Echocardiographic Assessment of Valvular Regurgitation: Choosing Patients for Valvotomy / Valve Replacements

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INTRODUCTION

Color Doppler echocardiography represents the most widely used non-invasive method for the assessment of valvular regurgitation. The various color Doppler criteria, their clinical usefulness as well as limitations, are discussed below.

TRANSTHORACIC ECHOCARDIOGRAPHIC ASSESSMENT OF MITRAL REGURGITATION*

Pulsed Doppler provides only a limited amount of information on the severity of MR. For example; it often erroneously indicates the presence of severe MR in patients with systemic hypertension. The severity of MV regurgitation is classified according to the maximum width of the mitral regurgitant jet and the distance it extends into the LA. This width and length of the jet depend significantly on the pressure gradient occurring across the MV during systole. In patients with systemic hypertension, the pressure gradient across the MV is high and may cause the regurgitant jet to extend almost to the back wall of the LA even when severe mitral valve regurgitation is not present. In addition, severe MR may be underestimated by pulsed Doppler if the regurgitant jet is eccentrically directed toward the atrial septum or toward the left atrial posterior wall in the apical 4-chamber view, because this may result in absence of high-velocity aliased signals near the back wall of the LA. In general, we have found that the distance to which the mitral regurgitant jet extends into the LA does not correlate well with the severity of the regurgitation. Pulsed Doppler is also tedious and time-consuming, especially when an attempt is made to map out the area of disturbed flow in multiple planes. Color Doppler, by providing multiple sample volumes almost simultaneously in the LA, eliminates the time-consuming mapping of the mitral regurgitant jet in any given plane.

MV regurgitation is indicated by color Doppler displaying systolic retrograde flow signals in the LA, which originate from the MV. These signals are often mosaic in color because of the presence of high-velocity turbulent flow, but in some cases, the mosaic color is not seen because either the ultrasonic beam is not oriented parallel to the flow in some of the available imaging planes, or mean velocities rather than peak velocities are displayed by color Doppler.

A localized area of flow acceleration may be seen on the ventricular side of the MV. The site of this flow acceleration is usually located exactly opposite the site of the mitral defect, allowing identification of the site of the anatomical defect in the MV. The site of the defect can also be found by color Doppler displaying the flow patterns moving through the MV. For example, a congenital "hole" or a defect due to endocarditis may be clearly outlined by color flow signals moving through it into the LA. In one patient with one of these defects, we have observed two separate jets of MR moving through the hole and the area of coaptation of the mitral leaflets. 2D echocardiography cannot be used in this determination because it may not be possible to differentiate the anatomical defect or the small area of discontinuity in the anterior mitral leaflet from a normally occurring echo dropout."

The severity of MR is estimated by noting the portion of the LA occupied by the regurgitant signals. This is expressed in terms of a ratio of the maximum area of regurgitant flow to the area of the left atrial cavity measured in the same frame. The maximum regurgitant area is determined from the areas planimetered in three orthogonal imaging planes: the long axis, the short axis, and the apical 4-chamber plane. In planimetering this area, both the mosaic signals resulting from the disturbed flow and the laminar flow signals moving in a phasic manner with the disturbed flow are used, because the systolic laminar flow signals usually seen at the distal end of mosaic signals represent mitral regurgitant flow with velocities lower than the Nyquist limit. These low velocity signals ran also result from the nonperpendicular orientation of the ultrasonic beam to the direction of the high velocity regurgitant flow. Other left atrial flow signals which do not move in a phasic manner with the disturbed flow, however, are not included in the area estimation because these signals, in all likelihood, represent pulmonary venous flow. In general, if the regurgitant jet occupies less than 20% of the left atrial cavity, the MV regurgitation present corresponds to the mild or grade 1/3 regurgitation determined by angiocardiography using Nagle's criteria. When the jet occupies between 20 and 40% or more than 40% of the LA, the MV regurgitation corresponds respectively to the moderate or grade 2/3 or severe or grade 3/3 regurgitation classification used by angiocardiography.

Although MR may be present throughout systole, the maximum area of the MR is measured at only one specific instant in time. This area, however, needs to be determined from areas measured during the entire period during which the MR occurs. This would be tedious, time-consuming, and not always reliable, because the size of the measured areas depends on the interrogation angle between the Doppler ultrasonic beam and the flow direction, which varies with the movement of the heart. In general, we have found that the accuracy of the MR assessment does not improve by making area measurements throughout the cardiac cycle. In addition, to obtain the maximum regurgitant jet area, the transducer also must be angled in various directions, because minimal transducer angulations can produce significant changes in the area size.

When a mitral regurgitant jet is narrow at its origin from the MV, the presence of a small defect in the valve is usually indicated. In many patients, however, MV regurgitation results from left ventricular dysfunction or dilatation rather than from an anatomic defect in the MV. This can cause the regurgitant jet to appear wide at its origin from the valve. In patients with huge left atria, the full extent of the MV regurgitation may not be correctly assessed, especially if the acoustic window is small and, thus, a complete interrogation of the LA is impossible. In addition, the severity of MR in patients with very low cardiac outputs may be underestimated because the resultant lower pressure gradient across the MV causes the regurgitant jet to be less turbulent and to become smaller in size (Fig. 1-1).

The severity of MR may not always be correctly assessed using color Doppler because the area of reversed flow signals rather than the actual amount of blood flowing back through the mitral orifice during systole is obtained. It also may not be correctly assessed because the area of systolic turbulence produced by MR is larger than the actual size of the mitral regurgitant jet. The additional area of turbulence results from the "bowling ball" effect or the moving flow from the regurgitant jet impacting on stationary blood cells already present in the LA and causing them to move and to show a Doppler shift (Fig. 1-2) and from entrainment that occurs when the jet moves into the chamber, pulling or "sucking" stationary red blood cells into its flow. Vegetations on the MV, producing considerable dispersion of the mitral regurgitant jet, and heavy fibrosis or calcification in a vegetation attenuating the ultrasonic beam also cause poor visualization of MV regurgitation and hence underestimation of its severity. Using the right parasternal imaging plane, however, this regurgitation may be well visualized in the LA because the LA can be interrogated without the ultrasonic beam having to pass through the vegetation or a calcified MV. Posterior MV leaflet prolapse often causes the mitral regurgitant jet to be directed anteriorly toward the aortic root rather than superiorly so that the flow signals seen using the long axis imaging plane are red rather than the usual blue or the blue and mosaic colors resulting from the normal posterior direction. Significant underestimation of severity of the MV regurgitation occurs if these red signals are considered to be associated with the pulmonary venous inflow rather than the MV regurgitation.

