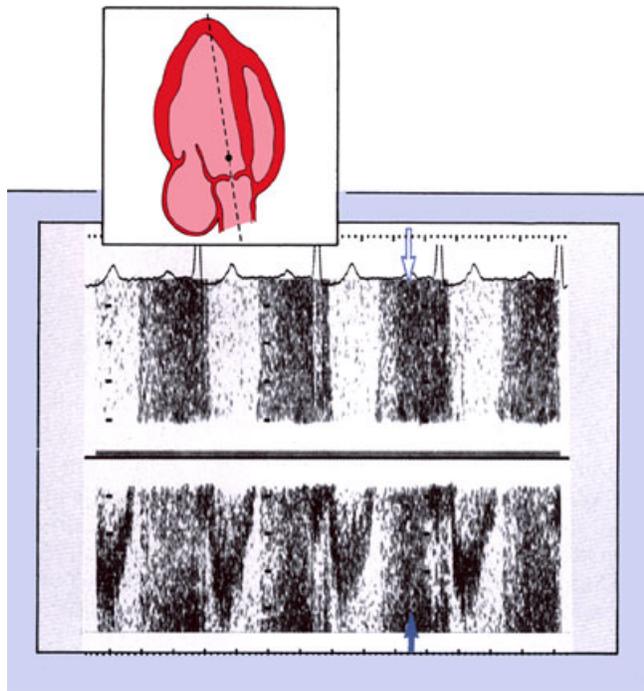


Figure 2.6 PW Doppler spectral recording of aortic insufficiency. Flow is toward the transducer and aliasing occurs (open arrow) with placement of the higher velocities at the bottom of the spectral tracing (closed arrow).

that the results of Doppler and cineangiography will ever correlate exactly because the two methods are so fundamentally different in the presentation of data concerning valvular regurgitation. Cineangiography, of course, requires invasive cardiac catheterization and is based upon the dilution

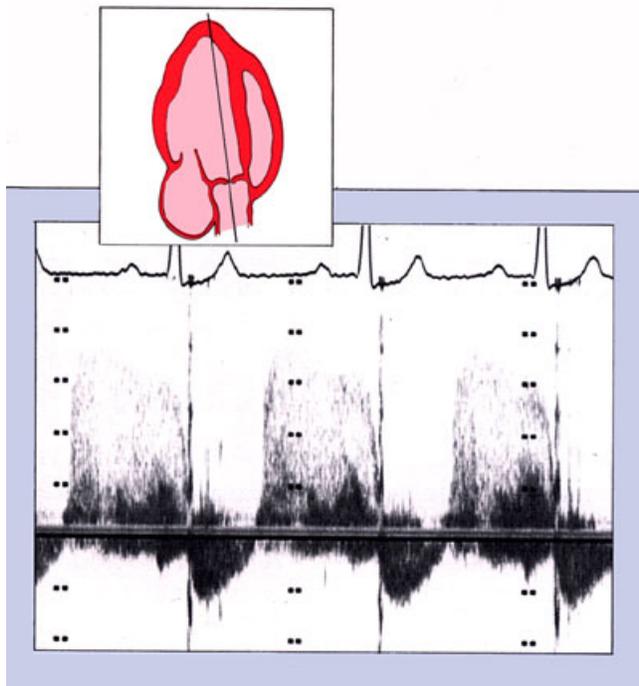


Figure 2.7 CW spectral velocity recording from the apex of the same patient as Figure 2.6. The full abnormal profile of aortic insufficiency is easily recorded toward the transducer (positive shift), (Scale marks – 1 m/sec).

Doppler must be used to record the full contour of the abnormal regurgitant profile in this same patient (Fig. 2.7). CW Doppler, in turn, has the disadvantage of lack of depth resolution, and is therefore not suitable for precisely localizing areas of turbulent flow in the heart.

VALIDATION OF DOPPLER FINDINGS

Limitations of Cineangiography

Almost all of the studies into the validation of Doppler detection of valvular regurgitation have been in comparison to cineangiography. Aside from physical examination, it is the only currently available clinical method for the detection of valvular regurgitation. Despite the present enthusiasm and interest concerning Doppler methodology, the beginner should understand the fundamental differences between these two approaches. It is unlikely

that the results of Doppler and cineangiography will ever correlate exactly because the two methods are so fundamentally different in the presentation of data concerning valvular regurgitation. Cineangiography, of course, requires invasive cardiac catheterization and is based upon the dilution of injected radio-opaque contrast on the final X-ray image. However, this catheterization based method is not an ideal "gold standard". When small regurgitant jets are directed into enlarged chambers the resulting dilution of the angiographic contrast agent may render the regurgitation undetectable. Small degrees of regurgitation by angiography may also be highly dependent upon precise catheter location. Angiographic evaluation of right sided lesions is particularly difficult, since catheters must be placed across the valve being evaluated causing at least some degree of catheter induced insufficiency (Fig. 2.8). Furthermore, the angiographic grading scheme for insufficiency used in most catheterization laboratories (0 to 4+) is based on subjective interpretation as contrast progressively opacifies a receiving chamber over several heart beats. There is general agreement that this method for estimation of severity is subject to considerable interpretive errors as a result.

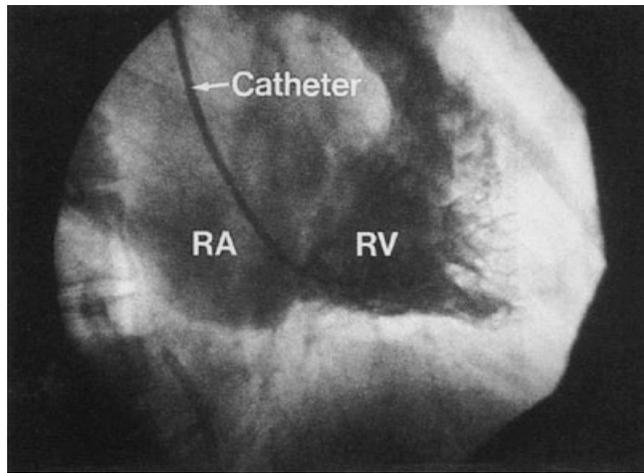


Figure 2.8 Right ventricular angiogram in slight right anterior oblique view. With a catheter across the tricuspid valve, some degree of tricuspid regurgitation almost always results.

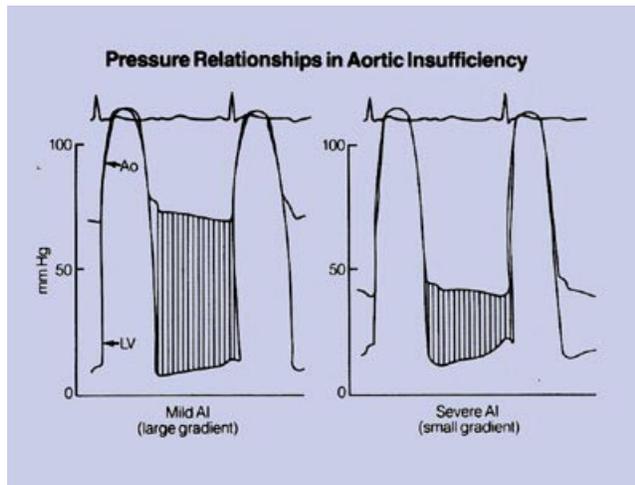


Figure 2.9 Idealized pressure relationships in aortic insufficiency. The left panel demonstrates the large gradient between aorta and left ventricle in mild aortic insufficiency. When aortic regurgitation is severe, central aortic pressure falls and ventricular diastolic pressure rises. This results in a small gradient and lower velocity by Doppler.

involved relatively small numbers of catheterized patients and, in some cases, the criteria for patient selection have not been specifically stated. Almost all studies have involved patients with insufficiency disease of the valve to warrant catheterization, and the very favorable results reported might not apply to larger groups of patients with less advanced disease. Some studies have even included Doppler evaluations performed after the angiogram by operators who have been influenced by the angiographic results.

Given the limitations of these techniques, in our institution Doppler angiographic comparisons yield a sensitivity and specificity approach 100% when significant (2+ or greater) angiographic regurgitation is present. When there is little or no angiographic regurgitation (1+ or 0), the two techniques are somewhat less likely to agree.

Limitations of Doppler Echocardiography

Doppler echocardiography also has its limitations. A beginner should always remember that Doppler detects the velocity and direction of moving blood. In situations where there is a small leak across a given valve there will be a large pressure gradient rendering high velocity of flow. This is illustrated in (Fig. 2.9 left panel) for trivial aortic insufficiency. Aortic insufficiency gradients occur in diastole. With large gradients (Fig. 2.9, right panel) the resultant high velocities might readily be detected. For very severe leaks, such as total absence of the aortic valve, little pressure differential would occur and result in very low velocities of flow. In this situation, the abnormal lesion might be missed. Indeed, we have encountered some cases where we have missed severe valvular regurgitation by Doppler that has been readily detected at catheterization by angiographic means.

In addition, the quality of Doppler signals is quite variable from patient to patient. Users of traditional ultrasound imaging methods are quite familiar with differences in the quality of images between patients. These differences may be accounted for by patient age, the presence of lung disease, chest wall configuration or other factors.

Doppler and Cineangiographic Comparisons

It is also important to remember that most Doppler-angiographic comparisons have

As we shall see, Doppler may detect the presence of valvular regurgitation in patients without any evidence of a cardiac murmur. In fact, there are surprisingly high rates of detectable lesions such as tricuspid and pulmonic insufficiencies in normal patients. In our laboratory, tricuspid regurgitation is found in 38% of normal healthy young volunteers, while mitral regurgitation is found in 23%, pulmonic regurgitation in 8%, and aortic regurgitation in 8%. Most regurgitations in this series were judged as minor.

This seemingly high prevalence of valvular regurgitation may surprise clinicians experienced with cardiac auscultation. In each case, no murmurs were heard or recorded by phonocardiography. These findings serve to highlight two important points.

First, careful Doppler examinations may reveal trivial regurgitations that are not heard by common auscultatory techniques. Clinicians who use Doppler echocardiography generally accept that small degrees of valvular regurgitation may occur in otherwise normal individuals.

Second, auscultatory events are the audible result of valvular regurgitation. Doppler events are the electronic phase shift result of the same regurgitation. These are two fundamentally different ways of measuring the same event. The sound emitted from a Doppler instrument is not the same as that heard through a stethoscope and beginners should not expect the two to be the same.

As a consequence of all these factors, it must be recognized that exact correlations between methods will never exist. Experienced Doppler operators will detect regurgitant jets which cannot be documented by angiography and may also miss some small jets recognized by angiographic methods. It is clearly best for beginners to Doppler echocardiography to perform some Doppler-angiographic comparisons of their own in order to establish the level of reliability in their own laboratories. Similarly, clinical correlations of Doppler with auscultatory findings will rarely be identical.

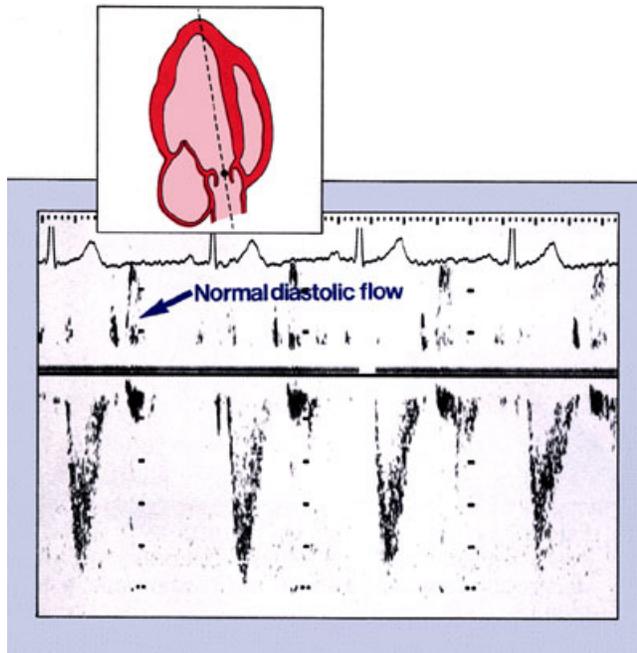


Figure 2.10 Normal spectral recording of left ventricular outflow using PW Doppler echocardiography. Systolic flow is away from the transducer and the velocity shift is negative. Some apparent "abnormalities" are usually recorded in diastole. (Scale marks=20cm/sec).

DOPPLER DETECTION OF VALVULAR REGURGITATION

Aortic Regurgitation

PW Doppler has been reported to have a sensitivity ranging between 86% and 100% for the detection of aortic regurgitation. PW Doppler examinations for this lesion are best begun using the apical two-or four-chamber two-dimensional views for operator guidance. **Figure 2.10** demonstrates a PW Doppler recording from just at the coaptation point of the aortic valve in a normal patient when the transducer was placed at the ventricular apex. Note that some low frequency diastolic sounds are normally encountered, which likely result from blood swirling through the mitral orifice and around the left ventricular outflow tract. The novice should not mistake these low velocity events for evidence of aortic insufficiency.

