QUANTITATION OF VALVULAR HEART DISEASE BY DOPPLER ECHOCARDIOGRAPHY: WHO NEEDS CARDIAC CATHETERIZATION?

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OVER the last three decades, developments in cardiac surgery and in cardiac catheterization and angiography have occurred to a large extent hand in hand; one complementing the needs of the other in providing optimal patient care. Thus, a cardiac surgeon, an invasive (catheterizing) cardiologist, and an angiographer-radiologist have, out of common interests, functioned as a team. Up until the mid 1970s, no other diagnostic technique offered a serious alternative to invasive diagnostic methods. Rapid, almost explosive, growth of newer noninvasive imaging techniques over the last 10 to 15 years has dramatically changed the picture.

The nuclear methods, with capability to assess myocardial perfusion and ventricular function, have supplemented, but not supplanted, the invasive methods. Diagnostic ultrasound methods, comprising of two-dimensional echocardiography, Doppler echocardiography, and color flow imaging have demonstrated the ability to provide detailed anatomic information, generally surpassing that obtained by angiography and hemodynamic information. These ultrasound methods, with the help of high fidelity catheters, are generally as accurate as the more carefully obtained intracardiac pressures. The methods are noninvasive, nonionizing, and far less costly. A number of surgeons at several medical centers are beginning to take notice of the promise and potential of diagnostic ultrasound techniques for providing anatomic and functional information relevant to patient management. Rapid computed tomographic (CT) scanning and magnetic resonance imaging (MRI) are rapidly developing cardiac applications for improved imaging, although their cost and availability may dampen their overall impact on routine patient management.

The present review will attempt to point out the numerous cardiac conditions in the surgical management of cardiac catheterization and angiography which have become almost unnecessary since they are being rapidly supplanted by the diagnostic ultrasound methods. The newer techniques of Doppler color flow imaging have found their way in the operating room in order to provide better anatomic definitions and immediate functional results of cardiac surgery.

It must be emphasized that delineation of coronary arterial anatomy requires, at the present time, selective coronary angiography. Whenever it is deemed important to rule out associated or incidental coronary artery disease, selective coronary arteriography must be carried out. This is often considered necessary in most patients over 50 years of age and in some younger patients with prominent risk factors that are associated with atherosclerotic coronary artery disease. It is the present surgical practice to perform coronary artery bypass surgery at the time of open heart surgery for unrelated conditions. Diagnostic coronary arteriography, in most laboratories, is a short procedure measured in minutes, associated with minimal risk, and designated as "limited" cardiac catheterization. This point will, therefore, not be reiterated in the discussions of the various conditions in which echocardiographic and Doppler methods are capable of supplanting cardiac catheterization.

A second point to emphasize is that the diagnostic quality imaging by echocardiography cannot be
lesion than similar gradients with normally functioning left ventricle.

In the evaluation of pressure gradients by continuous wave Doppler, a few considerations are important. It is necessary to have the Doppler ultrasound signal directed along the path of the flow jet. The velocity recorded with the angle of incidence between the ultrasound beam and the flow jet gives the most accurate assessment of pressure gradient. An angle of incident, up to 25 degrees, underestimates the velocity only by about 10%. It is important to record the velocity from more than one location over the precordium and use the highest recorded velocity for calculation of the pressure gradient. In our experience, the apical transducer position provides the highest recording of velocity in nearly 75% of adult patients with aortic stenosis. The right parasternal approach may provide the highest velocities in about 20% of the patients, and the subcostal or other precordial locations in the remainder. The suprasternal notch approach is, at times, useful in children and younger adults, although we have not found it to be a useful site in older adults. Since patient management decisions are often guided by Doppler-derived pressure gradients, it is important to persevere in order to obtain a technically adequate tracing before providing a definite interpretation. This can be determined by the audio and visual clues in the Doppler signal. Another source of potential errors is misinterpretation of tricuspid or mitral regurgitation for aortic signal. This can generally be avoided by careful attention to the timing and sound of the signal.