We have found the inter-observer variability in the measurement of the maximum regurgitation area and, thus, in the estimation of the severity of the MV regurgitation to be fairly low. lntermachine variability often exists, however, because of the different capabilities of the available color Doppler systems to detect the low-velocity flows. This intermachine variability is, in our experience so far, not significant enough to change the grading of MR in most patients. Therefore, the severity of the MV regurgitation present can be reliably assessed with any of the commercially available color Doppler systems.

To overcome some of the intermachine variability, the settings need to be adjusted for each system to provide the same optimal flow information. For example, the gain setting needs to be adjusted and standardized for a reliable estimation of the severity of MV regurgitation. As the gain is lowered, the flow signals begin to disappear and as it is increased, static or white noise begins to appear. To calculate the maximum area of disturbed flow due to MV regurgitation, the gain needs to be set so that the white noise just begins to appear. Another example is the color threshold setting or, in other words, the control of the strength of the 2D imaging signals versus the color flow signals on a color Doppler system. This setting determines whether or not the low-velocity flows are detected. When the color threshold is "high" or "on," depending on the system, the 2D imaging signals are stronger, causing the presence of ghosting artifacts, and thus the loss of the low-velocity flow signals, resulting in erroneous calculation of the area of disturbed flow. If the thresholding is "off" or "low", however, the color flow signals are stronger than the 2D imaging signals and the low-velocity flow signals are observed. A final example is the use of the power or amplitude mode, available on only some color Doppler systems. We have been investigating the use of this mode in providing a better quantitative estimation of MV regurgitation, because it is expected to be independent of the Doppler interrogation angle and gives flow information about the concentration of the blood cells in the left atrial cavity. When this mode is on, however, the MR signals may be hard to distinguish from the pulmonary venous inflow signals. The amplitude mode also depends greatly on the gain setting, which may be a significant disadvantage. Therefore, using both the amplitude and velocity modes may provide the most reliable information about the severity of MR.

The color Doppler assessment of MR may not always correlate well with angiography. Angiography, however, is not an ideal "gold standard," because it is highly subjective, and angiographic evaluation of MR depends on variables such as the enlargement of the LA and the amount of radio-opaque contrast material injected. It also depends on the position of the catheter through which the radio-opaque dye is injected. For example, when the catheter is positioned too close to the mitral leaflets, artificial MV regurgitation will be produced. The calculation of regurgitant jet fractions by cardiac catheterization is also not ideal because both the Fick and thermo-dilution techniques used for the measurement of cardiac output show considerable variability. A small error in the estimation of the angiographic total left ventricular stroke volume and the effective stroke volume across the AV can cause a disproportionately large error in the calculation of the regurgitant volumes and fractions. In addition, the assumption made in these calculations that the LV has a standard geometric configuration may not be valid.

Color Doppler is considered better than angiocardiography in assessing the changes in the severity of MR because MR is a dynamic event that depends on the pressure gradient between the ventricle and the atrium and the type of activity the patient is engaged in. Angiography cannot observe this dynamic change because when it is performed, the patient is either sedated or

Fig. 1-1: Effect of cardiac output on mitral regurgitation. This schematic of a parasternal long axis view shows severe MR resulting from a fail posterior leaflet and a large vegetation on the valve. Even though the MR is severe, a low cardiac output may cause its severity to be underestimated. This is due to the fact that the lower pressure gradient acrros the MV resulting from the low cardiac output causes the regurgitant jet to be less turbulent and much smaller in size. In general, for normal cardiac outputs, the presence of severe MR is indicated when a large area of reversed flow signals is displayed(1). As shown by this figure, this area decreases as the cardiac output decreases(2), and when the cardiac output is very low, the area of flow signals decreases markedly(3).

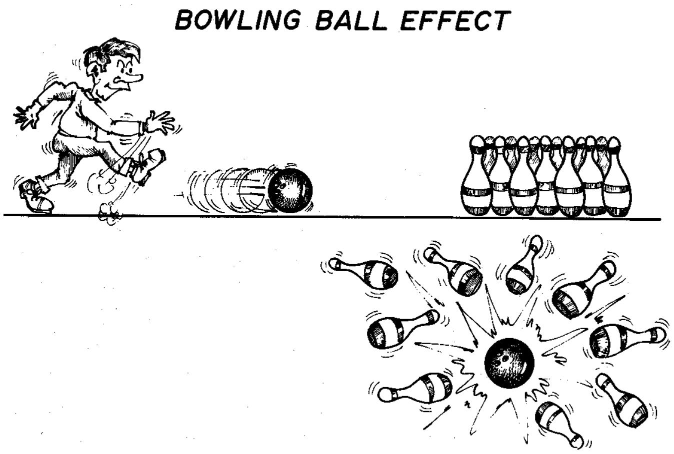

Fig. 1-2: "Bowling ball effect." The severity of the regurgitant lesion can be overestimated because moving flow from the regurgitant jet impacts on stationary blood cells already present in the LA and thus causes them to move and to show a Doppler shift. This"bowling ball" effect increases the area of turbulence and the color Doppler displays a larger area of turbulence. The area of turbulence is also significantly increased because of entrainment. This phenomenon occurs when the jet moves into the chamber, pulling or "sucking" stationary red blood cells into its flow.

premedicated. Thus, the severity is assessed at only one point in time and, being invasive, the procedure cannot be done repeatedly. Color Doppler, however, is completely noninvasive, and may be performed whenever necessary under various clinical conditions to evaluate the presence and severity of MV regurgitation.