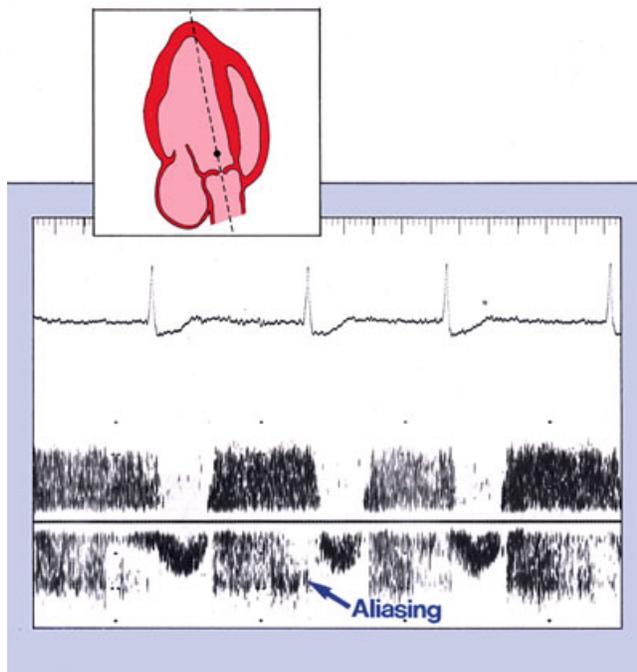


Figure 2.11 PW Doppler recording of aortic insufficiency with severe aliasing (Scale marks = 0.5 m/sec).

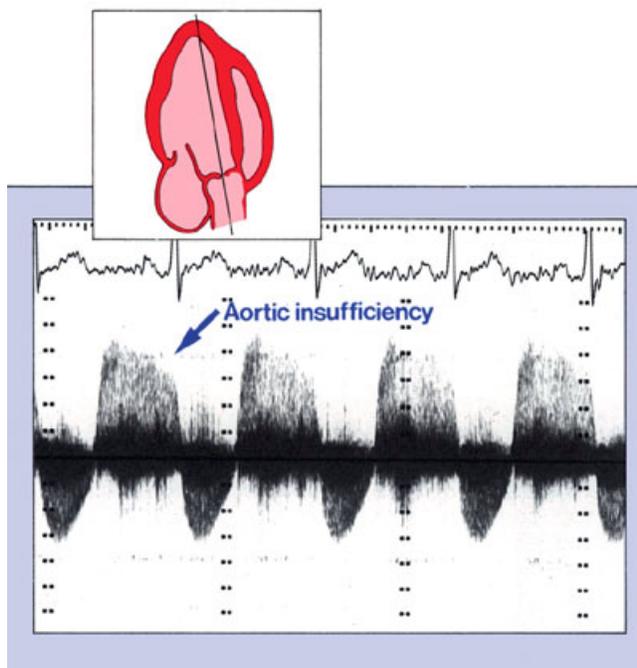


Figure 2.12 Aortic insufficiency as recorded from the ventricular apex using CW Doppler is represented as diastolic flow toward the transducer (Scale marks = 1 m/sec).

When regurgitation is present, careful searching just on the ventricular side of the aortic valve with PW Doppler reveals the high frequency sounds and diastolic spectral broadening typical of aortic insufficiency. This is shown in **Figure 2.11**, where almost all regurgitation jets are severely aliased and the top of the spectral trace appears cut off and placed at the bottom of the display. Note that the zero baseline of the spectral display has been moved to the bottom of the display, as described in Unit 1, in an attempt to eliminate the aliased diastolic signal and to provide as much display of the spectral profile as possible. Even with this maneuver, the top of the aliased signal is still missing.

Similarly, the best window for the evaluation of aortic insufficiency with CW Doppler is the apical window. Using this approach, aortic insufficiency appears as a holodiastolic, high frequency turbulent jet with spectral broadening and flow toward the transducer as noted in **Figure 2.12**. The resultant spectral shift is positive (i.e., above the baseline). Doppler spectral recordings of aortic insufficiency are invariably holodiastolic.

It is usually of interest to beginners to Doppler echocardiography who are familiar with auscultation, that the Doppler spectrum in aortic insufficiency has a holodiastolic duration and its duration does not vary with severity. This example serves to highlight the differences between the audible sounds generated by the Doppler shift device and those heard by auscultation. Using the latter approach, the typical murmur of aortic insufficiency is early diastolic and decrescendo. These differences emphasize the fact that the Doppler instrument is not an elaborate electronic stethoscope.

The operator should keep in mind some possible causes for false positive or false negative examinations when evaluating patients with suspected aortic insufficiency. One common reason for a false positive test is confusion with mitral valve diastolic inflow, particularly when mitral stenosis is present. **Figure 2.13** shows a CW recording taken from the apical window in a patient with aortic valve disease. Note the different timing of the aortic diastolic jet and the mitral inflow signal. The duration of diastole is longer in aortic insufficiency than mitral inflow.

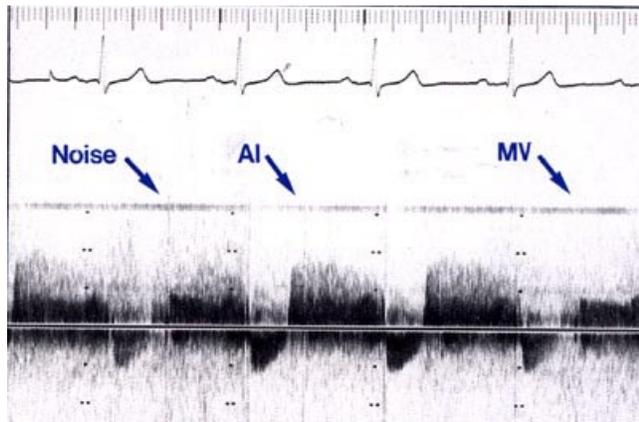


Figure 2.13 Changing CW spectral patterns encountered when mobbing the direction of the transducer (at the apex) from aortic outflow where aortic insufficiency (AI) is noted to mitral valve (MV) inflow. Note the mitral profile superimposed on the AI spectra. (Scale marks = 2 m/sec).

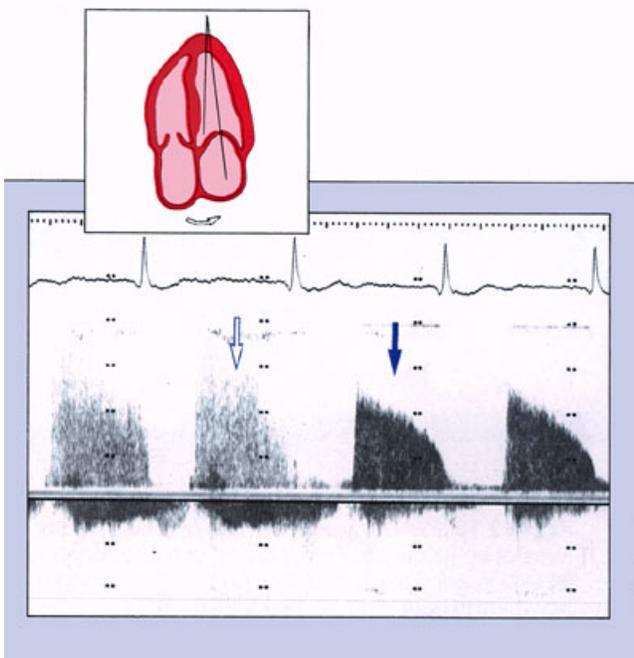


Figure 2.14 Similar spectral patterns of aortic insufficiency (open arrow) and mitral stenosis (closed arrow) occurring with slight movement of the Doppler beam. For details, see text. (Scale marks = 1 m/sec).

a small aortic regurgitant jet into the large left ventricular cavity probably accounts for the failure to appreciate this event by angiographic means.

The probable reason for a false negative diagnosis of aortic insufficiency is that the jet is small and not easily detected with either pulsed or continuous wave Doppler. Not only may the jet be small, it may move through the interrogating beam with the phases of the cardiac cycle. This makes it difficult to record a full profile because the jet is never positioned in the Doppler beam long enough to record the entire event, as seen in **Figure 2.15**.

Such an occurrence is the likely explanation for the PW Doppler spectral recording shown in **Figure 2.16**. Here, the full diastolic duration of the aortic insufficiency jet is poorly appreciated on some beats. The recording was obtained with the transducer held at the ventricular apex.

A maneuver performed from the apical window using a CW Doppler transducer is demonstrated in **Figure 2.14**. The first two beats were obtained with the beam angled toward the left ventricular outflow tract, and demonstrate aortic insufficiency. The beam is then angled toward the mitral orifice where the diastolic jet of mitral stenosis is encountered in the second two beats.

These jets are both diastolic events and are quite similar in contour. Note also that the spectral distribution of both abnormal jets is wide, but much less intense in aortic insufficiency when compared with mitral stenosis. Recognition of the different features of the spectral display in these two lesions, plus a thorough examination of the location of the suspected abnormal diastolic jet using the PW approach, should allow the operator to reliably separate aortic insufficiency from mitral stenosis in most cases.

It is also possible that a false positive recording of aortic insufficiency may result from inadvertent detection of coronary blood flow. Although coronary flow is mostly diastolic and the size of the Doppler beam is usually large at remote distances from the transducer, it seems unlikely that this is a very frequent cause of false positives in clinical practice.

It is worthwhile to keep in mind that detection of aortic regurgitation by Doppler with a negative cardiac catheterization may not necessarily constitute a false positive study. However, the amount of regurgitation in this situation is probably minimal. Rapid dilution of

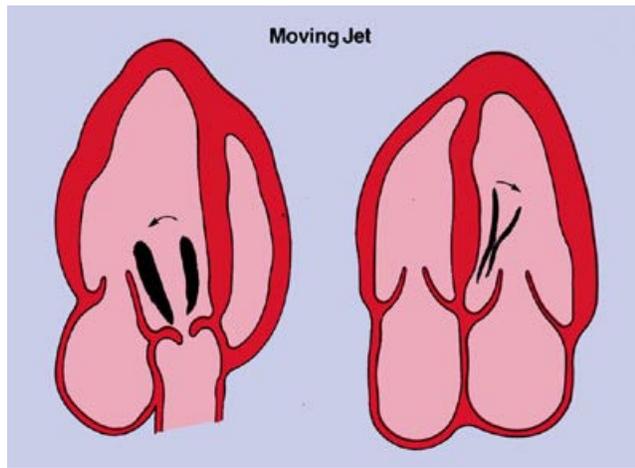


Figure 2.15 Regurgitation jets may move eccentrically during the cardiac cycle and cross the Doppler beam.

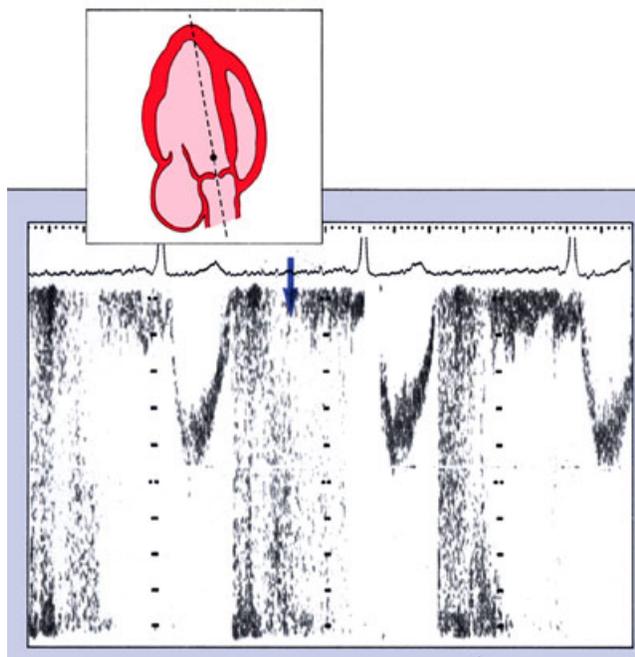


Figure 2.16 PW Doppler recording of changing patterns of an incompletely visualized aortic regurgitant jet that is encountered from slightly different angles from beat to beat (Range marks = 20 cm/sec).

This phenomenon also may occur due to the phases of the respiratory cycle. This is not because the volume of the jet is varying with respiration. Rather, the direction of the jet is probably changing slightly with respect to the direction of the interrogating Doppler beam as the heart moves up and down with the moving diaphragm. This phenomenon is demonstrated in **Figure 2.17** where the full profile of aortic insufficiency is seen from the ventricular apex using CW Doppler. Here the full profile of aortic insufficiency is recorded on some beats and not on others. When this occurs, and differences due to respiration are suspected, the operator should try many different transducer positions and angulations to record as much of the suspected abnormal profile as possible.

Some jets may be so small as to require interrogation from slightly different transducer positions to record the full profile. The spectral profiles in **Figure 2.18** are not the result of a continuous strip recording but are a five-panel composite demonstration of the diastolic appearance of aortic insufficiency from five slightly different apical positions in a patient with aortic insufficiency. The only way to overcome this problem is to be assured that every possible area has been adequately interrogated for aortic insufficiency during the Doppler examination.

Although the apical approach is the most profitable window for the detection of aortic insufficiency, it is worth keeping in mind that some jets are directed eccentrically and may be detectable only from some other window such as the left parasternal. Caution should be

exercised, however, when using CW Doppler from parasternal windows. It might be possible to mistake pulmonic insufficiency, which can be recorded in many subjects, for aortic valve insufficiency. Fortunately, most aortic insufficiency encountered from the left parasternal approach is directed posteriorly toward the mitral valve and away from the transducer (a negative jet). This contrasts with pulmonic insufficiency, which is uniformly directed anteriorly into the right ventricle toward the transducer (a positive jet).