Once the pressure gradient is determined, the next step is to estimate the aortic valve area. A combined use of echocardiography and Doppler methods permits the assessment of the aortic valve area by using the continuity principle. This approach is based on the fact that the volume of blood flow across the left ventricular outflow is the same as that going through the valve. Since the flow by Doppler equals the integral of velocity times the area, one could measure the area and velocity in the left ventricular outflow, as well as the velocity of the jet, through the stenotic aortic valve and then derive the aortic valve area.slt Thus, \[ Q = \text{AreaLvo} \times \text{Velocity IntegralLvo} = \text{AreaAv} \times \text{Velocity IntegralAv} \] The LV outflow area is derived by measuring the diameter in the parasternal long-axis view and using a formula for the area of a circle \((m^2)\). The LV outflow velocity is recorded by using pulsed Doppler method to place the sample volume in the outflow tract approximately 1 cm below the valve. The aortic valve velocity is obtained from the continuous wave Doppler signal of the stenotic aortic jet.

Thus, the aortic valve area may be simply calculated. The Doppler-derived aortic valve area has correlated well with that obtained at cardiac catheterization using the Gorlin formula. In adult patients with suspected aortic valve stenosis, one can provide meaningful information relevant to patient management by the integration of echocardiographic and Doppler data. The aortic valve, capable of opening with two cusps which are separated by more than 1.4 cm in an older adult patient (above 45 years of age), nearly always excludes significant stenosis. On the other hand, a heavily calcified valve without discernible motion of more than one cusp generally indicates a need for careful exclusion of significant stenosis. An interpretation of the Doppler aortic stenosis velocity signal, in concert with the echocardiographic assessment of the left ventricular size and function, may also provide valuable insights. For instance, a peak aortic velocity of 3.5 m/s (peak systolic gradient = 50 mm Hg), when associated with markedly depressed left ventricular function (ejection fraction < 35%), has different connotation as compared with the same peak velocity when associated with hyperdynamic left ventricle (ejection fraction > 70%). Similarly, the association of significant aortic regurgitation will also influence the interpretation of a high pressure gradient. Although it would be more accurate to use the valve area in making management decisions, one should be aware of possible errors in some of the measurements. The left ventricular outflow diameter may be in error, and a small error may be magnified in the calculations of the area. Secondly, the pulsed wave Doppler signal of left ventricular outflow may be obtained in close proximity to the valve giving a falsely higher value. Finally, the aortic valve stenotic jet velocity may be underestimated. Careful attention to details in obtaining all the data is important in order to avoid errors in the interpretation which might adversely affect management decisions.
Pathologic Anatomy of Aortic Stenosis
This is generally quite easy to visualize by echocardiography. Congenital bicuspid aortic valve can be discerned from the short-axis view at the aortic valve level. Rheumatic pathology is associated with valve thickening, especially along the commissures. In older patients, heavy calcification may make it indistinguishable from the degenerative, calcific variety. The latter presents with variable sclerosis and calcification. It has been possible to define the precise areas of calcific deposits on the valve cusps using echocardiography. In general, the more extensive the calcification, the more the severity of the disease. The ability of echocardiography to localize and quantitate calcification may prove useful in the selection of patients for balloon valvuloplasty or for procedures intended to decalcify the valve at time of surgery.

Functional and Hemodynamic Consequences
A direct consequence of increased afterload is the development of concentric hypertrophy. Echocardiography is useful in the accurate assessment of wall thickness and can permit the estimation of mass. The diagnosis of left ventricular hypertrophy and its extent is better made with echocardiography than electrocardiography or chest x-ray. The functional consequences of ventricular hypertrophy include diastolic dysfunction associated with decreased compliance and systolic dysfunction associated with ventricular dilatation. An assessment of diastolic function can be attempted by examination of the mitral inflow signal by pulsed Doppler technique. A clue to the abnormal ventricular filling rate may be obtained from the abnormalities in the mitral inflow signal. Left ventricular dilatation and systolic dysfunction are most conveniently assessed by echocardiography.

Hemodynamic consequences include elevation of left ventricular end-diastolic pressure and, occasionally, pulmonary hypertension. There is no easy quantitative way to assess the former, however, the latter can be quantitatively determined by continuous wave Doppler signal of tricuspid regurgitation. The reader is referred to the section on mitral stenosis, where this approach will be described in greater detail.

Associated Conditions
The more commonly associated conditions include aortic regurgitation, rheumatic mitral valve disease, hypertrophic obstructive cardiomyopathy, and coronary artery disease. Echo Doppler evaluation of patients will permit accurate diagnosis of all of these conditions except for coronary artery disease. In summary, aortic valve stenosis can be accurately quantitated without a need for cardiac catheterization, and appropriate management decisions may be made in over 90% of adult patients on the basis of echo-Doppler findings. Limited selective coronary arteriography may be all that is necessary in appropriate patients prior to valve surgery.