Although the presence of a small amount of MV regurgitation can be easily detected by pulsed Doppler and continuous wave Doppler, it may not be easily detected by color Doppler, and thus multiple 2D imaging planes may be needed to detect its presence. Imaging in multiple planes must be done to obtain a complete picture of the mitral regurgitant jet because this jet has three dimensions, and at any given time only two di- mensions of the jet are shown in any given plane. When the presence of MR is questionable by color Doppler due to the difficulty in differentiating a small jet of MR from a ghosting artifact caused by MV motion, the use of the hand-grip maneuver may be helpful. With this maneuver, the blood pressure and the afterload increase, causing the pressure gradient across the MV and the area of disturbed flow in the left atrial cavity to increase during systole. This allows the mitral regurgitant flow signals to be differentiated from the ghosting artifact.

MR may occur in some patients only during exercise and, in some patients studied by us; this appeared to be a good indicator of ischemic heart disease, especially three-vessel disease. The exact cause of the development of MR during exercise is not clear, but it is probably related to ischemic left ventricular dysfunction or papillary muscle dysfunction produced by ischemia, which, in turn, is induced by exercise.

Color Doppler evaluation of MR has also been found useful in patients with cardiac transplantation who develop acute rejection with myocyte necrosis seen on endomyocardial biopsy. In these instances, because of left ventricular dysfunction, MR may develop or increase significantly in severity, indicating acute rejection. This MR disappears or decreases considerably when the acute rejection is alleviated after chemotherapy. When MR does not develop or increase in severity, the acute rejection process is absent in the cardiac transplant patient. A color Doppler examination may thus reduce the need for multiple endocardial biopsies, which presently are routinely performed in the follow-up of these patients.

Color Doppler is also useful in the assessment of diastolic MV regurgitation and associated lesions such as aortic, tricuspid, and pulmonary regurgitation. For example, color Doppler clearly delineates diastolic MV regurgitation by displaying flow signals moving through a partially closed MV into the LA. This occurs in some patients with severe aortic regurgitation (AR) which results from the left ventricular end-diastolic pressure being higher than the left atrial pressure during late diastole. Diastolic MR may also be observed when the pulmonary regurgitation (PR) interval is prolonged, as may occur in first-degree or complete atrio-ventricular block.

For timing events in the cardiac cycle and also timing the onset and duration of MV regurgitation, a color M-mode examination is better than a 2D examination because its faster frame rate prevents overlapping of flows from occurring at adjacent but different times in the cardiac cycle. Most MV regurgitations, even mild, are pansystolic eventhough the murmurs are not audible on clinical examination throughout the duration of systole. In some patients with MV prolapse, color M-mode clearly shows MR occurring only during middle to late systole and, as mentioned previously, patients with first-degree atrioventricular block or severe AR may show diastolic MR.[1]

TRANSESOPHAGEAL ECHOCARDIOGRAPHIC ASSESSMENT OF MITRAL REGURGITATION**

The severity of mitral regurgitation cannot be assessed by comparing jet area to left atrial area, as is done in transthoracic echocardiography, because the entire left atrium is not visualized. Instead, a semiquantitative grading system based on total jet area may be used. A jet area smaller than 4 cm^2 indicates mild mitral regurgitation; an area 4 to 8 cm^2 indicates moderate regurgitation; and an area larger than 8 cm^2 indicates severe regurgitation. The entire area of jet flow, including low velocity flow, should be planimetered because the angle at which the flow is measured, which is nearly perpendicular at times, may cause the appearance of low velocity in a high velocity jet.

Sometimes the total jet area is misleading. In the case of eccentric jets (typically seen with mitral valve prolapse or flail mitral valve) or jets that strike a vegetation or course along a mitral leaflet or the atrial wall, momentum and jet energy are lost, less blood is entrained, and the jet size suggests less severe regurgitation than is actually the case. To determine the severity of mitral regurgitation, therefore, the entire study must be considered. Visible extension of the regurgitant flow into the left atrial appendage or any of the pulmonary veins indicates the presence of severe regurgitation. In such cases, pulse Doppler interrogation of a pulmonary vein near its entrance into the left atrium demonstrates systolic flow reversal that may be aliased. This typically occurs in midsystole or late systole because the jet has to traverse the whole length of the left atrium before it reaches the pulmonary vein. It is important to interrogate all the pulmonary veins by Doppler because systolic flow reversal may be found in only one of them. Reduction in the height of the systolic wave without flow reversal may be seen with moderate regurgitation, but this is not a specific finding. It may also occur in patients with left ventricular dysfunction without mitral regurgitation.

Prominent proximal flow acceleration also alerts the echocardiographer to the presence of significant mitral regurgitation in patients with small eccentric regurgitant jets. The size of this proximal flow convergence varies according to the Nyquist limit that has been set, with the best results usually obtained with a very low Nyquist limit. However, quantitation of regurgitant volume using proximal flow convergence is fraught with inaccuracies that make the qualitative approach more appropriate.

TRANSTHORACIC ECHOCARDIOGRAPHIC ASSESSMENT OF AORTIC REGURGITATION*

A pulsed Doppler examination helps detect the presence of AR by showing aliased signals in the LVOT during diastole. It has comparable sensitivity to a color Doppler examination in the detection of the presence of AR, but limited ability in assessing its severity. The severity of AR is estimated with pulsed Doppler by measuring the distance in the LV that turbulent flow signals are seen. If a small area of high-velocity aliased signals is localized near the AV, the AR is classified as mild, and if these signals extend to the level of the anterior mitral leaflet, it is classified as moderate. Turbulent signals extending beyond the MV to the level of the papillary muscles or toward the left ventricular apex indicate severe AR. In many patients with an eccentrically oriented regurgitant jet, the diastolic turbulent signals may, however, be directed toward the anterior mitral leaflet or toward the ventricular septum and may not extend beyond the anterior mitral leaflet to the level of the papillary muscles in even severe AR. The aortic regurgitant jet may also extend past the level of the anterior mitral leaflet in patients with mild regurgitation because of a high diastolic pressure gradient across the AV, such as occurs in patients with systemic hypertension.