Some information as to left ventricular end-diastolic pressure may be gained in the setting of aortic insufficiency. Since the velocity of any jet relates to the pressure drop across the valve, there exists a pressure gradient between the aorta and left ventricle at end-diastole. This pressure gradient may be estimated by measuring the velocity of the aortic regurgitant jet at end-diastole using the simplified Bernoulli equation. Subtracting this pressure from diastolic blood pressure (as measured

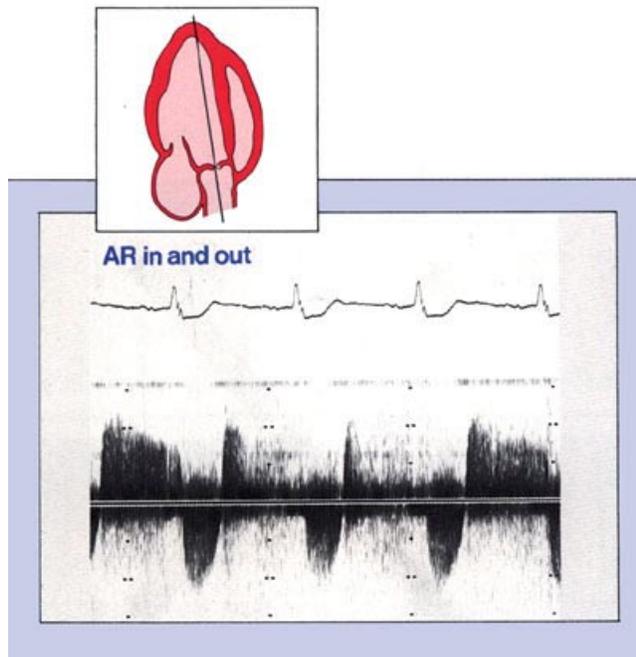


Figure 2.17 CW spectral recording of aortic regurgitation from apex where the regurgitant jet moves in and out of the beam. (Scale marks = 2 m/sec)

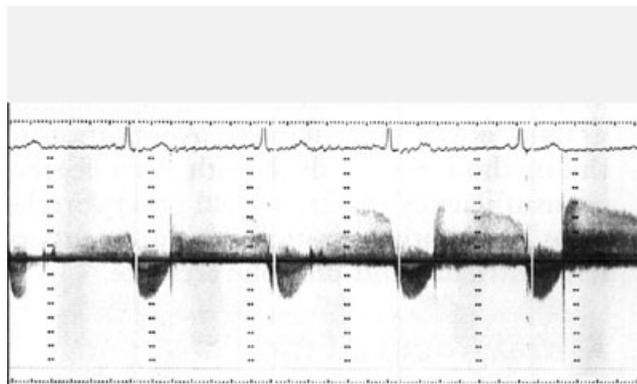


Figure 2.18 Five panels showing differing appearances of aortic regurgitation from five slightly different positions near the apex using CW Doppler. The best spectral profile is right. (Scale marks = 1 m/sec)

valve (**Fig. 2.20**). Because of the high velocities of the regurgitant jet and the distance from the transducer to the jet, aliasing of the mitral regurgitant jet invariably occurs. As with all regurgitant lesions, location of the abnormal turbulence is done in pulsed Doppler mode and continuous wave Doppler is then used to record the full spectral profile.

The full spectral profile of mitral regurgitation obtained from the ventricular apex by CW Doppler commonly reaches peak velocities of between 3 and 6 m/sec, depending on the systolic pressure gradient between the two chambers. It is usually quite symmetric, as seen in **Figure 2.21**. The opening and closing motions of the mitral valve will sometimes result in sharp spikes on the spectral velocity recording because the rapidly moving valves will also render a Doppler signal. This phenomenon of valve opening and closing is seen in **Figure 2.22**.

Mitral regurgitation associated with endocarditis, ruptured chordae tendinae and/or partial leaflet flail, is frequently associated with loud clicking noises and high frequency spikes on the spectral recording. These are created by rapid movements of the diseased target through the field of view.

by cuff at the time of the Doppler examination) provides an estimate of left ventricle end-diastolic pressure.

A typical aortic regurgitant jet obtained by CW Doppler from the left ventricular apex is shown in **Figure 2.19**. In the example shown, the end-diastolic velocity is approximately 1.9 m/sec which corresponds to a pressure gradient estimate of 14mmHg. This patient had severe aortic insufficiency, and the measure diastolic blood pressure was 55mmHg by brachial arterial cuff measurement. This resulted in an end-diastolic pressure estimate of 41 mmHg. At catheterization, the actual measured pressure was 38 mmHg.

It should be noted, however, that this approach only shows satisfactory correlation in patients with severe (3+ to 4+) angiographic aortic insufficiency. Application of this method to individuals with lesser degrees of insufficiency does not yield good correlations with catheterization measurements of left ventricular end-diastolic pressure.

Mitral Regurgitation

A number of studies have shown that Doppler echocardiography is both very sensitive and very specific for the detection of mitral regurgitation when compared with cardiac catheterization. Using PW Doppler, most cases of mitral regurgitation can be detected with the transducer at the apex and the sample volume located in the left atrium just behind the mitral

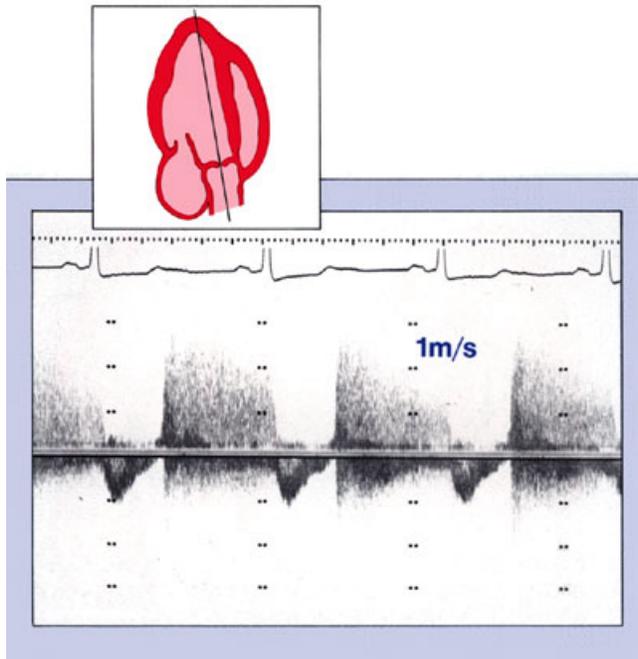


Figure 2.19 CW spectral recording of aortic insufficiency showing measurement of end-diastolic pressure gradient (Scale marks = 1 m/sec)

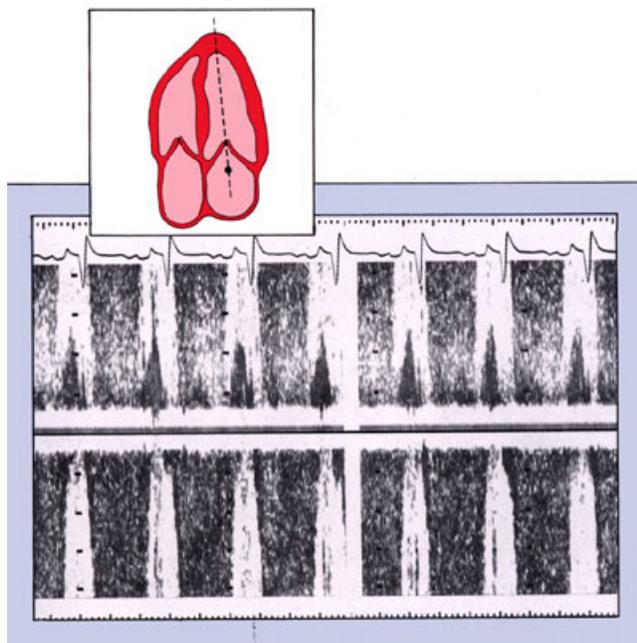


Figure 2.20 PW Doppler spectral analysis of mitral insufficiency with the sample volume located in the left atrium. The high velocities encountered produce aliasing. (Scale marks = 20 cm/sec)

Thus, multiple high velocity spikes may be demonstrated on the spectral recording as seen in **Figure 2.23**. Occasionally, the systolic profile of mitral regurgitation peaks slightly early, as is seen in this patient with endocarditis when the regurgitation is severe and end-systolic pressures are high. These results occur because the gradient between left ventricle and left atrium is small.

Other factors may alter the usually symmetry of the mitral regurgitant spectral tracing. The *left panel* of **Figure 2.24** shows combined aortic insufficiency with aortic outflow tract obstruction. This tracing was obtained from an individual with hypertrophic cardiomyopathy and a resting outflow tract

gradient. Note that the systolic peak velocity approaches almost 5 m/sec. Interrogation of the mitral valve (**Fig. 2.24, top panel**) shows a clear, late systolic profile typical of the late systolic mitral regurgitation seen in this disorder. This presumably occurs because the pressure within the left ventricle rises rapidly with the dynamic outflow obstruction and creates a very high gradient between left ventricle and atrium in mid-to-late systole.

False positive examinations for mitral regurgitation do occur. One common reason for false positive examinations is confusion of the aortic outflow signal with that of the mitral regurgitation. The similarity between the systolic flow profile away from the transducer in mitral regurgitation and aortic stenosis is shown in **Figure 2.25**. As previously mentioned, the longer duration of mitral systole may help to differentiate these two lesions. In addition, it is usual to see mitral diastolic flow in the same spectral recording with mitral insufficiency.

Even though the use of PW Doppler may help to locate the systolic turbulent jet in the left atrium rather than the aortic outflow tract, it is important to remember that the size of the sample volume becomes larger at remote distances from the transducer. For example, when the sample volume is positioned in the left atrium from an apical transducer location, the sample volume is almost always larger than it appears on the two-dimensional display (because of the diverging shape of the ultrasound beam). Therefore, it is best to use caution when a negative jet within the left atrium can be detected only in the vicinity of the aortic root, as it may represent aortic outflow (**Fig. 2.26**) rather than mitral regurgitation.

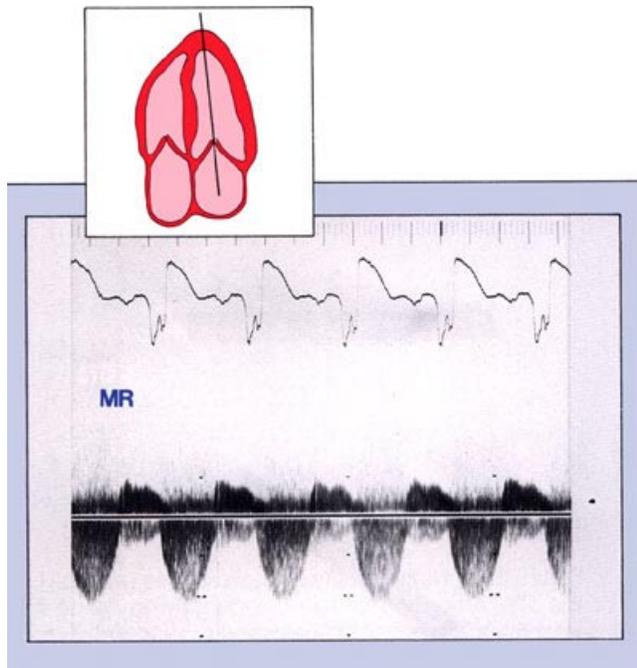


Figure 2.21 CW recording of typical mitral regurgitation from the apex. The jet is away from the transducer in systole and is usually symmetric in shape. (Scale marks = 2 m/sec)

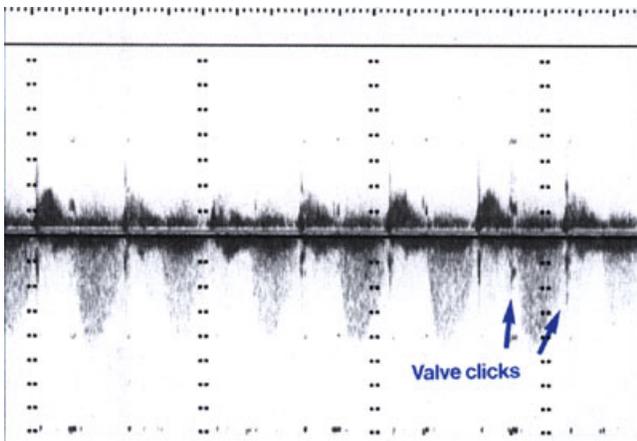


Figure 2.22 CW spectral recording of typical mitral regurgitation. Note valve closing and opening spikes or clicks. (Scale marks = 1m/sec)

phases of the respiratory cycle as the orientation of the jet to the interrogating beam alters with the movement of the heart. **Figure 2.29** demonstrates the effect of these changing relationships on the mitral insufficiency recording. Mitral insufficiency may also be obscured by significant aortic stenotic lesions.

Mitral regurgitant jets, like others, are often eccentrically directed, and it is important to examine the left atrium from all available windows. Besides the apical window, the left parasternal region is very useful for this purpose.