Aortic Regurgitation
The diverse etiologies of aortic regurgitation include congenital anomalies, traumatic, rheumatic, rheumatoid arthritis, ankylosing spondylitis, infective endocarditis, degenerative calcific valve disease, myxomatous valve, Marfan's syndrome, aortic root dilatation, dissection, or aneurysm. It would be outside the scope of this review to discuss the echo-Doppler aspects of each condition. In general, clinical presentations are commonly noted as chronic or acute aortic regurgitation. Chronic aortic regurgitation results in volume overloading of the left ventricle with resultant ventricular dilatation and eccentric hypertrophy. The peripheral circulatory signs include increased systolic and decreased diastolic arterial pressures with signs of wide pulse pressure and peripheral vasodilation. Acute aortic regurgitation is associated with acute increase in the left ventricular end-diastolic pressure without cavity dilatation or compensatory hypertrophy. In severe cases, systemic vasoconstriction may result from low cardiac output. Compensatory sinus tachycardia tends to minimize the regurgitant flow by abbreviating the diastole. The diagnosis of acute aortic regurgitation is often difficult and echoDoppler techniques may provide important clues of quantitation of acute regurgitation.

Severity of Aortic Regurgitation
Quantitative assessment of regurgitant lesions is far less precise than that of valvular stenoses. A
common clinical practice is to grade the severity of regurgitation on a semiquantitative scale, whether it is from selective angiography or by Doppler techniques. The severity of aortic regurgitation by Doppler techniques is based on the determinations of the area of the regurgitant jet and of the width of the jet at the level of the aortic root or the left ventricular outflow. Although careful mapping with pulsed Doppler method is capable of determining the jet area and width, they are more readily visualized by color flow imaging. Thus, color flow imaging can provide an objective assessment of semiquantitative index of the severity of aortic regurgitation. Additional indirect clues may consist of echo cardiographic evidence of enlarged ventricular cavity with increased ejection fraction, indicative of large stroke volume, and of premature mitral valve closure secondary to marked elevations in left ventricular diastolic pressures which are often seen in severe chronic or acute aortic regurgitation.

A strong, continuous wave, aortic regurgitant, Doppler signal generally indicates a moderate or severe degree of regurgitation. The diastolic slope of the velocity waveform has also been correlated with severity, although it appears to be related more to left ventricular end-diastolic pressure.

Pathologic Anatomy of Aortic Regurgitation

Two-dimensional echocardiography permits the accurate assessment of valvular anatomy in long-axis views, as well as parasternal short-axis views, at the level of the aortic valve. The leaflet thickening, calcification, tear, or presence of vegetative lesion can be recognized. The aortic root size and various pathologies involving the root may be diagnosed. Thus, it is rare to see a patient with hemodynamically significant aortic regurgitation in whom an etiologic identification cannot be made by echocardiography. A variety of clues which are of additional relevance to surgical management, such as ring abscess, sinus of Valsalva deformities, or fistula between the sinus and one of the right heart chambers, may be visualized. In adult patients, aortic root dissection may readily be recognized by echocardiography as a cause of aortic regurgitation.

Functional and Hemodynamic Consequences

Functional consequences of diastolic overload of the left ventricle include cavity dilatation and hyperdynamic ventricle with augmentation of stroke output. The late consequences of prolonged severe diastolic overload include extreme degrees of dilatation with depressed ejection fraction. Hypertrophy, as evidenced by increase in muscle mass rather than increase in wall thickness, is also present. Two-dimensional echocardiography permits accurate assessment of left ventricular end-diastolic volumes, ejection fraction, and mass.