A color Doppler examination overcomes these limitations of a pulsed Doppler examination, making it currently the technique of choice in the noninvasive assessment of the severity of AR. This lesion is detected by color Doppler when mosaic signals originating from the AV are located in the LVOT during diastole. The width or height of these signals at their origin from the AV is a good indicator of the severity of AR. When the proximal jet width (height) occupies less than 25 % of the width of the LVOT at the same location, the regurgitation correlates with mild or Grade I regurgitation found by angiocardiography using Hunt's criteria. When the jet width (height) is between 25 and 46% or 47 and 64% of the width of the LVOT, the AR is classified as moderate or Grade II, or moderately severe or Grade III regurgitation, respectively, by angiocardiography. A regurgitant jet width (height) greater than 64% of the width of the LVOT indicates severe or Grade IV and V AR by angiocardiography. These criteria for estimating the severity of AR are based on the rationale that the width (height) of the aortic regurgitant jet signals moving through the AV is related to the size of the defect in the aortic valve. For example, if the defect is very small, the width (height) of the regurgitant signals moving into the LV at its origin from the AV is small; if the defect is large and occupies a significant proportion of the AV, the flow signals moving through that defect also have a larger width (height).

It is important to remember that the aortic regurgitant jet produces turbulence and "entrainment" in the blood already present in the LVOT, and therefore the width of the turbulence is usually greater than the width of the defect in the AV. This has been documented by our in vitro studies with a flow model reproducing AR. Also, the aortic regurgitant jet has three dimensions, and therefore measuring only two dimensions of the jet as in the long axis imaging plane may not be adequate to determine its size. To eliminate this problem, the aortic regurgitant jet must also be examined in the short axis imaging plane taken at the high LVOT just proximal to the level of the AV. This view gives the exact shape of the jet as it originates from the AV, allowing for its area and the amount of the LVOT it occupies to be accurately measured or the severity of the AR present to be estimated. In this short axis view at the level of the high LVOT, the severity expressed as a ratio of the areas of the regurgitant signals to the LVOT ranges from 0 to 3%, 4 to 24%, 25 to 59%, and 60 to 100% to correspond to angiographic gradings of Grades, I, II, III, IV, and IV - V, respectively, using Hunt's criteria. These ratios correlate better with the angiographic grading than the long axis measurements because in the short axis view, an estimate of the jet area at its origin from the AV can be obtained in all three dimensions. This is technically more difficult to perform, however, because the 2D echo "slice" at the level of the LVOT has to be perpendicular to the jet or an overestimation of the severity of AR may occur. Also, to obtain this view in many patients is very difficult, and if the view is obtained below the level of the high LVOT, the jet appears to be much larger because the aortic regurgitant jet frequently widens immediately after its origin from the AV due to the driving pressure across the AV during diastole. Therefore, when assessing the severity of AR in short axis view, only high LVOT planes, preferably those in which the AV elements are also imaged, must be used. This guarantees an accurate measurement of the regurgitant jet area at its origin from the AV. Although the aortic regurgitant jet appears circular in the short axis view, in most patients with AR, especially mild, it can appear elliptical or irregular in other patients. The width of the aortic regurgitant jet may also be measured in the apical long axis view, and the severity of this regurgitation expressed as a percent ratio of the widths of the regurgitant jet to LVOT width can be estimated using this view.

In our experience, expressing the width of the jet at the level of the high LVOT in the long axis view as a ratio to the width of the LVOT is an adequate method for estimating the severity of AR in most patients. The severity of AR can be reliably estimated using our criteria even when there is coexisting mitral stenosis because, at its origin from the AV, the jet is clearly distinguishable from the mitral stenotic jet. The two jets, however, may merge farther downstream, making it difficult to distinguish between them and to measure the maximum area of AR in the LV in many cases. We have found this to be true even in patients who do not have mitral stenosis because the prominent normal mitral inflow signals mix with the lower-velocity AR signals farther downstream in the LV, making the exact aortic regurgitant area difficult to delineate. The area, unlike the proximal width of the aortic regurgitant jet, also depends on the diastolic pressure gradient across the AV. For example, when the size of the anatomical defect in the AV remains constant, the aortic regurgitant area is much larger in a patient with systemic hypertension than in one with normal blood pressure (Fig. 2-1).

The measured width of aortic regurgitant signals in a patient may vary when the patient is examined on different color Doppler systems because of the different instrument settings available on each system. These differences are generally not significant enough to alter the grading of the AR in the most patients. In assessing the presence and severity of AR, however, it is recommended to use a set of standard optimal instrument settings and to move and angle the transducer in small increments and multiple directions to obtain the maximum proximal width of the aortic regurgitant jet.

Occasionally, a localized area of flow acceleration is seen on the aortic side of the AV, directly opposite the origin of the aortic regurgitant jet during diastole. This flow acceleration often indicates the site of the defect in the AV and may provide an estimate of the size of the defect because this flow acceleration tends to take the shape of the defect in the valve.

We have encountered difficulties in assessing the severity of AR in some specific clinical situations. For example, we have found that, if the aortic root is aneurysmally enlarged, the jet width in the long axis underestimates the severity of AR. This is probably because the wide LVOT and aortic root tend to cause a small width ratio despite even a large jet width. In patients with AV vegetations also, we have sometimes underestimated the severity of aortic regurgitation. This may have occurred because the vegetation causes dispersion of the aortic regurgitant jet and resultant difficulty in measuring its width at the level of the AV.