Tricuspid Regurgitation

Tricuspid regurgitation is also best evaluation from the apical window. The left parasternal right ventricular inlet view and short axis at the aortic valve level are other useful positions. In tricuspid insufficiency, systolic turbulence is detected just behind the tricuspid valve leaflets. The contour of the flow profile is very similar to that of mitral regurgitation. AS with other regurgitant jets, CW

It is also possible to confuse tricuspid with mitral regurgitation. This is more of a problem with CW than with PW echocardiography for a beginner, and the use of PW with concurrent imaging helps in recognizing this error. Another reason for false positives is the interpretation of a loud systolic closure sound of the mitral valve leaflets, commonly known as "valve slap", as partial recording of the early profile of a moving mitral regurgitation jet (**Fig. 2.27**).

Detection of mitral regurgitation when it has not been found by angiography is uncommon, especially when an apical transducer position is used. It is, however, possible that a very small amount of regurgitation may be detected by Doppler and yet fail to be seen on left ventriculography, particularly if there is rapid dilution and poor opacification of the left ventricle with a contrast agent.

False negative evaluations for mitral regurgitation insufficiency also may occur and are probably most frequently due to a small jet that was missed on examination. A moving jet may also be encountered but is frequently difficult to differentiate from "valve slap" demonstrated in **Figure 2.27**.

Mitral insufficiency jets may also vary in appearance with arrhythmias. The CW spectral recording shown in **Figure 2.28** illustrates the altering profiles of mitral regurgitation encountered with premature ventricular contractions. As with all abnormal jets, mitral regurgitation can change its appearance with

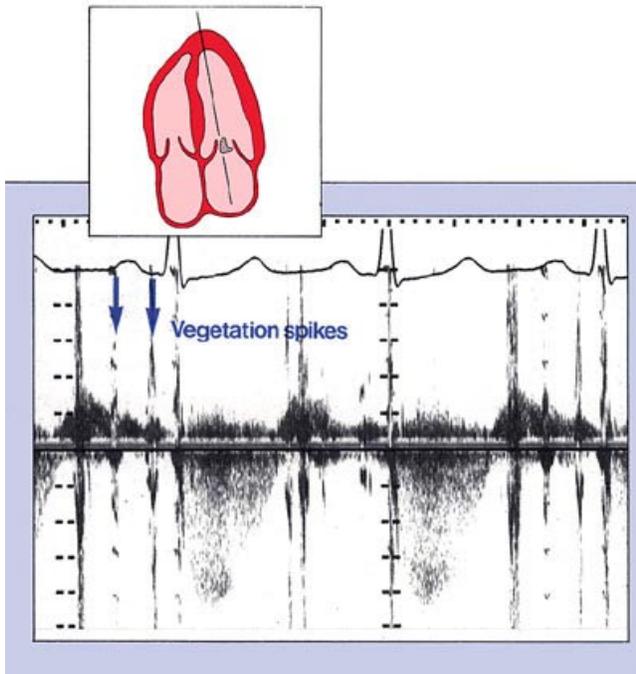


Figure 2.23 High velocity diastolic spikes (arrows) on the CW recording of mitral regurgitation made by vegetation movement. (Scale marks = 1m/sec)

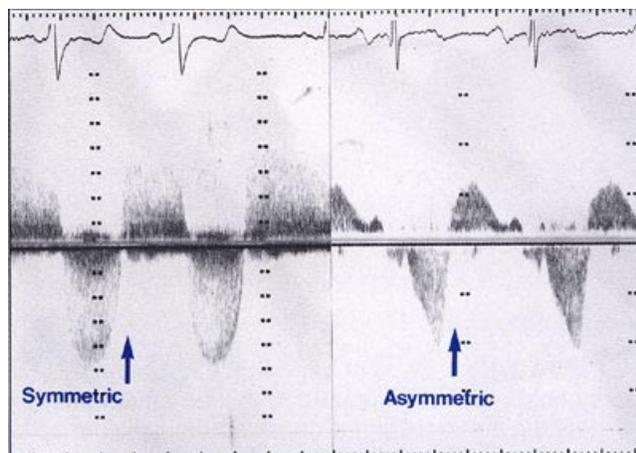


Figure 2.24 Left panel: typical recording of aortic insufficiency and obstruction. Note how the aortic outflow tract turbulence resembles the symmetric profile of mitral insufficiency (arrow) with continuous beam angles through

insufficiency when using the blind CW Doppler approach. They result from differential volume filling into the right atrium and ventricle during respiratory cycle. During inspiration, right ventricular filling is augmented due to a fall in intrathoracic pressure.

A tricuspid regurgitant jet may be used to estimate right ventricular systolic pressure (RVSP) in mmHg. This method, like all Doppler pressure estimates, is based on the modified Bernoulli equation ($dp=4V^2$) discussed in Unit 1. **Figure 2.32** shows the rationale for this calculation based upon idealized pressure tracings. When normal RVSPs are encountered and tricuspid regurgitation is present, only small pressure gradients occur and low velocity spectral recordings would be anticipated. When high RVSPs are encountered and tricuspid regurgitation is present, much higher systolic gradients exist between the right ventricle and right atrium in systole. Thus, much higher velocity spectral recordings would be anticipated.

Doppler is usually needed to obtain an unaliased recording of the full spectrum as seen in **Figure 2.30**.

We frequently detect tricuspid regurgitation by Doppler in otherwise normal individuals and find that even beginners to Doppler instrumentation will readily record this entity in between 25% and 50% of their patients. Earlier studies found a similar, frequent systolic reversal of flow in normal individuals using contrast echocardiography of the inferior vena cava. Some investigators have indicated that a small degree of tricuspid regurgitation may be seen in as many as 96% of normal volunteers by Doppler. These findings were felt to be due to true valvular tricuspid regurgitation, and not to coronary sinus systolic flow.

These findings indicate that Doppler evidence for tricuspid regurgitation is common and presents an interpretive dilemma for echocardiographers. It is clear to us that the physical findings of tricuspid regurgitation are extraordinarily insensitive and are usually seen only when the regurgitation is severe. There is no widely accepted standard method for reporting this lesion. Currently, we prefer not to report tricuspid regurgitation if it is localized just behind the tricuspid leaflets; it is only reported if the regurgitant jet can be found, by PW Doppler, to extend at least halfway between valve leaflets and posterior wall of the right atrium.

Respiratory variations are frequently observed in tricuspid insufficiency Doppler spectra, as noted in **Figure 2.31**, and may be occasionally used to distinguish between mitral and tricuspid

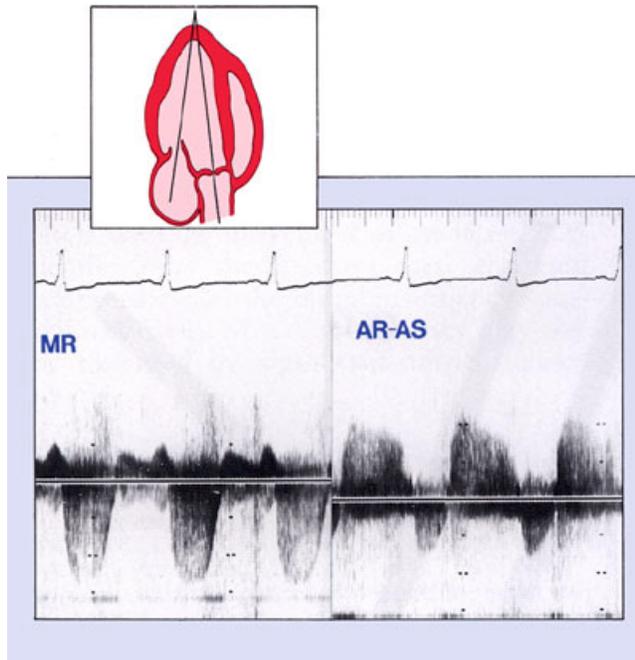


Figure 2. 25 With a transducer located at the apex, both mitral regurgitation (MR) and aortic stenosis (AS) appear as systolic movement in a negative direction. Note that mitral systole is longer in duration than aortic. Aortic regurgitation (AR) is also present. (Scale marks = 2m/sec) the mitral orifice. (Scale marks = 1m/sec)

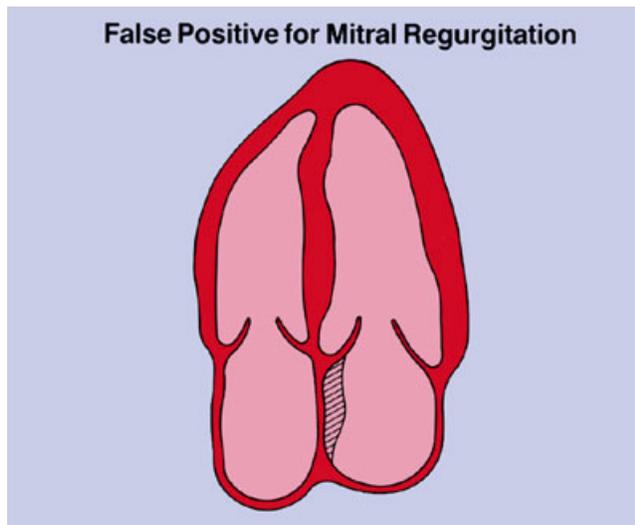


Figure 2. 26 A Doppler sample volume is large in the far field and, when placed in the left atrium in areas near the aortic root, may cause spurious evidence for mitral regurgitation.

It must be understood that the pressure within the right atrium exerts a significant effect on the peak systolic velocity of tricuspid regurgitation. **Figure 2.33** demonstrates this influence and shows the importance of estimating the pressure within the right atrium before attempting these calculations. For any given systolic pressure in the right ventricle, a low pressure in the right atrium would result in a higher gradient between atrium and ventricle and, therefore, a higher velocity than when a high right atrial pressure exists. In the latter case, the higher right atrial pressure reduces the gradient and, therefore, the resultant velocity of the tricuspid regurgitation jet.

The right atrial pressure may be estimated by examination of the patient's neck veins. Using this method, mean jugular venous pressure (JVP) in cmH₂O is first estimated by inspection of the jugular venous pulse with the patient at 45 degrees. Right atrial pressure (RAP) is estimated by adding 5 cm to the venous pressure measurement (to approximate the distance between the right atrium and the clavicle) and then converted to mmHg by dividing by 1.3. This is then added to the trans-tricuspid systolic gradient estimated from the peak tricuspid velocity. The formula is:

$$RVSP = (JVP + 5 / 1.3) + (\text{peak systolic velocity}^2 \times 4)$$

The patient pictured in **Figure 2.30** has a peak systolic velocity of 2.4 m/sec that is equivalent to a peak trans-tricuspid systolic gradient of 23mmHg. Since the jugular venous pulse was estimated at 15 cm., the right atrial pressure would be 20 cmH₂O (=15mmHg). Using the above equation, we would predict a right ventricular systolic pressure of 38mmHg.

Doppler catheterization correlations for measurement of RVSP have been reported as being very accurate, and practical application of these methods in our laboratory supports the reliability of this approach. When pulmonary stenosis does not exist, peak RVSP should reflect peak systolic pulmonary artery pressure.

Thus, many factors influence the peak velocity and appearance of the spectral tricuspid regurgitant jet. A demonstration of these differences is seen in **Figure 2.34** where one patient has a high velocity jet measuring 6 m/sec (left panel) and another has a systolic jet measuring 3 m/sec (right panel). If both patients had 5 cm of neck vein distension, the patient on the left would have a

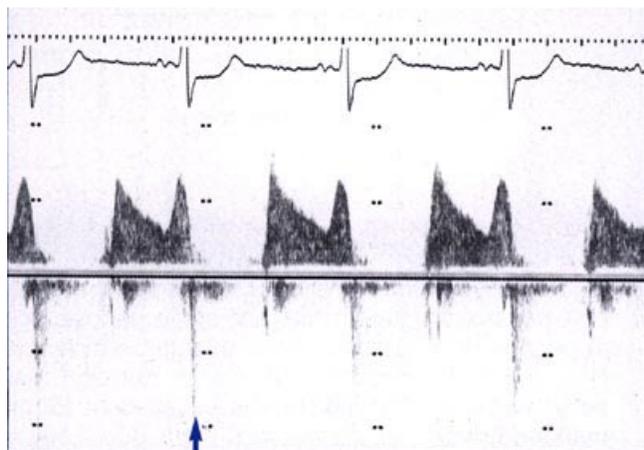


Figure 2.27 CW spectral recording from patient with "valve slap" (arrow) that may be wrongly interpreted as incomplete recording of mitral regurgitation.