Hemodynamic consequences of significant regurgitation almost always include some increases in the left ventricular end-diastolic pressure. Some echo-Doppler clues, indicative of increased left ventricular end-diastolic pressure, are often useful, although precise determination of pressures is generally not possible. Diastolic slope of the continuous wave Doppler signal of the aortic regurgitant jet often reflects an elevated end-diastolic pressure when the slope exceeds 3.5 mls. The diastolic slope is determined by the instantaneous gradients between the aorta and the left ventricle, hence, a steeper slope is associated with lower aortic diastolic pressure and increased left ventricular end-diastolic pressures. This observation provides a basis for the use of the regurgitation flow velocity diastolic slope to reflect the end-diastolic pressure in the left ventricle; this is generally of practical usefulness. Another important sign of markedly elevated left ventricular end-diastolic pressure consists of the premature closure of the mitral valve, m–st readily appreciated by M-mode echocardiographic recordings. A sudden increase in the left ventricular diastolic pressure exceeding the left atrial pressure provides a mechanism for the premature valve closure. Since presystolic closure of the mitral valve may also be observed in association with prolonged PR interval, it is important to exclude the presence of first degree atrioventricular block in a patient with aortic regurgitation and with premature mitral valve closure.

Associated Conditions

The commonly associated conditions include aortic stenosis, mitral valve disease, congenital defects, e.g., ventricular septal defect, subaortic stenosis, and coronary artery disease. All these conditions, with possible exception of coronary
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artery disease, are readily diagnosed by echoDoppler evaluation. In summary, the echo-Doppler techniques permit the complete evaluation of patients with suspected aortic regurgitation by assessment of its severity, etiopathology, effects of left ventricular size and function, and indirect clues of left ventricular end-diastolic pressure. The clinical data and the echo-Doppler techniques together assist in determining the timing for cardiac surgery. In acute conditions, such as vegetative endocarditis, aortic dissection, and cusp rupture, little additional information can be obtained from cardiac catheterization; surgical intervention may be considered without invasive studies. In chronic severe aortic regurgitation, progression of left ventricular dysfunction on serial noninvasive follow-up evaluations provides important clues for surgical intervention, and limited coronary angiography is all that is necessary in patients with appropriate indications. It is important to stress that angiographic assessment of the severity of aortic regurgitation is no more precise than that obtained by Doppler evaluation and is subject to erroneous interpretation based on factors such as position of catheter, timing, and pressure of dye injection. The hemodynamic evaluation by cardiac catheterization and angiography should be reserved for a few cases in whom clinical and echo Doppler data appear to be at sharp variance; or the ultrasound data are technically inadequate.

Mitral Stenosis

Mitral stenosis is nearly always of rheumatic etiology although, rarely, congenital or degenerative calcific conditions may be responsible.

Severity of Mitral Stenosis

There are two echocardiographic methods for assessing mitral valve area, one is utilizing real time two-dimensional echocardiographic cross sectional imaging and the other is using Doppler flow velocity signals of mitral valve inflow jet. Both methods demonstrate a high level of accuracy and are often complementary and confirmatory of each other. In two-dimensional echocardiographic assessment of mitral valve area, the parasternal shortaxis views, obtained at the level of free margins of

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In addition to the enlargement of the left atrium, a common complication is the development of left atrial thrombus. This is commonly located in the atrial appendage where little flow occurs, especially with atrial fibrillation. In some patients, the thrombus may extend to the left atrial posterior wall or may occupy a large portion of its cavity. A floating or pedunculated thrombus, moving in and out of the mitral orifice, may be rarely observed. Echocardiography is reported to have sensitivity of 50% in the diagnosis of surgically proven left atrial thrombus. The diagnostic yield is considerably low when the thrombus is predominantly localized to the appendage. When it extends into the posterior or lateral walls, or when it is pedunculated, a predictive value of echocardiography may exceed 90%.

A major hemodynamic consequence of mitral stenosis is the development of pulmonary hypertension. There are a number of echocardiographic and Doppler clues to diagnose pulmonary hypertension, the most precise and reliable method is the one based on measuring the velocity of tricuspid regurgitation by Doppler. The echocardiographic clues of pulmonary hypertension consist of loss of the "A" dip on the pulmonary valve motion and of the mid-systolic notch or flutter. The mid-systolic notch gives an appearance of the letter "W." Although these clues are often helpful in pointing to the presence of pulmonary hypertension, they are not quantitative of its degree. The mid-systolic notch is generally associated with moderate or severe elevations in pulmonary artery pressures. The Doppler clues of pulmonary hypertension may be provided from the profile of the pulmonary systolic flow velocity. The acceleration time, defined as time to peak velocity, is normally in excess of 120 ms. When this value is decreased to less than 100 ms, a diagnosis of pulmonary hypertension is probable. Its accuracy is further enhanced for time intervals of less than 80 ms. The correlation is somewhat quantitative; the shorter the acceleration time, the higher the pulmonary arterial pressure. Although generally reliable, this approach is not precisely quantitative. A quantitatively accurate Doppler approach consists of transcription of tricuspid regurgitation velocity, which can be obtained in over 90% of patients with mitral stenosis. The peak tricuspid regurgitation velocity is related to the systolic pressure difference between the right ventricle and the right atrium. Based on the simplified Bernoulli principle, the peak pressure difference = 4 x peak velocity^2.