In patients with moderate or severe AR, color Doppler examination of the aorta frequently shows prominent retrograde flow in both the ascending and descending aorta during diastole. In our experience, these prominent retrograde flow signals in the descending aorta during diastole indicate the presence of severe AR. It is, however, important to emphasize that the presence of a few retrograde flow signals in the ascending aorta in diastole does not necessarily imply the presence of AR.

Color Doppler has also been found useful in diagnosing the presence of diastolic MR. This regurgitation may be associated with severe AR when the high left ventricular end diastolic pressure exceeds the left atrial pressure during late diastole. Usually this diastolic regurgitation is mild in severity, but whenever it is detected, it signifies the presence of severe AR. This is true only in the absence of first-degree or complete atrioventricular block, because if the P wave occurs much earlier during diastole mitral diastolic regurgitation may occur even in the absence of AR.

The aortic regurgitant jet signals may be directed centrally into the LV, posteriorly along the anterior mitral leaflet, or anteriorly toward the ventricular septum (VS). In some patients, we have observed this jet to move posteriorly, striking the anterior mitral leaflet and then being deflected by the leaflet anteriorly toward the VS. We have also seen this regurgitant jet directed anteriorly toward the VS until it is deflected posteriorly toward the MV. This appears as a characteristic inverted "U" shape. The jet, which strikes the MV and then is deflected anteriorly toward the septum, produces a characteristic "J" shape or "hockey stick" appearance. An occasional aortic regurgitant jet may first be directed centrally into the LV until it suddenly changes its direction anteriorly toward the septum or posteriorly toward the anterior mitral leaflet. In some instances, especially with bicuspid AVs, the jet may originate anteriorly or posteriorly near the junction of the aortic wall with the VS. The AR jet has also been noted to bifurcate, with one portion moving posteriorly toward the left ventricular wall and the other moving anteriorly toward the VS. Two distinct jets of AR may also sometimes be seen directed toward the VS and toward the anterior mitral leaflet. In our experience, most patients have an aortic regurgitant jet originating centrally from the coaptation point of the aortic leaflet. Occasionally, in the parasternal long axis view, an apparently wide jet originating from the anterior aspect of the aortic valve may be observed to be directed posteriorly along the AV, leading to the conclusion of the presence of severe AR, but if the origin of the regurgitant jet is examined, it may be discovered that an erroneous diagnosis of severe AR has been made. In other words, even when the AR is mild, the jet may originate eccentrically near the junction of the anterior aortic wall with the VS causing it to move posteriorly along the AV, and this posterior direction of the jet may be misinterpreted as a wide aortic regurgitant jet filling the entire width of the LVOT. To avoid this misinterpretation, the examiner must pay careful attention to delineating the width of the aortic regurgitant jet at its origin from the AV. In numerous patients with mild AR, the width of the aortic regurgitant jet at its origin from the AV

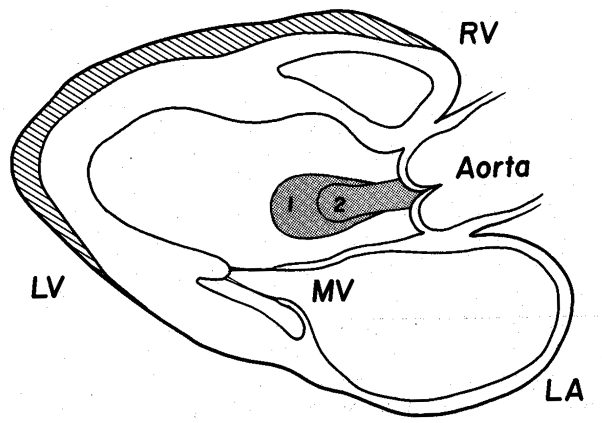

Fig. 2-2: Effect of sytemic hypertension on aortic regurgitation. The area and not the proximal width of the aortic regurgitant jet depends on the diastolic pressure gradient across the AV. For example, the aortic regurgitant area is much larger in the parasternal long axis view of a patient with systemic hypertension (1) than in one with normal blood pressure (2), even though approximately the same size defect is present. The depth that the regurgitant jet extends into the LV also depends on the diastolic pressure gradient across the AV. In general, the observed depth is larger in a patient with stemic hypertension.

does not seem to change significantly as the jet moves down stream into the LV. In other patients, the jet appears to widen considerably downstream in the LVOT. The aortic regurgitant jet often loses its mosaic color pattern deep into the LV because its velocity decreases to below the Nyquist limit for that particular examination. Color Doppler studies in patients with AR also facilitate the parallel placement of the continuous wave Doppler cursor to the direction of the aortic regurgitant jet so that reliable diastolic spectral velocity waveforms may be obtained. Inspection of deceleration of the peak velocity in patients with AR has been found useful in providing some information regarding the left ventricular end-diastolic pressure and in estimating the severity of AR using the pressure half-time method. If the velocity deceleration during diastole is fast, it suggests the presence of an increased left ventricular diastolic pressure, and if it is slow, a normal left ventricular diastolic pressure exists.

Careful attention should be paid to the timing in the cardiac cycle when assessing patients for AR. For example, anteriorly directed signals appearing to originate from the AV may sometimes be seen near the VS during systole. These signals can be easily mistaken for AR if careful attention is not paid to the timing of the cardiac cycle. Because these signals are present during systole and consistently absent during diastole, they possibly result from a ghosting artifact from the motion of the VS.

For timing the onset and duration of AR, color M-mode is more accurate than 2D color Doppler because of its increased frame rate. The slower frame rate of the 2D color Doppler may cause errors in timing because it may cause overlapping of flow information from two adjacent areas. Using color M-mode, we have found that even with mild AR, the regurgitant jet is pandiastolic, although clinically the murmur is audible by auscultation only during early diastole.