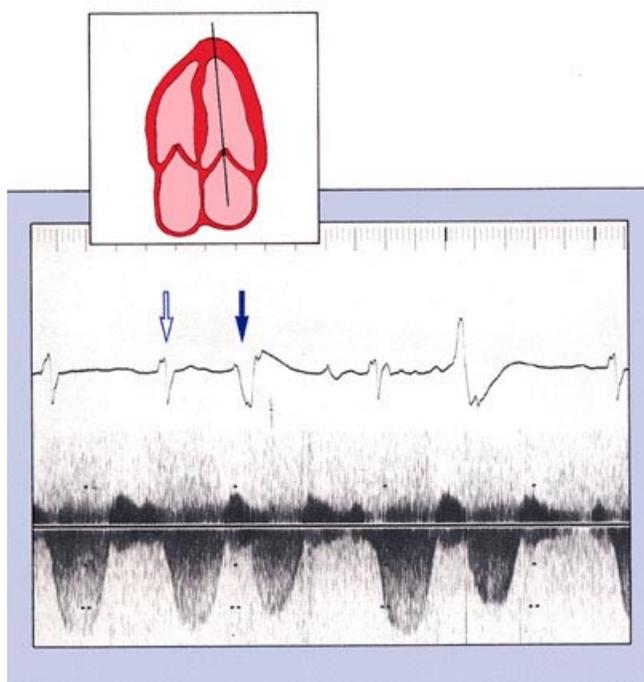


Figure 2.28 Varying appearances of mitral insufficiency with arrhythmias. A smaller profile follows the PVC (closed arrow) than the normal beat (open arrow). (Scale marks = 2m/sec).

seen in **Figure 2.37**. This lesion is best detected from the left parasternal window with angulation of the beam toward the patient's left shoulder. As with tricuspid regurgitation, this abnormal pattern is found in a surprisingly high number of otherwise normal individuals. False positive results may occur from confusion with aortic insufficiency. Usually a careful PW Doppler examination will readily differentiate between these two entities. In addition, pulmonary insufficiency frequently has an end-diastolic movement that reflects atrial contraction. Some authors have suggested that flow in the left coronary artery (which crossed just below the right ventricular outflow tract) may also account for a false positive diagnosis. False negatives may occur as a result of small jets missed by an inadequate examination.

predicted peak RVSP of 152 mmHg and the one on the right would have a predicted peak RVSP of 44mmHg.

Arrhythmias will also profoundly affect the contour and peak velocities noted. A CW Doppler recording of tricuspid regurgitation from a patient with atrial fibrillation is seen in **Figure 2.35**. Note the differing velocities with the irregular rhythm.

As with the left-sided valves, there are reasons for the detection of false positive and false negative results that are similar to those previously discussed. One interesting cause of a false positive diagnosis is excessive upward angulation of the interrogating beam that thus intercepts aortic, rather than tricuspid flow (**Fig. 2.36**). The left panel shows the assumed proper orientation of the CW beam while the center panel shows the actual superior angulation with the beam intercepting the aortic root. The right panel shows the superior plane superimposed on the assumed plane when this error occurs. This is of particular importance in patients with aortic stenosis when higher velocity jets will be seen in the aorta.

Other reasons for a false positive diagnosis include confusion with mitral regurgitation or with valve slap as discussed previously. False negatives may occur due to small jets missed by inadequate examinations, moving jets, or intermittent jets due to the respiratory cycle.

Pulmonic Insufficiency

The diastolic pattern of pulmonic insufficiency greatly resembles that of aortic insufficiency as

PROSTHETIC VALVE INSUFFICIENCY

Concept of Flow Masking

Understanding the role of Doppler for detection of abnormal flows through prosthetic valves begins with appreciation of the concept of flow masking. Once emitted from the transducer into the tissues, ultrasound is either reflected, attenuated (absorbed) or continues on to another tissue interface where the process is repeated. All prosthetic valves contain some degree of nonbiologic material which can be plastic, metal or cloth. Each of these materials may have highly reflective or attenuative properties that may not allow the ultrasound to penetrate and pass through the nonbiologic

portion of the valve.

The nonbiologic material can interfere with the transmission of sound waves to such a degree that it may be impossible to detect some valvular regurgitation. Six commonly used heart valves are shown in Figure 2-A to demonstrate the varied appearance and materials used in fabrication of these devices: Starr-Edwards silastic ball, Starr-Edwards stellite ball, Bjork-Shiley, St. Jude's, Hall-Kastor, and a Carpentier-Edwards porcine bioprosthesis.

It is remarkable that all of the cardiac prosthetic valves cast a characteristic shadow, or mask, on the chamber behind them that obscured proper flow detection by Doppler. **Figure 2.38** shows idealized masks from two valves with the largest and smallest flow-masked areas.

The largest masked area emanates from behind the Starr-Edwards silastic ball, and the smallest is the Carpentier-Edwards porcine bioprosthesis where flow masking is limited only to the sewing ring of the prosthesis.

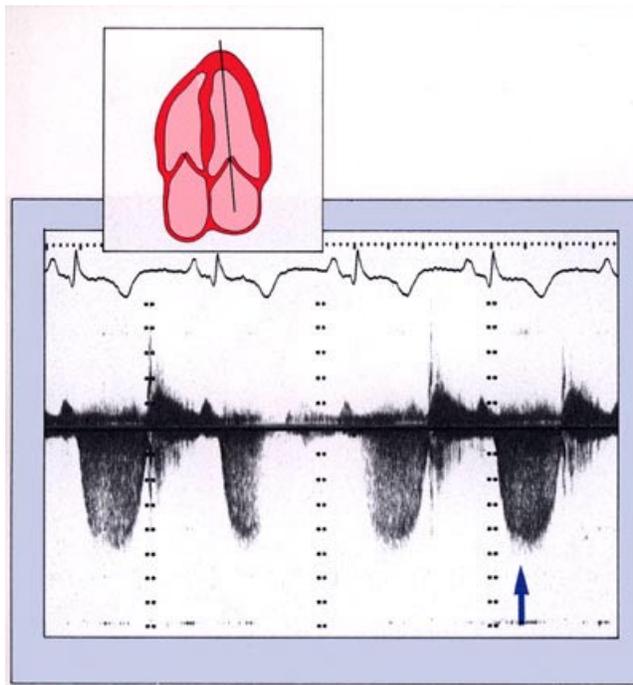


Figure 2.29 The jet of mitral regurgitation is incompletely recorded due to movement of the jet in and out of the beam. The best spectral profile is indicated (arrow). (Scale marks = 1m/sec)

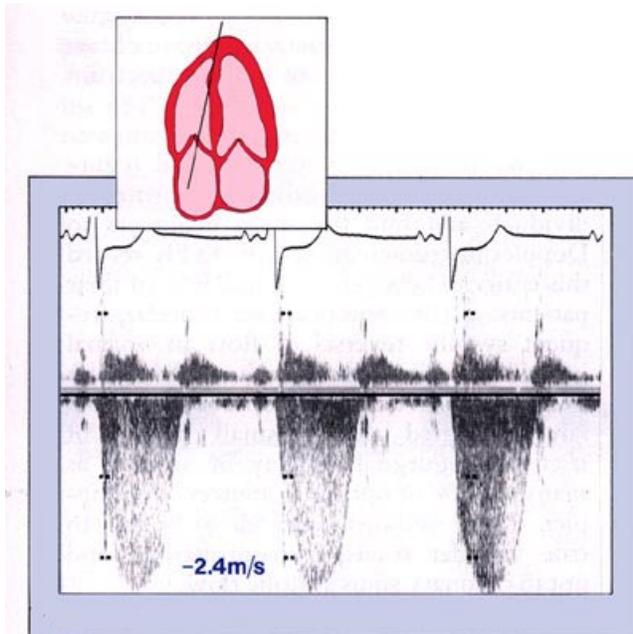
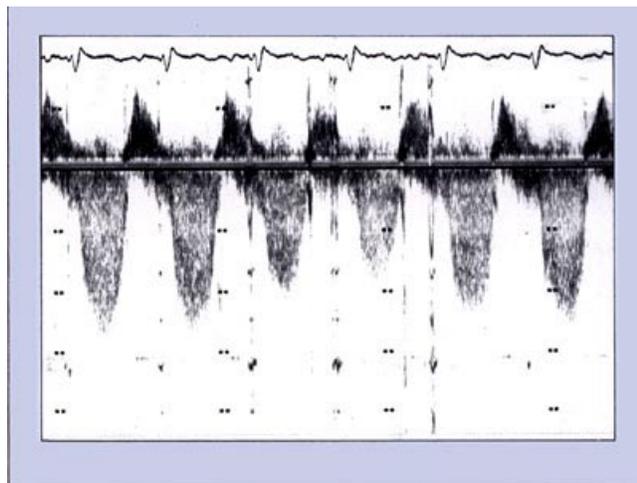


Figure 2.30 Typical CW spectral recording of tricuspid regurgitation from the apex. The peak velocity in the jet measures 2.4m/sec. (Scale marks = 1 m/sec)

All valve sewing rings prevent proper transmission of ultrasound, and without the central occluding objects the area of masking would resemble that from the Carpentier-Edwards porcine valve. With the central occluding objects in place and seated in the close position, each of the valves depicted earlier has differential central transmission characteristics. The worst penetration is clearly



This differential penetration is illustrated in **Figure 2.39** where a CW Doppler system was used to attempt simulated flow behind these various valves placed on a stage. In a large water tank, a large flow phantom was positioned beneath the stage. Each valve was successively placed on the stage, before and after control (con) periods with no prosthesis in place. A strong signal was obtained from the flow during the control periods, which are shown on either end of the figure. Resultant spectral displays from all the valves are illustrated. Although system gain is held constant, there is a significant reduction in the flow signal resulting from the interposition of the prosthetic valves. Panel A demonstrates no flow detection through a Starr-Edwards valve with stellite poppit, panel C is through a Bjork-Shiley valve, panel D through a St. Jude's valve, panel E through a Hall-Kastor and panel F through a Carpentier-Edwards porcine valve.

figure 2. 31 Varying configuration of tricuspid insufficiency with respiration. (Scale marks = 1m/sec)

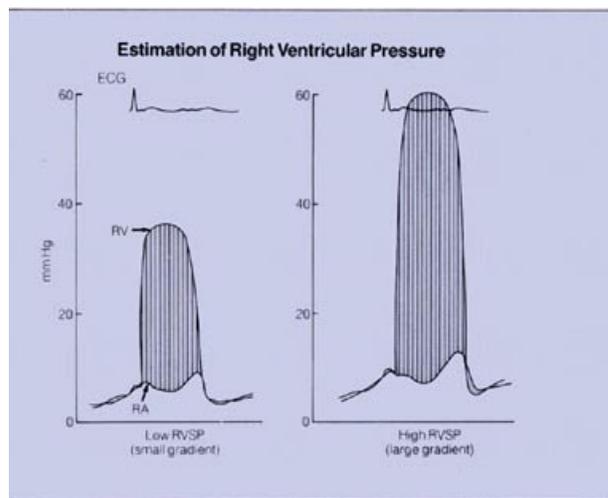


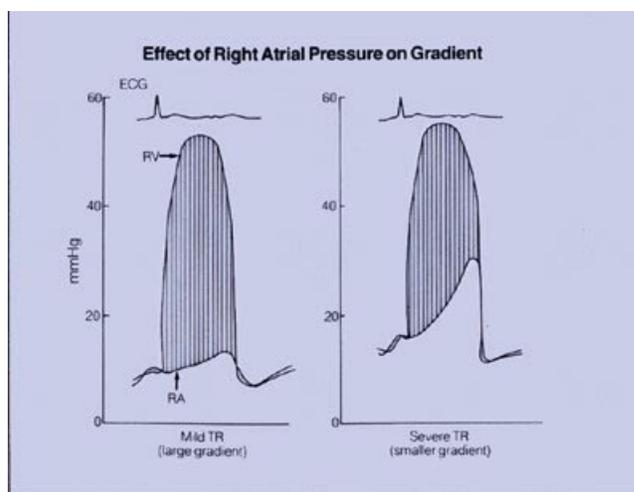
figure 2. 32 Idealized right atrial (RA) and right ventricular (RV) pressure relationships in tricuspid insufficiency. This demonstration is with similar right atrial pressures.

Implications

This concept has important implications for the clinical of prosthetic valvular regurgitation. physical properties of prosthetic may significantly alter the ability of systems to detect abnormal flow even when present. Such masks also exist in vivo and evidence for their presence may be found in certain patients. Considerable clinical caution must, therefore, be exercised when encountering patients with prosthetic valves. It may be impossible to detect any flow on the opposite side of a prosthetic valve when the valve is interposed between the interrogating transducer and the area being examined.

figure 2. 33 The pressure within the right atrium also has an effect on the gradient between right atrium and ventricle. Thus, right atrial pressures must be estimated from the jugular veins for proper prediction of peak right ventricular

encountered with the two Starr-Edwards prostheses, each casting a large mask field behind. Very little ultrasound passes the Bjork-Shiley or the St. Jude's valves. Only slightly more penetrates the Hall-Kastor. Note that this valve's occluding disc has a hole in the center to allow the disc to interact with the central pivot arm. The Carpentier-Edwards bioprosthesis masks sound only around the valve sewing ring. The central portions of this valve assembly, made up of preserved biologic tissue, allow the sound to penetrate readily.



Clinical

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These
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Doppler

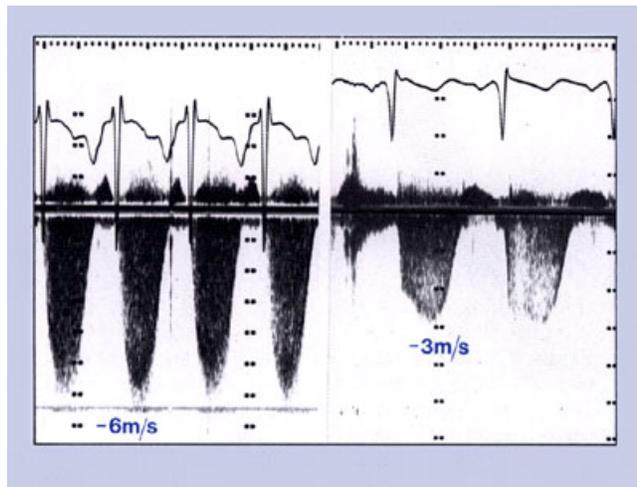


Figure 2.34 Marked elevation in right ventricular systolic pressure will result in high velocity tricuspid regurgitant jets (left panel) in comparison to lower right ventricular systolic pressures (right panel).