Thus, RVs - RAs = 4 x TR velocity^2, where RVs and RAs refer to systolic pressures in the right ventricle and right atrium, respectively. Transposing this equation, RVs = 4 x TR velocity^2 + RAs' the RA pressure can be evaluated by examination of the jugular venous pressure. When normal, a value of 10 mmHg may be substituted for the RA systolic pressure, and an accurate RV systolic pressure may be calculated. Simultaneous recordings of Doppler and catheterization data have validated the accuracy of this Doppler approach. In the absence of pulmonary stenosis, the peak RV systolic pressure represents the pulmonary artery systolic pressure. This approach makes the use of right heart catheterization to assess the severity of pulmonary hypertension generally unnecessary.

Associated Lesions

The commonly associated conditions are mitral regurgitation, rheumatic tricuspid stenosis, rheumatic aortic valve disease, and atrial septal defect (Lutembacher's disease). All of these conditions can be accurately diagnosed and their severity assessed by echo-Doppler methods; cardiac catheterization is almost always a redundant test prior to surgery. Thus, cardiac catheterization should only be indicated, in rare cases, in which clinical and echocardiographic assessments are at considerable variance or when diagnostic angiography is indicated to delineate coronary artery anatomy.

Mitral Regurgitation

The most common etiology of chronic mitral regurgitation shows marked geographic variation, being rheumatic in developing nations and nonrheumatic in more affluent countries where acute rheumatic fever is rare. In the western hemisphere, two of the more common etiologies include myxomatous change in floppy mitral valve syndrome and coronary artery disease with papillary muscle dysfunction. Other common etiologies include dilated cardiomyopathy or severe left ventricular dilatation secondary to other causes, infective endocarditis, mitral annu
lar calcification, and occasional rheumatic heart disease. Congenital causes include cleft mitral valve with or without atrioventricular canal defects or less common anomalies such as parachute mitral valve or anomalous origin of coronary arteries.

Severity of Lesions
Quantitation of mitral regurgitation is equally as impressive as that of aortic regurgitation. Most methods permit semiquantitative assessment such as mild, moderate, and severe or four grades of severity. Despite the lack of precision, such approaches are helpful in making management decisions. The severity assessment by Doppler techniques is based on the area of the regurgitant jet. Nanda and associates express the regurgitant jet area as percent of the left atrial area. This approach of correction, as the basis of left atrial size, is useful only in small or normal atria, as in acute mitral regurgitation. In other cases, with moderate or severe atrial enlargement, this correction would appear unnecessary. Although the regurgitant jet area may be determined by careful mapping of the left atrium using pulsed Doppler sample volume, it is more readily and perhaps more accurately determined by color flow imaging. Multiple cross sectional planes have to be utilized in order to observe the cross section demonstrating the maximal regurgitant jet.

Pathologic Anatomy
In patients with mitral regurgitation, the underlying pathologic anatomy may determine the therapeutic approach. For instance, a heavily calcified rheumatic valve would, in almost all instances, need to be replaced. Some patients with combined stenosis and regurgitation on rheumatic basis, having preserved mobility of the leaflets, may be candidates for reconstructive surgery. Patients with myxomatous floppy mitral valve syndrome are often suitable for extensive reconstructive surgery. Echocardiography can often identify those patients in whom reconstructive surgery will successfully reduce or eliminate mitral regurgitation. Severe mitral regurgitation, associated with marked prolapse or flail posterior mitral leaflet, is ideally suited for attempt at reconstructive surgery. Those with extensive anterior mitral leaflet involvement are less suitable. Echocardiographic techniques permit quantitative assessment of mitral valve annulus size. Patients with markedly dilated annuli may require annuloplasty. Those with small annuli may require smaller valvular prosthesis. In patients with infective endocarditis as primary etiology of regurgitation, new or old vegetations may be observed. At times, localized erosion of a leaflet may be evident and color flow Doppler jet may be observed to emerge through the hole. Congenital abnormalities associated with cleft mitral valve are clearly demonstrable on echocardiography as is the presence of cleft valve. Color flow imaging shows the site of flow across the valve, as well as overall direction of the jet. In general, lesions of the posterior mitral leaflet are associated with a regurgitant jet directed medially, anteriorly, and superiorly along the atrial septum, adjacent to the ascending aorta. The anterior mitral leaflet pathology often results in the jet being directed posterolaterally. Mitral regurgitant jet, when secondary to left ventricular dilatation, is generally central. Thus, echocardiography and Doppler techniques provide important insights into the pathologic anatomy of the valve.