In patients with AR and a "bowing" or "bent knee" deformity of the anterior mitral leaflet, color Doppler examination generally shows moderate to severe AR with the aortic regurgitant jet impinging on the anterior mitral leaflet at the site of the deformity. In our experience, this deformity is not seen in patients in whom the aortic regurgitant jet is not directed toward the anterior mitral leaflet. This deformity is thus shown by color Doppler to probably result from the high-velocity aortic regurgitant jet impinging on the anterior mitral leaflet.[2]

TRANSESOPHAGEAL ECHOCARDIOGRAPHIC ASSESSMENT OF AORTIC REGURGITATION

Assessment of the severity of AR is based on semiquantitation using the fraction of the left ventricular outflow tract (LVOT) at the origin of the diastolic jet on the ventricular aspect of the aortic valve that is covered by the jet. The ratio of proximal jet width to LVOT diameter (taken at the same location) of <39% represents mild or moderate regurgitation; 39% to 74% represents moderately severe AR; and ≥75% represents severe AR. Two technique points are important. First, the assessment must be made the origin of the jet. Second, the Nyquist limit is important if it is set higher than 35 to 45 cm/sec, changes in the color filter result in loss of imaging of lower velocities and thus change the size of the proximal jet.[3]

TRANSTHORACIC ECHOCARDIOGRAPHIC ASSESSMENT OF TRICUSPID REGURGITATION*

Color Doppler echocardiography provides a better evaluation of tricuspid regurgitation (TR) than pulsed Doppler echocardiography because this type of regurgitation can be viewed in multiple imaging planes in a much shorter period of time with color Doppler than with pulsed Doppler.

A color Doppler examination of TR using either the aortic short axis, right ventricular inflow, or apical 4-chamber view shows mosaic signals originating from the tricuspid valve (TV) and extending into the RA during systole. In some patients, however, TR is best visualized using the right parasternal imaging plane combined with suitable transducer angulations because it produces a larger view of the right atrial cavity. TR may also be seen using the apical right ventricular 2-chamber view or, in younger patients, subcostal views such as 4-chamber views.

The tricuspid regurgitant jet in the RA is initially mosaic in color because of turbulence and aliasing. It may, however, become laminar farther in the RA as its velocity decreases below the Nyquist limit, causing it to be shown as either red or blue depending on the direction of the flow in relation to the transducer. Diastolic frames may show prominent inflow signals moving into the RV from the RA, representing increased flow across the TV during diastole. This increased flow occurs because the tricuspid regurgitant flow combines with right atrial inflow. In some patients, the tricuspid regurgitant jet may not show any aliasing or obvious turbulence because of a nonparallel orientation of the Doppler beam to the tricuspid regurgitant flow or, in some cases, because of a small difference between the right ventricular and right atrial systolic pressures.

The tricuspid regurgitant signals in some imaging planes may not appear to originate from the TV, but careful manipulation of the transducer clearly defines the TV as the origin of these flow signals. The TR jet must also be distinguished from a thin linear vertical and of high-frequency signals which may be seen at the closure point of the TV during color M-mode examination. The tricuspid regurgitant signals are broader than the ghosting, artifact signals that result from rapid closing movement of the TV.

Tricuspid regurgitant signals may be oriented laterally, centrally, or medially toward the atrial septum (AS). In the latter case, the jet may be located very close to the AS and, when pulsed Doppler is used, may be mistaken for a mitral regurgitant jet because of its proximity to the AS. Color Doppler, however, clearly displays no signals in the left atrial cavity and shows the tricuspid regurgitant jet limited by the AS and originating from the TV. In patients with right ventricular pacemakers, the tricuspid regurgitant jet may have a markedly eccentric direction because of the presence of a pacemaker lead in the TV orifice. In patients with moderate or severe TR and a nondilated right atrial cavity, the TR flow may swirl back toward the TV after impacting the back wall of the RA. When it hits the back wall it swirls back toward the TV, the regurgitant jet loses kinetic energy; that is, its velocity decreases, causing it to be displayed by mainly laminar flow signals. These laminar signals occur during systole and can be distinguished as a part of the tricuspid regurgitant flow by their continuity with the mosaic-colored tricuspid regurgitant jet. In the presence of a dilated right atrial cavity, we have noticed this phenomenon of swirling only in patients with severe TR.

Two distinct mosaic jets of TR may be seen in some patients originating from the same leaflet or from two different leaflets. These two jets may not merge with each other or may merge downstream in the RA. We have sometimes seen one jet of TR that bifurcates farther upstream in the right atrial cavity.

The exact site of the defect in the TV may sometimes be pinpointed by noting the location of the flow acceleration on the ventricular aspect of the TV. Flow acceleration is shown as an increase in the color brightness of the retrograde flow signals or as aliasing. It may also take on a shape that can reflect the size of the defect in the TV. Occasionally, multiple sites of flow acceleration or regurgitation are observed in the TV because of the presence of multiple anatomic defects.

No real "gold standard" for estimating the severity of TR exists. Cardiac catheterization cannot be used to evaluate this lesion because the catheter passing through the TV for right ventricular injection interferes with the closure of the TV leaflets, causing artificial TR. In our experience, the severity of TR is best estimated with use of color Doppler by planimeterizing the maximum tricuspid regurgitant jet obtained, using the available multiple imaging planes and transducer angulations. This jet area is expressed as a percentage of the area of the right atrial cavity, obtained by using the frame in which the maximum tricuspid regurgitant jet was noted. A ratio of 20% or less indicates the presence of mild TR and a ratio between 20 and 34% indicates the presence of moderate TR. Severe TR is indicated by a ratio greater than or equal to 35%. These color Doppler criteria have been indirectly validated. We recently assessed the presence and severity of TR by color Doppler in patients who were scheduled to undergo MV or AV replacement and correlated our results with intraoperative assessment of TR. In approximately 90% of patients judged by the surgeon to have TR severe enough to require TV annuloplasty, the maximum tricuspid regurgitant jet area by color Doppler occupied 35% or more of the right atrial area. On the other hand, the maximum tricuspid regurgitant jet area by color Doppler occupied less than 35% of the right atrial area in about 90% of patients judged by the surgeon not to have severe TR and therefore not candidates for TV repair or replacement. Therefore, color Doppler can be used to identify patients with severe TR who would require TV repair in conjunction with AV or MV replacement. It is important to realize that intraoperative assessment of TR is not absolutely reliable, and the surgeon often uses both intraoperative and the clinical findings to make a judgment on whether or not to replace the TV. Color Doppler can also be used to estimate the severity of residual TR after TV annuloplasty repair.