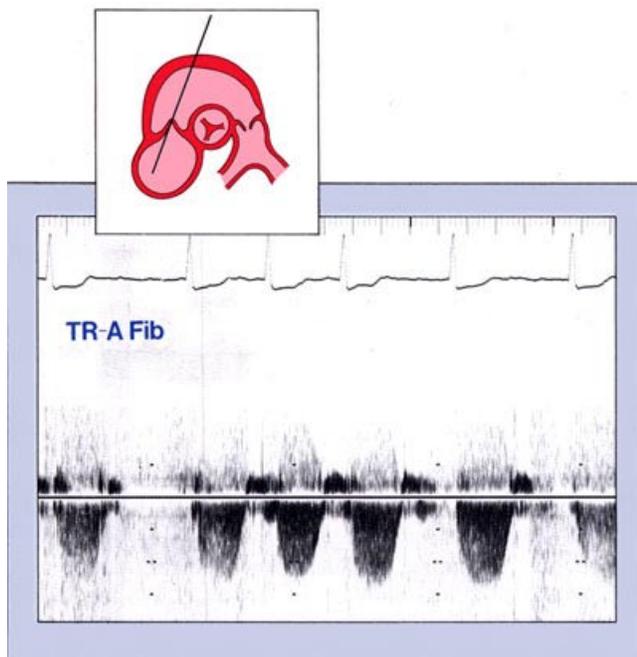


Figure 2.35 Varying appearances of tricuspid regurgitation with atrial fibrillation. (Scale marks = 1 m/sec)

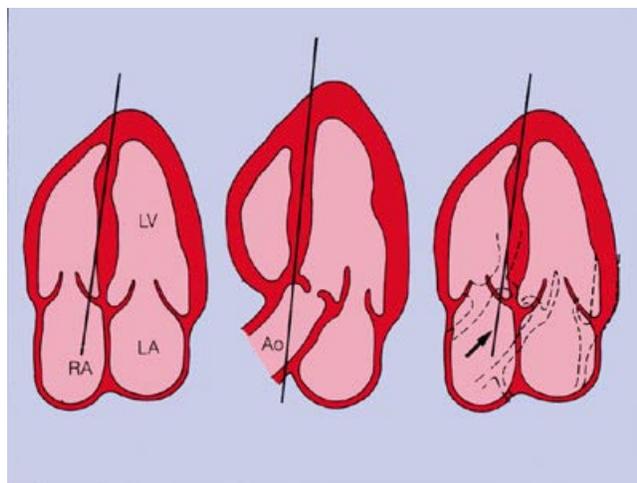


Figure 2.36 Schematic diagram of CW beam direction for detection of tricuspid regurgitation (left). If angled a little too superiorly, the beam will actually intercept the aortic root (middle, right). Thus, aortic outflow may be a reason for false positive tricuspid regurgitation (arrow).

The best clinical example of this problem is when an operator is examining a patient with a prosthetic mitral valve for mitral regurgitation from the apical view (**Fig. 2.40, left panel**). From this approach, almost the whole of the left atrium is masked by the prosthesis and the operator could incorrectly conclude that no mitral regurgitation existed. In this case, a very high parasternal view or a subcostal view of the left atrium must be selected for detection of the mitral insufficiency.

The problem is made worse (**Fig. 2.40, right panel**) in patients with both aortic and mitral prosthetic valves. The left atrium is inaccessible from the apical views due to the presence of the mitral prosthesis. Both prostheses obscure the left atrium from the parasternal views. In this setting, only the subcostal view is available for viewing the left atrium and, in our experience, this approach is rarely rewarding. Prosthetic aortic regurgitation may, of course, be detected from the apical view because the prosthesis is not between the transducer and the area of interest in the left ventricular outflow tract.

Because of these observations concerning the difficulty in detecting flow on the far side of a prosthetic valve, we always adjust our examination methods to interrogate these valves from all possible views, so that the prosthetic valve does not lie between the transducer and the chamber being examined. This requires considerable operator skill and is true for all Doppler methods. In many instances there is no view available in which the beam can be properly directed. Thus, we strongly suggest that operators of ultrasound equipment do all that is possible to detect flow properly. When none is detected on the far side of a prosthetic valve, it should not be assumed that none is present. We have seen cases of severe valvular regurgitation where the Doppler examination was rendered artifactually negative due to the masking effect. There are, however, some exceptions to this rule. In cases where the valve ball or disc is not allowed to seat correctly due to thrombus or vegetation,

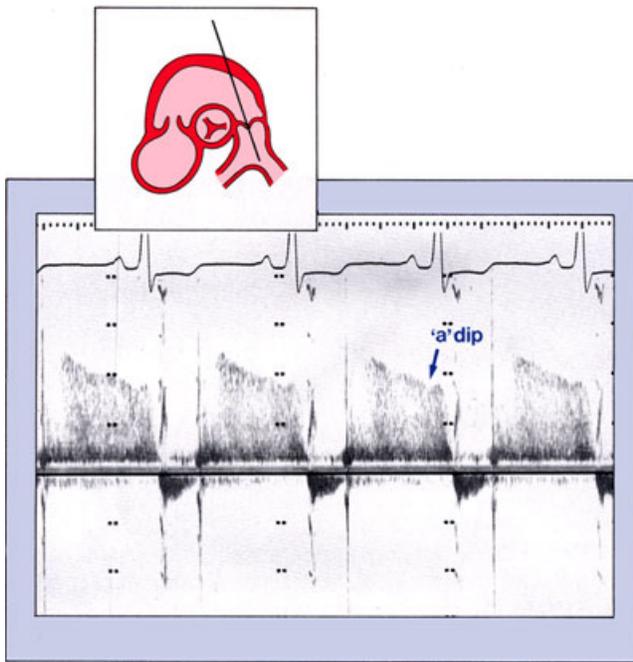


Figure 2.37 Typical pulmonic insufficiency by CW Doppler. Pulmonic insufficiency may occasionally be differentiated from aortic by the presence of the “a” dip.

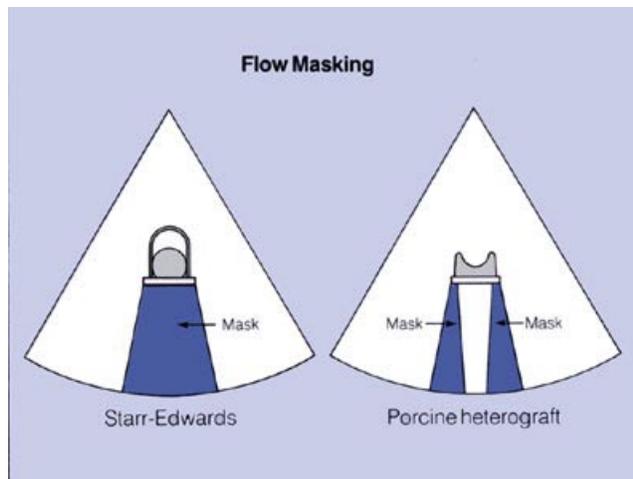


Figure 2.38 A large flow mask is seen behind a Starr-Edwards prosthesis while only the area of flow making from a Carpentier-Edwards heterograft is seen behind the sewing

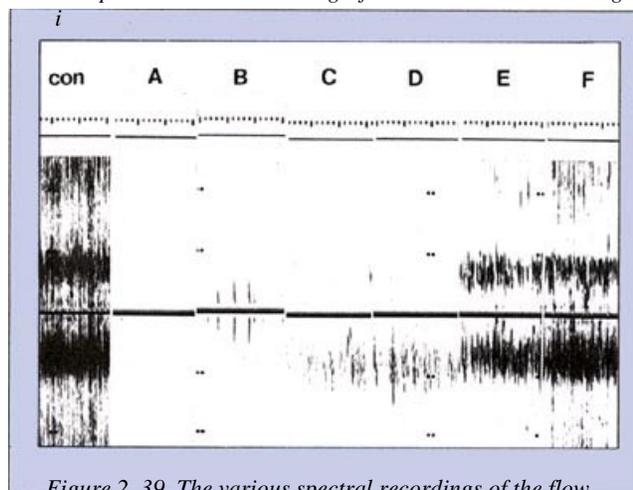


Figure 2.39 The various spectral recordings of the flow behind prosthetic valves using CW Doppler echocardiography. The control period of flow detection when no valves were in place are shown at either end (con). The letters correspond to the valves shown in Figure 2-A,

some sound may be transmitted through the partially open area if it is correctly oriented to the sound beam.

SEVERITY OF VALVULAR INSUFFICIENCY

Quantifying Valvular Insufficiency

It can now be generally accepted that Doppler echocardiography is a reliable method for the detection of the presence of valvular regurgitation. Doppler assessment of the severity of valvular regurgitation has also been moderately successful in comparison with angiographic techniques. The invasive “gold standard” for quantifying valvular insufficiency is the volume of regurgitant blood flow calculated by subtracting the total cardiac output, calculated angiographically, from the forward output (calculated by some other method—usually by the Fick principle). The regurgitant volume divided by the total angiographic stroke volume (i.e., the sum total of blood ejected forwards and backwards out of the left ventricle with each systole) is referred to as the regurgitant fraction and the formula is:

$$\text{Regurgitant fraction} = \frac{\text{total output} - \text{forward output}}{\text{total output}}$$

This approach requires considerable time and effort and is not in widespread use in most catheterization laboratories.

The other commonly used measure of severity is a subjective grading (usually 0-4+) based on a visual evaluation of the amount of regurgitation judged by progressive opacification of the receiving chamber as seen by contrast angiography. Both methods have limitations, and there is only an approximate correlation between them. Thus, it has been difficult to find a suitable “gold standard” for comparison with Doppler methods. Remember that the subjective angiographic criteria are based upon progressive opacification of a receiving chamber, usually over several heart beats. When Doppler methods are used, regurgitation is detected on a beat-to-beat basis

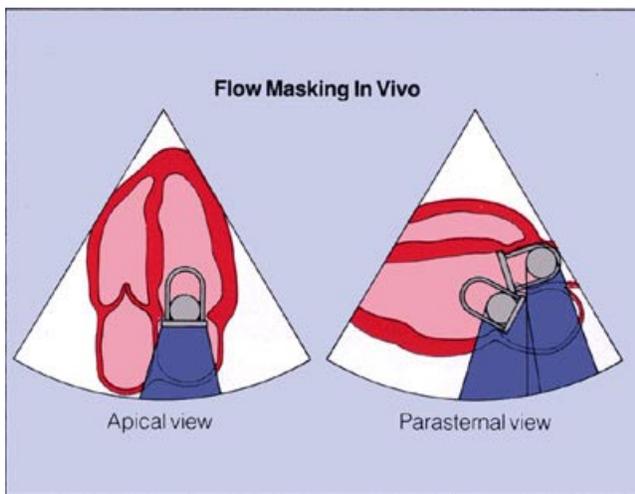


Figure 2.40 Flow masking also occurs in vivo. The left panel demonstrates that most of the left atrium is obscured in the apical four-chamber view. When aortic and mitral valves are in place, almost all the left atrium is obscured from the parasternal approach (right panel).

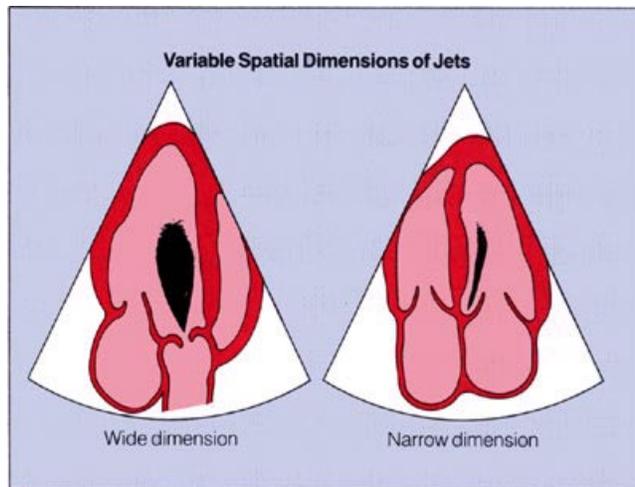


Figure 2.41 Jets have variable spatial dimensions. On the left is an aortic insufficiency jet that is wide in the apical two-chamber view. The same jet may be quite narrow in the apical four-chamber view.

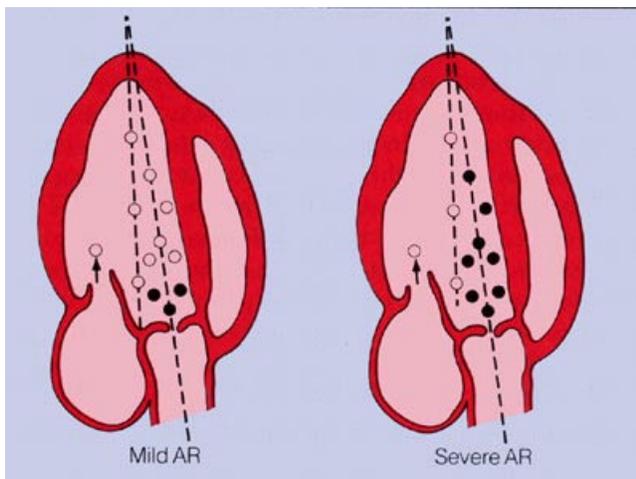


Figure 2.42 Various sample sites for mapping the severity of aortic regurgitation (circles). Left panel shows positive detection of regurgitation just below the aortic valve (closed circles). Right panel shows broader distribution compatible with more severe disease. Sampling near the mitral orifice will invariably detect mitral inflow (arrows).

and differences between any comparisons should be expected.