Functional and Hemodynamic Consequences
Chronic mitral regurgitation results in left ventricular overload type of hypertrophy with cavity enlargement and increased ejection fraction. It has been reported that ventricular shape assumes more spherical or globular appearance. The augmented ejection fraction partially represents regurgitant flow into the left atrium, which is almost always enlarged and, at times, of gigantic proportion. In late cases, with the development of pulmonary hypertension, right heart chambers are affected. The characteristic hemodynamic effects of chronic mitral regurgitation constitute a large V wave in the left atrial pressure tracing with some increase in the mean left atrial pressure and elevation of the left ventricular end-diastolic pressure. The mean left atrial pressure may markedly increase as the left ventricle "fails." The height of the V wave depends, besides regurgitant volume, on size and compliance of the left atrium. Pulmonary hypertension in chronic cases is a late feature. There are no distinct echocardiographic or Doppler clues to assess the left ventricular end
diastolic pressure or the mean left atrial pressures. With huge V waves, as may be seen in acute (or acute on chronic) regurgitation, continuous wave Doppler may provide some clues (see below under discussion of acute regurgitation).

Acute mitral regurgitation is often associated with mild left ventricular or left atrial enlargement, but the ventricle is hyperdynamic, owing to a large regurgitant fraction. However, dramatic hemodynamic changes consist of marked increase in the height of the left atrial V wave, reaching at times to near left ventricular systolic pressure. The continuous wave Doppler registration of the regurgitant jet velocity wave-form assumes a distinct appearance. There is an early peak representing a high pressure difference between left ventricular systolic and left atrial pressures, followed by rapid deceleration, toward the baseline as the tall V wave approaches the left ventricular pressure in late systole. This dramatic shape of acute mitral regurgitation may be altered, following vasodilatation (e.g., nitrates), as the V wave is lowered in amplitude. Pulmonary hypertension, which may be assessed by Doppler techniques, develops early in acute as compared to chronic mitral regurgitation.

**Associated Conditions**

The association is partly dependent on the etiology, and the following includes some of the more common conditions: mitral stenosis in rheumatic cases, tricuspid and aortic valve prolapse in floppy mitral valve cases, ostium primum atrial septal defect and/or ventricular septal defects in cleft mitral valve, aortic regurgitation in Marfan's syndrome, and coronary artery disease as etiologic factor in papillary muscle ischemia or as associated unrelated condition in other patients. Nearly all of these conditions, with the possible exception of coronary artery disease, can be diagnosed by echo-Doppler methods.

**Tricuspid Valve Disease**

The principles of echo-Doppler evaluation of tricuspid valve stenosis and/or regurgitation are somewhat similar to those for the mitral valve. The Doppler method provides accurate assessment of tricuspid stenosis, as determined by diastolic flow velocity profile. Although a faint tricuspid regurgitant signal may be often observed in normal subjects, a strong signal which is capable of being mapped into the right atrium nearly always indicates abnormal tricuspid regurgitation.34-38

Tricuspid lesions, such as infective endocarditis in intravenous drug "users" and carcinoid syndrome, can be accurately and completely assessed by echo-Doppler techniques, requiring little, if any, further need for cardiac catheterization.

**Conclusion**

The value of echocardiography and Doppler techniques in the diagnostic evaluation of a number of conditions has been amply demonstrated. It is now possible to assess the severity of the lesion as well as its hemodynamic and functional consequences. The cross sectional imaging provides a far better assessment of the pathologic anatomy than angiographic methods. In general, most associated conditions, except for the diagnosis of coronary artery stenosis, can be accurately assessed using the ultrasound methods.

**References**