When tricuspid regurgitant signals are observed moving into the IVC and hepatic veins during systole, the regurgitation is not classified as mild but as moderate to severe. This flow pattern can be best visualized by interrogating a vertical hepatic vein so that the Doppler beam is parallel to the flow patterns in this vein. Severe TR is indicated when systolic retrograde flow is observed moving into the SVC. Although this finding is specific for severe TR, it lacks sensitivity and is rarely observed. Tricuspid regurgitant signals may also be occasionally seen moving into the coronary sinus in patients with severe TR. This is best observed using the right parasternal imaging plane, but it may also be observed in the right ventricular inflow view.

After color Doppler identifies the presence of TR, the systolic pulmonary artery pressure can be estimated using the results obtained from color-guided continuous wave Doppler. The mosaic signals of TR displayed by color Doppler help to provide a reference for the positioning of the continuous wave Doppler cursor parallel to the regurgitant flow and to record reliable peak velocities during systole. The Bernoulli equation then can be used to calculate the pressure gradient across the TV using these velocities. Adding an assumed right atrial pressure of 10 mm Hg to this calculated pressure gradient, the pulmonary artery systolic pressure can be estimated. We have found this estimation technique extremely useful in assessing the severity of pulmonary hypertension in patients with both AV and MV disease and in patients being considered for cardiac transplantation.

Although color Doppler allows diagnosis of TR, its etiology is often determined by 2D echocardiography. For example, a mass on the TV in a patient with a febrile illness alerts the examiner to the presence of bacterial endocarditis. Patients with rheumatic involvement show TV thickening and patients with papillary muscle, dysfunction due to ischemic heart disease show an inferiorly displaced coaptation point of the TV below it's annulus. The TV may appear to be flail in patients with chordae rupture due to endocarditis or trauma. In many other patients, however, the etiology of TR is not clear even though the dilatation of the RA, tricuspid annulus and RV suggest the presence of "functional" TR, or regurgitation due to right heart enlargement. It should be emphasized also that minimal TR may occur in apparently normal healthy individuals and thus may not necessarily be pathologic.[4]

TRANSESOPHAGEAL ECHOCARDIOGRAPHIC ASSESSMENT OF TRICUSPID REGURGITATION**

Tricuspid regurgitation is far more common than stenosis. The most common cause of moderate or severe tricuspid regurgitation is right heart dilatation. Mild tricuspid regurgitation is commonly seen in normal healthy individuals and, therefore, often is not pathological. The absolute jet area is used to semiquantitate the severity of tricuspid regurgitation; therefore, it is important to image the tricuspid valve in multiple planes to find the maximum jet area. In the absence of an angiographic "gold standard," the criteria used for assessing the severity of mitral regurgitation also are used to grade the severity of tricuspid regurgitation. Mild tricuspid regurgitation is considered to be present when the maximum jet area is <4 cm^2, moderate when the jet area is 4 to 8 cm^2, and severe when the jet is >8 cm^2. Proximal flow acceleration is also an important marker of significant regurgitation.[5]

TRANSTHORACIC ECHOCARDIOGRAPHIC ASSESSMENT OF PULMONARY REGURGITATION*

Color Doppler is superior to pulsed Doppler in the examination of pulmonary valve (PV) regurgitation. The width and depth of the regurgitant signals can be delineated rapidly and accurately with color Doppler. With pulsed Doppler, however, much time is required to assess these parameters, making these measurements tedious for the examiner and inconvenient for the patient.

The presence of PV regurgitation is indicated by color Doppler when retrograde signals are displayed originating from the PV and moving into the RVOT during diastole. These retrograde signals are usually mosaic in color because of turbulent flow. Non-turbulent red signals may, however, occasionally result from lower velocity flows when a small pressure gradient exists across the PV during diastole or when the Doppler ultrasonic beam is not oriented parallel to the flow. These signals are best visualized using the aortic and mitral pulmonic short axis and left ventricular-pulmonic imaging planes. In some patients, PV regurgitation may also be well delineated using the subcostal right ventricular inflow-apical outflow imaging plane.

The severity of PV regurgitation is assessed by considering both the length and width of the regurgitant jet. If the proximal width of the pulmonary regurgitant jet at its origin from the PV is less than 50% of the RVOT width at the same location, the severity of the regurgitation is classified as mild or moderate. If this jet width is wide and greater than 50% of the RVOT width, the severity of the pulmonary valve regurgitation is classified as moderately severe to severe. In patients with severe PV regurgitation, the proximal RVOT width may be completely filled with diastolic mosaic signals and prominent antegrade signals may be seen moving into the pulmonary artery during systole because of the combined flow resulting from the pulmonic regurgitant flow and the normal flows occurring in the right heart. Severe PV regurgitation is also indicated when the regurgitant jet extends the entire distance to the level of the TV. When the pulmonic regurgitant jet in an adult extends more than and less than four cm into the RVOT, moderate and mild pulmonary valve regurgitations are present, respectively. To ensure that the maximum width and length of the regurgitant jet are measured, a complete 3-dimensional view of the jet must be obtained by angling and rotating the transducer in multiple directions. In addition, the mosaic regurgitant jet may lose its mosaic color farther downstream in the RVOT because the velocity of the jet decreases below the Nyquist limit and the flow becomes laminar. This must be considered when noting the length of the regurgitant jet.

Occasionally, in patients with infundibular stenosis and severe pulmonary regurgitation, pulmonic regurgitant jet may appear narrow because of the narrowing of the RVOT. Observation of this jet extending down-stream into the RV up to the level of the TV, however, allows a definite conclusion to be made that this PV regurgitation is severe. In these cases, an examination of the TV inflow region is very useful because this allows the extension of the pulmonary regurgitant jet to be observed.