Many approaches have been proposed to estimate the severity of valvular regurgitation using Doppler. One method relies on the use of PW Doppler to map the size and distribution of the regurgitant jet within a cardiac chamber and is the most common method used. Another is based upon the relationship of forward to reverse flow, while another has attempted to quantify the absolute flow through each valve orifice and then use these flow volumes to calculate the regurgitant fraction. The latter two methods are more complex and not easily performed by beginners to Doppler echocardiography. Another method based upon rate of descent of the velocity spectrum in diastole has been proposed for estimation of the severity of aortic insufficiency.

Pulsed Doppler Mapping Techniques

Even though mapping is the most straightforward approach to the evaluation of severity of valvular regurgitation, it can be a difficult and time-consuming process. It is important to keep in mind the three-dimensional geometry of the chamber being studied. Also, regurgitant jets may be directed anywhere within the chamber and may also be of any three-dimensional configuration. One such possible spatial configuration of an aortic insufficiency jet in the apical four-chamber and apical two-chamber views is shown in **Figure 2.41**.

Simply using a single standard two-dimensional view without angling the transducer in other planes in order to examine the whole chamber may result in significant under- or over-estimation of severity.

The mapping technique can only be performed with PW Doppler echocardiography. It requires some experience with the Doppler technique as well as facility with two-dimensional imaging, since the sample volume has to be systematically located in various places, sampling for valvular regurgitation.

The interrogating two-dimensional plane in the frozen or periodic updated image must be kept constant as each area is sampled until one view has been completely evaluated. Keep in mind

that the mapping technique only provides rough estimates of the severity of valvular insufficiency, and further comparisons with standards such as carefully validated angiographic volume measurements must still be made to assess the value of the technique.

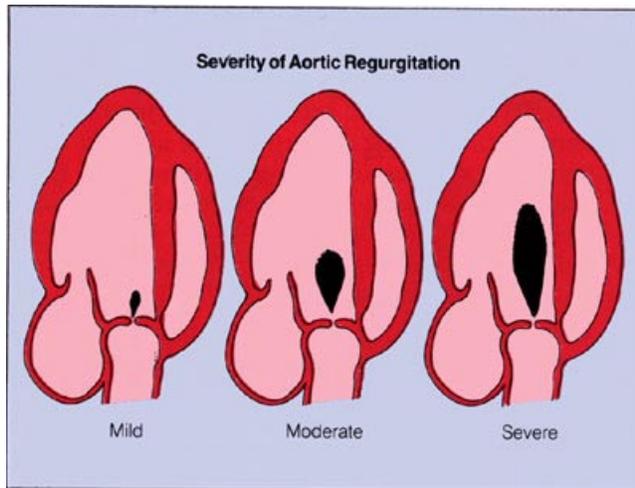


Figure 2.43 Schematic diagram showing the relative areas of turbulence for mild, moderate, and severe aortic regurgitation.

In **Figure 2.42** there is an example of multiple areas sampled (circles) by the pulsed Doppler sample volume while in the apical two-chamber view. In the left panel, the PW Doppler detects aortic insufficiency only on the ventricular side of the aortic valve leaflets (closed circles) and this corresponds to mild aortic insufficiency. The right panel demonstrates the areas where aortic insufficiency was detected (closed circles) much deeper into the left ventricle and this corresponds to severe aortic insufficiency. Sampling directly in the mitral orifice (arrow) will almost always detect mitral diastolic flow that may be interpreted incorrectly as aortic insufficiency, particularly when there is associated mitral stenosis. Frequently these

two abnormal jets blend together and coalesce into one jet directed toward the ventricular apex.

The general areas where turbulent flow would be found in mild, moderate and severe aortic regurgitation are shown in **Figure 2.43**. These are only approximate estimates of severity. The mapping technique assumes that the volume of a jet is proportional to the area of turbulence detected by PW Doppler. While this may be true for the most part, other factors are also likely to affect the area of the regurgitant jet. These are: the size and configuration of the regurgitant orifice, the pressure difference across the orifice, the size and configuration of the receiving chamber, and a host of other factors.

For mitral regurgitation the process is similar, and mapping of the left atrium may be done either

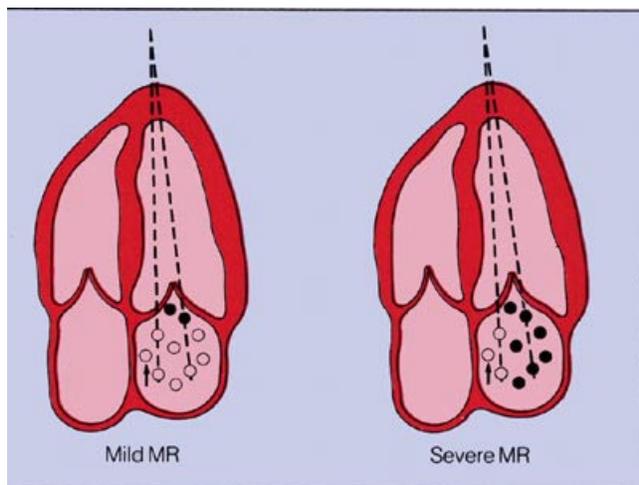


Figure 2.44 Schematic diagrams showing many possible pulsed Doppler sample volume sites (circles). Left panel shows positive detection of mitral regurgitation just near the valve, consistent with mild disease (closed circles). Right panel shows wider distribution of positive sample sites compatible with more severe regurgitation. Sampling near the aortic root (arrows) may bring interference from the

from the parasternal long axis window or from an apical window. We generally prefer to begin with the apical window because mitral regurgitant jets are then usually parallel to the interrogating beam. Further spatial information about the size and direction of the regurgitant jet is then obtained using additional apical and parasternal views. **Figure 2.44** shows multiple placements of the pulsed Doppler sample volume (circles). In the left panel, regurgitation is detected only on the atrial side of the mitral leaflets, a finding consistent with mild mitral regurgitation (closed circles). The right panel shows abnormal flow detected over almost all the atrium and this corresponds to severe valvular regurgitation (closed circles). If higher velocity flows are detected only medially this may be due to aortic outflow because the sample volume is relatively large at this depth.

Interception of aortic outflow signals can present a particular problem in patients with aortic stenosis since this lesion, like mitral regurgitation, produces high velocity systolic flow away from the transducer. A schematic diagram of the general distribution of mild, moderate and severe mitral regurgitation is shown in **Figure 2.45**.

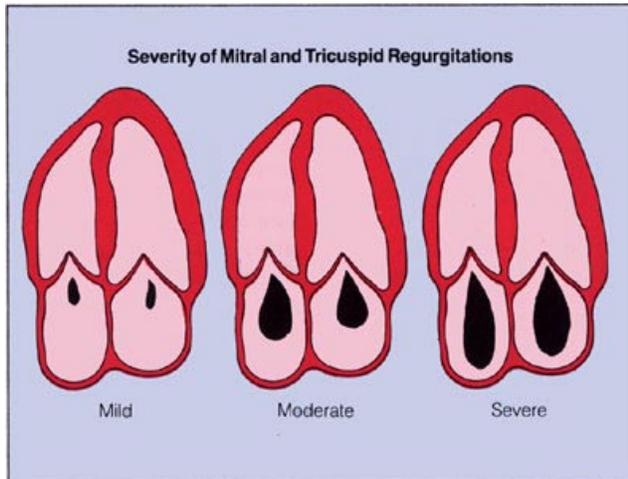


Figure 2. 45 Schematic diagram showing the relative areas of turbulence for mild, moderate, and severe mitral regurgitation.ascending aorta.

used CW Doppler to study systolic velocity in the descending aorta. They divided the area under the velocity curve into two halves and compared the ratio of the two (first half of systole to the second half of systole) in normal subjects and mitral regurgitation patients. They found that in mitral regurgitation patients, more blood was ejected in the first half of systole. While these ratios showed a good correlation with the regurgitant fraction measured at cardiac catheterization, this approach is not in common use.

More recently, some investigators have explored the use of direct volume of flow measurement with Doppler (described in Unit 3) to calculate directly the regurgitant volume and regurgitant fraction. Again, these methods are very time-consuming and not in general use.

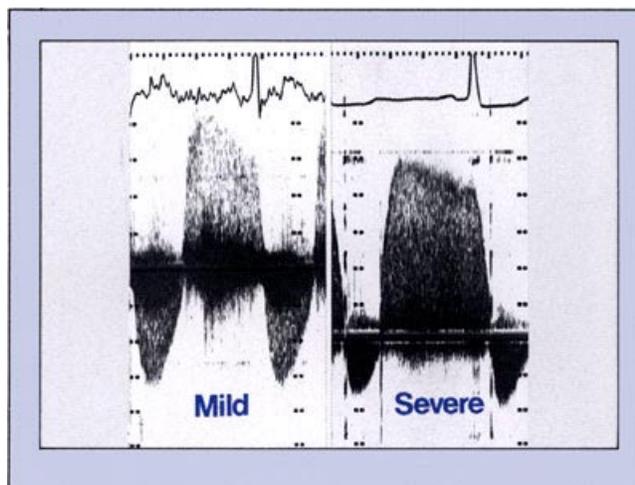


Figure 2. 46 The amplitude or intensity of a given signal is another method for judging the approximate severity of valvular regurgitation.

Similar methods are available for mapping tricuspid regurgitation which involve movement of the sample volume in various areas of the right atrium. A schematic representation of mild, moderate and severe tricuspid regurgitation is also shown in **Figure 2.45**. Mapping methods for estimation of the severity of pulmonic insufficiency are based on the same principles.

Other Doppler Methods

The other approaches to the estimation of severity of valvular regurgitation are more complex. The first attempts were indirect in assessing the amount of regurgitant flow in mitral regurgitation. Some investigators have

Direct inspection of the CW Doppler spectral recordings demonstrate some interesting relationships between flow and the Doppler spectral tracings. In Unit 1, we discussed the importance of amplitude (or intensity) of the spectral recording as a reflection of the number of red blood cells at that given velocity. Using this principle, the more intensive the spectral recording, the more severe the given amount of regurgitation that can be expected when compared with one of lesser intensity. The resultant spectra from a jet of mild aortic regurgitation compared with that of more severe regurgitation are demonstrated in **Figure 2.46**. Note that the more severe regurgitation results in greater amplitude (or intensity).

Obviously, this approach is highly subjective and is dependent upon gain and gray scale settings. Despite its subjectivity, experienced interpreters of Doppler data will use these criteria to separate

mild from more severe degrees of valvular regurgitation when observing examinations performed by experienced operators. Poorly formed, less intense profiles usually result from trivial regurgitations. Well-formed, highly intense jets usually result from more severe valvular regurgitation.

There have been attempts to directly quantify regurgitant flow in aortic insufficiency. One method involves obtaining a CW Doppler spectrum from the ascending aorta from the suprasternal notch. In this approach the area under the forward spectrum is compared with the area under the reverse spectrum and a ratio of retrograde to forward flow is derived. This ratio has been compared with direct measurements made at operation using an electromagnetic flow meter as well as with regurgitant fractions measured at cardiac catheterization. While these results seemed favorable, they are not in common use. Many factors other than volume alone influence the area under the spectral velocity curves.

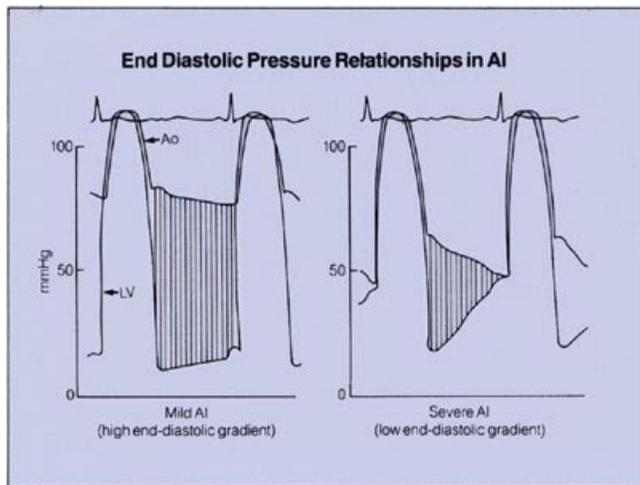


Figure 2. 47 Idealized pressure tracing in mild aortic insufficiency (left panel) and severe aortic insufficiency leaves a negligible end-diastolic gradient in comparison

There are several other methods for assessing aortic insufficiency that are based upon the rate of descent of the diastolic velocity. The theory behind these methods is demonstrated in **Figure 2.47** where idealized pressures from a patient with mild aortic insufficiency are compared with those from a patient with severe aortic insufficiency. When insufficiency is mild, left ventricular diastolic pressures are generally low and aortic diastolic pressure does not fall substantially. Significant diastolic pressure gradients are therefore maintained throughout this portion of the cardiac cycle and at end-diastole the resultant velocities are high. When insufficiency is severe, left ventricular diastolic pressures usually rise and aortic diastolic pressure may fall and approach that of

the left ventricle. In this case, a large diastolic pressure gradient is not maintained throughout this portion of the cardiac cycle and end-diastolic velocities are low.