In many patients with PV regurgitation, flow acceleration may be seen on the pulmonary artery side of the PV. These signals may pinpoint the exact location of an anatomical defect in the PV leaflets and, by noting their width near the PV, may provide an estimate of the size of this anatomical defect.

A narrow band of diastolic flow signals, occurring usually at the coaptation point of the PV leaflets and extending only a short distance into the RVOT, consistent with minimal or mild PR, may occur in a significant number of apparently healthy individuals, and thus its presence may not indicate any pathologic abnormality of the pulmonary valve or annulus. The presence of a wide jet originating from the PV and extending deep into the RVOT, however, indicates significant PV regurgitation and is always abnormal. Multiple jets of PR originating from either one leaflet or two different leaflets of the PV may also be seen in some patients. A pulmonic regurgitant jet originating from the PV as a single jet and bifurcating into two jets farther downstream in the RVOT or two pulmonic regurgitant jets occurring separately during early diastole and mid-diastole may also sometimes be observed.

The pulmonic regurgitant jet signals may be oriented centrally, medially, or laterally. Occasionally, instead of being centrally located, the jet may be directed posteriorly in the RV until it hits the VS and turns anteriorly, taking on a "J"-shaped appearance. In some patients, the pulmonic regurgitant jet may be directed anteriorly until it strikes the anterior right ventricular wall and turns posteriorly. The flow pattern for this jet is thus displayed as an inverted "U" shape. The pulmonic regurgitant jet may also swirl in the RV after impacting the wall of the RVOT. Some of this flow may then turn back toward the PV during late diastole.

As mentioned previously, in patients with severe PR, the regurgitant jet may extend all the way down to the TV level and its impingement on the TV may cause it to flutter in diastole. In some patients, severe PR may cause late diastolic TV regurgitation. This can be confirmed by color M-mode examination, which clearly shows reversed flow signals in late diastole in the RA originating from the TV and reversed diastolic flow signals in the RV impinging on the TV. This diastolic TR results from transient reversal of the pressure gradient across a partially closed TV in late diastole due to marked increase in right ventricular diastolic pressure from severe PR. It is important to emphasize that late diastolic TR may also be noted in patients with a prolonged PR interval who have no evidence of PR. Thus, in patients with severe PR, it is important to exclude first degree atrio-ventricular block or complete heart block before attributing the late diastolic TR to marked increase in right ventricular diastolic pressure.

Color Doppler can diagnose the presence of PR even in patients with tricuspid prostheses. In these patients, the inflow originating from the prosthesis and the PV regurgitation are displayed by mosaic signals. The origin of these two different sets of signals can be easily delineated, allowing their classification, but farther downstream in the RV, these signals from PR and tricuspid inflow through the prosthesis tend to merge, making their delineation difficult. In these patients, only the width of the PR signals at their origin from the pulmonic valve can be used to estimate the severity of regurgitation. Color-guided continuous wave Doppler can also be used in the evaluation of patients with pulmonic regurgitation. A continuous wave Doppler cursor passed through the pulmonic regurgitant jet signals obtains a reliable diastolic pressure gradient across the PV. In the absence of right heart failure, a high peak pressure gradient between the PA and RV indicates an increased diastolic gradient which occurs with significant pulmonary hypertension, while a low-pressure gradient across the pulmonary valve indicates normal PA pressure. This low-pressure gradient is often noted in an apparently healthy individual with minimal PV regurgitation. A rapid deceleration in the spectral trace of the pulmonary diastolic waveform indicates a rapid equalization of the PA and right ventricular diastolic pressures. This suggests that the right ventricular end-diastolic pressure may be elevated. Therefore, evaluation of the PV regurgitation may be useful in assessing the presence of pulmonary hypertension and providing an estimate of the right ventricular end-diastolic pressure.

A color M-mode examination is useful to assess the duration of the pulmonic regurgitant flow. Even in patients with mild PR, abnormal retrograde signals may be seen throughout diastole, indicating that the leakage is pandiastolic. Prominent color signals of very brief duration observed during PV closure should not be mistaken for PR because these signals simply represent a ghosting artifact resulting from the valve moving rapidly. These signals are similar to the linear high frequency signals observed during conventional Doppler examination.[6]

TRANSESOPHAGEAL ECHOCARDIOGRAPHIC ASSESSMENT OF PULMONARY REGURGITATION**

Pulmonary stenotic lesions are primarily the realm of congenital heart disease. However, mild pulmonary regurgitation often is noted in healthy individuals, and therefore may be considered "normal" or "physiologic." More severe degrees of pulmonary regurgitation result from pulmonary hypertension or right heart/ pulmonary artery dilatation from other causes. In the absence of an angiographic "gold standard," the criteria used for assessment of the severity of aortic regurgitation have also been applied for grading the severity of pulmonary regurgitation. A ratio of jet width at its origin from the pulmonary valve to the right ventricular outflow tract diameter, taken at the same point, of 38 % or less is considered mild or moderate pulmonary regurgitation, 39% to 74% is moderately severe, and 75% or more indicates severe regurgitation. The distance the pulmonary regurgitation jet travels in the right ventricular outflow tract also has been found useful in assessing its severity, especially in the presence of infundibular stenosis, which narrows the outflow tract. In our experience, a regurgitation jet reaching to within 1 cm of the tricuspid valve always denotes severe pulmonary regurgitation. It is particularly important not to rely on the presence of turbulent flow to identify tricuspid or pulmonary regurgitation since the regurgitant flow signals may be laminar and totally devoid of aliasing and variance when the right atrial or pulmonary artery diastolic pressures are high. In some such instances, torrential pulmonary and tricuspid regurgitation have been completely missed. The pulmonary valve may show redundancy, thickening, and prolapse resulting from myxomatous degeneration, and the resulting regurgitation may be eccentric.[7]

SUMMARY

In summary, if performed properly, color Doppler is extremely useful in reliably assessing regurgitation severity from all the four cardiac valves.

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