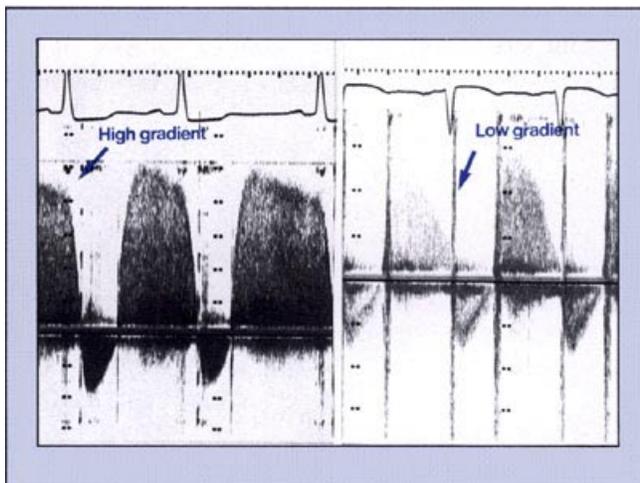


Figure 2. 48 CW Doppler spectral recording from two different patients, one with a high end-diastolic gradient and one with a very low end-diastolic gradient.

In **Figure 2.48**, a CW Doppler spectral recording from a patient with mild aortic insufficiency is compared with that from a patient with mild aortic insufficiency is compared with that from a patient with severe aortic insufficiency where there is little velocity at the end of diastole. These general observations have been extended into a variety of calculations of descend rates for more precision, with generally favorable results.

THE DOPPLER EXAMINATION FOR VALVULAR REGURGITATION

As seen from the many examples described in this Unit, there are several major points to keep in mind when examining patients for the presence of valvular insufficiency. These hints, which incorporate principles described in Unit 1, may increase the reliability of the Doppler data.

Hint 1: One practical point not previously emphasized is that the audible output may be more sensitive than the spectral display. Frequently, a given lesion is heard by audio but cannot be adequately recorded on the spectral hard copy. Interpretation in these cases is often difficult, and, in our experience, usually involves a compromise. Accepting audio evidence of a regurgitant lesion without hard copy confirmation increases the sensitivity of the procedure but will also result in an increased number of false-positive diagnoses. Currently, we require hard-copy confirmation before we will report definite evidence of valvular regurgitation.

Hint 2: It is important for the operator to take time to search for small regurgitant jets. When searching for insufficiency by PW Doppler with an instrument that has a variable sample volume size, the operator should not routinely begin the examination with a sample volume size that is as large as possible. While this may seem desirable for locating small jets, the operator must remember that this process will frequently result in a loss of system sensitivity.

Hint 3: The operator should expect regurgitant jets to exceed a velocity of 1.5 m/sec and result in aliasing when in PW mode. This is certainly true in most adults, since regurgitant lesions are located far enough away from the transducer to cause the Nyquist limit to be exceeded. Thus, in almost every instance, PW Doppler operators should expect aliasing of regurgitant lesions.

Hint 4: Doppler operators, particularly beginners, should be prepared to switch back and forth between pulsed and continuous wave modes. This will help locate areas of turbulence more precisely and will also make it easier to recognize the typical spectral profiles of these lesions. The end result will be an enhanced ability to separate one abnormal lesion from another.

Figure Legends

Figure 2.1 Valvular regurgitation is characterized by inappropriate retrograde flow during the cardiac cycle. The left panel demonstrates mitral regurgitation in systole, the right panel demonstrates inappropriate aortic insufficiency in diastole.

Figure 2.2 During systole, left ventricular pressure is greater than left atrial pressure (left panel). In the presence of mitral regurgitation, the flow communication between these chambers allows a high gradient to exist.

Figure 2.3 The gradient between the left ventricle and the left atrium in mitral insufficiency is reflected by the velocity of the Doppler spectral recording. A high gradient is seen in the left panel while a lower gradient is seen in the right panel. If systolic pressures are the same in both individuals, the recording on the right would suggest higher pressure within the left atrium.

Figure 2.4 Schematic diagram of a mitral regurgitant jet recorded from the apex. Most regurgitant jets result in velocities that exceed 1.5 m/sec and require CW Doppler to record the full spectral velocity profile (left panel). PW Doppler recordings of mitral regurgitation are always aliased (right panel).

Figure 2.5 Left panel demonstrates that regurgitant jets may be directed in just about any direction; right panel shows that the area of the jets may also be widely different, from very small to very large. A complete PW Doppler examination requires tedious mapping throughout the image for detection of abnormal flow.

Figure 2.6 PW Doppler spectral recording of aortic insufficiency. Flow is toward the transducer and aliasing occurs (open arrow) with placement of the higher velocities at the bottom of the spectral tracing (closed arrow).

Figure 2.7 CW spectral velocity recording from the apex of the same patient as Figure 2.6. The full abnormal profile of aortic insufficiency is easily recorded toward the transducer (positive shift), (Scale marks – 1 m/sec).

Figure 2.8 Right ventricular angiogram in slight right anterior oblique view. With a catheter across the tricuspid valve, some degree of tricuspid regurgitation almost always results.

Figure 2.9 Idealized pressure relationships in aortic insufficiency. The left panel demonstrates the large gradient between aorta and left ventricle in mild aortic insufficiency. When aortic regurgitation is severe, central aortic pressure falls and ventricular diastolic pressure rises. This results in a small gradient and lower velocity by Doppler.

Figure 2.10 Normal spectral recording of left ventricular outflow using PW Doppler echocardiography. Systolic flow is away from the transducer and the velocity shift is negative. Some apparent “abnormalities” are usually recorded in diastole. (Scale marks=20cm/sec).

Figure 2.11 PW Doppler recording of aortic insufficiency with severe aliasing (Scale marks = 0.5 m/sec).

Figure 2.12 Aortic insufficiency as recorded from the ventricular apex using CW Doppler is represented as diastolic flow toward the transducer (Scale marks = 1 m/sec).

Figure 2.13 Changing CW spectral patterns encountered when moving the direction of the transducer (at the apex) from aortic outflow where aortic insufficiency (AI) is noted to mitral valve (MV) inflow. Note the mitral profile superimposed on the AI spectra. (Scale marks = 2 m/sec).

Figure 2.14 Similar spectral patterns of aortic insufficiency (open arrow) and mitral stenosis (closed arrow) occurring with slight movement of the Doppler beam. For details, see text. (Scale marks = 1 m/sec).

Figure 2.15 Regurgitation jets may move eccentrically during the cardiac cycle and cross the Doppler beam.

Figure 2.16 PW Doppler recording of changing patterns of an incompletely visualized aortic regurgitant jet that is encountered from slightly different angles from beat to beat (Range marks = 20 cm/sec).

Figure 2.17 CW spectral recording of aortic regurgitation from apex where the regurgitant jet moves in and out of the beam. (Scale marks = 2 m/sec)

Figure 2.18 Five panels showing differing appearances of aortic regurgitation from five slightly different positions near the apex using CW Doppler. The best spectral profile is right. (Scale marks = 1 m/sec)

Figure 2.19 CW spectral recording of aortic insufficiency showing measurement of end-diastolic pressure gradient (Scale marks = 1 m/sec)

Figure 2. 20 PW Doppler spectral analysis of mitral insufficiency with the sample volume located in the left atrium. The high velocities encountered produce aliasing. (Scale marks = 20 cm/sec)

Figure 2. 21 CW recording of typical mitral regurgitation from the apex. The jet is away from the transducer in systole and is usually symmetric in shape. (Scale marks = 2 m/sec)

Figure 2.22 CW spectral recording of typical mitral regurgitation. Note valve closing and opening spikes or clicks. (Scale marks = 1m/sec)

Figure 2.23 High velocity diastolic spikes (arrows) on the CW recording of mitral regurgitation made by vegetation movement. (Scale marks = 1m/sec)

Figure 2.24 Left panel: typical recording of aortic insufficiency and obstruction. Note how the aortic outflow tract turbulence resembles the symmetric profile of mitral insufficiency (arrow) with continuous beam angles through the mitral orifice. (Scale marks = 1m/sec)

Figure 2. 25 With a transducer located at the apex, both mitral regurgitation (MR) and aortic stenosis (AS) appear as systolic movement in a negative direction. Note that mitral systole is longer in duration than aortic. Aortic regurgitation (AR) is also present. (Scale marks = 2m/sec)

Figure 2. 26 A Doppler sample volume is large in the far field and, when placed in the left atrium in areas near the aortic root, may cause spurious evidence for mitral regurgitation.

Figure 2. 27 CW spectral recording from patient with “valve slap” (arrow) that may be wrongly interpreted as incomplete recording of mitral regurgitation.

Figure 2. 28 Varying appearances of mitral insufficiency with arrhythmias. A smaller profile follows the PVC (closed arrow) than the normal beat (open arrow). (Scale marks = 2m/sec)

Figure 2.29 The jet of mitral regurgitation is incompletely recorded due to movement of the jet in and out of the beam. The best spectral profile is indicated (arrow). (Scale marks = 1m/sec)

Figure 2. 30 Typical CW spectral recording of tricuspid regurgitation from the apex. The peak velocity in the jet measures 2.4m/sec. (Scale marks = 1 m/sec)

Figure 2. 31 Varying configuration of tricuspid insufficiency with respiration. (Scale marks = 1m/sec)

Figure 2. 32 Idealized right atrial (RA) and right ventricular (RV) pressure relationships in tricuspid insufficiency. This demonstration is with similar right atrial pressures.

Figure 2. 33 The pressure within the right atrium also has an effect on the gradient between right atrium and ventricle. Thus, right atrial pressures must be estimated from the jugular veins for proper prediction of peak right ventricular systolic pressure.

Figure 2. 34 Marked elevation in right ventricular systolic pressure will result in high velocity tricuspid regurgitant jets (left panel) in comparison to lower right ventricular systolic pressures (right panel).

Figure 2. 35 Varying appearances of tricuspid regurgitation with atrial fibrillation. (Scale marks = 1 m/sec)

Figure 2. 36 Schematic diagram of CW beam direction for detection of tricuspid regurgitation (left). If angled a little too superiorly, the beam will actually intercept the aortic root (middle, right). Thus, aortic outflow may be a reason for false positive tricuspid regurgitation (arrow).

Figure 2. 37 Typical pulmonic insufficiency by CW Doppler. Pulmonic insufficiency may occasionally be differentiated from aortic by the presence of the “a” dip.

Figure 2. 38 A large flow mask is seen behind a Starr-Edwards prosthesis while only the area of flow making from a Carpentier-Edwards heterograft is seen behind the sewing ring.

Figure 2-A Composite photographs of six different prosthetic heart valves. A-Starr Edwards silastic ball valve; B-Starr-Edwards stellite ball valve; C-Bjork-Shiley tilting disk valve in the open position; D-St.Jude’s rotating disk valve in the open position; E-Hall-Kastor tilting disk valve in the open position; Figure 2.-Carpentier-Edwards porcine heterograft valve. For details, see text.

Figure 2. 39 The various spectral recordings of the flow behind prosthetic valves using CW Doppler echocardiography. The control period of flow detection when no valves were in place are shown at either end (con). The letters correspond to the valves shown in Figure 2-A, page 28.

Figure 2. 40 Flow masking also occurs in vivo. The left panel demonstrates that most of the left atrium is obscured in the apical four-chamber view. When aortic and mitral valves are in place, almost all the left atrium is obscured from the parasternal approach (right panel).

Figure 2. 41 Jets have variable spatial dimensions. On the left is an aortic insufficiency jet that is wide in the apical two-chamber view. The same jet may be quite narrow in the apical four-chamber view.

Figure 2. 42 Various sample sites for mapping the severity of aortic regurgitation (circles). Left panel shows positive detection of regurgitation just below the aortic valve (closed circles). Right panel shows broader distribution compatible with more severe disease. Sampling near the mitral orifice will invariably detect mitral inflow (arrows).

Figure 2. 43 Schematic diagram showing the relative areas of turbulence for mild, moderate, and severe aortic regurgitation.

Figure 2. 44 Schematic diagrams showing many possible pulsed Doppler sample volume sites (circles). Left panel shows positive detection of mitral regurgitation just near the valve, consistent with mild disease (closed circles). Right panel shows wider distribution of positive sample sites compatible with more severe regurgitation. Sampling near the aortic root (arrows) may bring interference from the ascending aorta.

Figure 2. 45 Schematic diagram showing the relative areas of turbulence for mild, moderate, and severe mitral regurgitation.

Figure 2. 46 The amplitude or intensity of a given signal is another method for judging the approximate severity of valvular regurgitation.

Figure 2. 47 Idealized pressure tracing in mild aortic insufficiency (left panel) and severe aortic insufficiency leaves a negligible end-diastolic gradient in comparison with mild regurgitation.

Figure 2. 48 CW Doppler spectral recording from two different patients, one with a high end-diastolic gradient and one with a very low end-diastolic gradient.