Impact of Noninvasive Cardiology on The Definitive Diagnosis of Valvular Disease: Is Cardiac Catheterization Necessary Before Cardiac Surgery?

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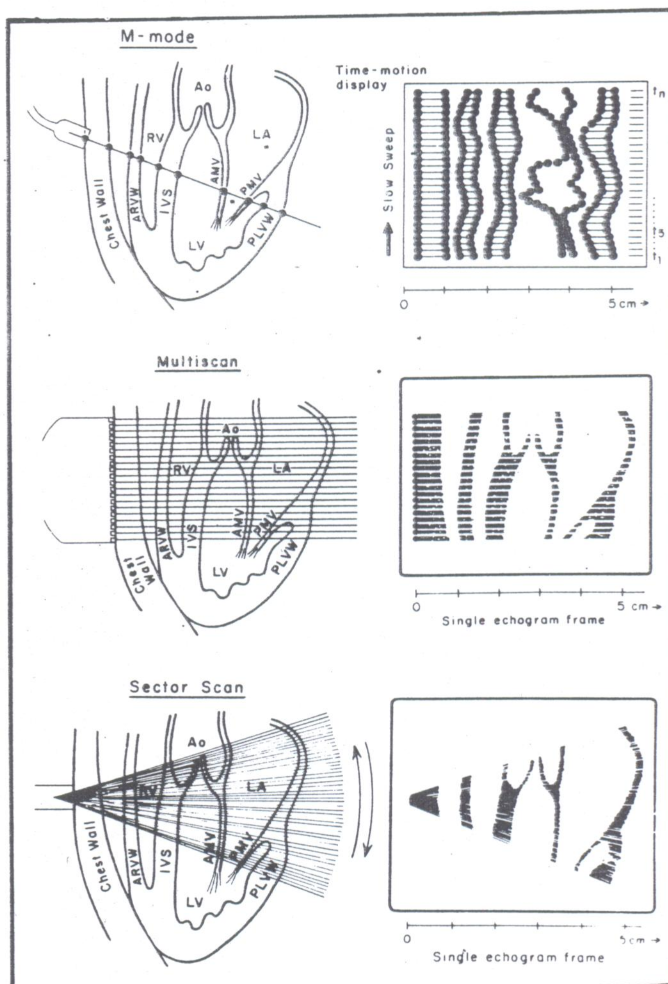
During the past decade significant strides have been made in the noninvasive cardiac diagnosis. This is mainly due to new innovations in the ultrasound and Doppler technology. Phonocardiography is much less commonly used today, and then only as an adjunt to echocardiography. Nuclear imaging and more recently introduced cine CT imaging are noninvasive procedures. They, however, require peripheral injection of radioactive material or radiopaque dye, respectively, and expose the patient to radiation, and in addition, are quite expensive. Magnetic resonance imaging is totally noninvasive but its cost is prohibitive at the present time.

In this communication I will discuss therole of moticn-mode (M-mode) and two dimensional (2-D) echcardiography and Doppler in assessment of valvular heart disease.

M-mode echocardiography uses a single crystal transducer which is normally rotated across the chest in order to visualize different cardiac structures. Permanent records may be obtained on a videotape or a strip chart or both. M-mode is an inexpensive test, the equipment is portable and records are easy to interpret. However, because of the single beam used, M-mode electrocardiography is like looking at the heart through a keyhole. Currently, in the U.S.A., 2-D mode is used most commonly and M-mode is derived from 2-D images by using a cursor which could be placed through any area of the cardiac image. However, in many laboratories, measurements of cardiac chamber size and calculations involving valvular or myocardial motion are still made on M-mode because of its higher resolution and ease of interpretation [1]. In 2-D echocardiography, multiple crystals are used, or when a single crystal is utilized, it is moved rapidly, mechanically or electronically (Fig. 1) [1]. It, therefore, has a distinct advantage of showing a much larger area of the heart in real time. Images are easily identi-



1. Figure 1-A, diagram to demonstrate single crystal, M-mode, multi-scan and mechanical sector-scan 2-D, imaging. Reproduced by permission (Ref. I).

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fied, especially by surgeons, because 2-D images appear similar to angiographic pictures that surgeons are used to seeing and accepting as gold standard. One of the major hurdles for echocardiography to be acceptable as a definitive diagnostic test has been our nonfamiliarity of with multiple 2-D images of the heart which are actually slices of the heart in different orientations rather than "shadow grams" that we are used to seeing by angiography.

While 2-D echocardiography gives us details of anatomical structure, Doppler is extremely useful in evaluating interacardiac flow disturbance. The combinatin of these two techniques has made noninvasive diagnosis very precise. The role of these modalities will now be discussed in detail for each cardiac valve.

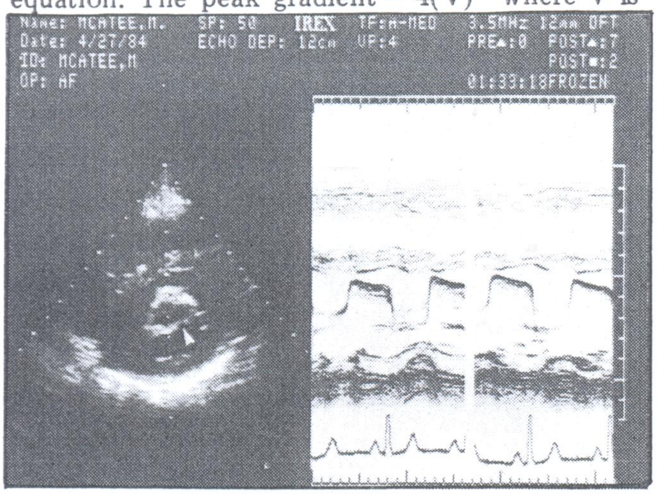
Mitral Stenosis

Mitral stenosis was the first entity diagnosed by M-mode cardiography [2]. Normal mitral valve motion excludes the diagnosis of mitral stenosis. The assessmen tof the degree of mitral stenosis is, however, more precise by using two dimensional echocardiography (Fig. 2). Mitral leaflet calcification and mobility, as well as the valve aera, can be determined even in the presence of mitral regurgitation [3-4]. Additional confirmatory information may be obtained by measuring diastolic Doppler flow through the mitral valve [5-7] (Fig. 3-4). The peak gradient across the valve is calculated by amodified Bernoulli equation. The peak gradient = $4(V)^2$ where V is the peak diastolic transmitral Doppler flow in meters per second. Thus, if V is 2 meters, peak mitral gradient = $4 \times (2)^2 = 16$ mm Hg. Since the valve area depends both on the gradient and flow across the valve, pressure half time of the mitral valve (i.e. the time it takes the peak pressure to drop to half of the original velocity) is a more useful concept [7]. Normal pressure half time is 20 to 60 milliseconds. In severe mitral obstruction (i.e.; valve area of < 1 cm^2), pressure half time is close to 220 milliseconds. This is the basis for the empirical formula for valve area which equals 220 divided by pressure half time in msc. If the latter is 220 msc., the valve area = 220/220 = 1 cm^2.

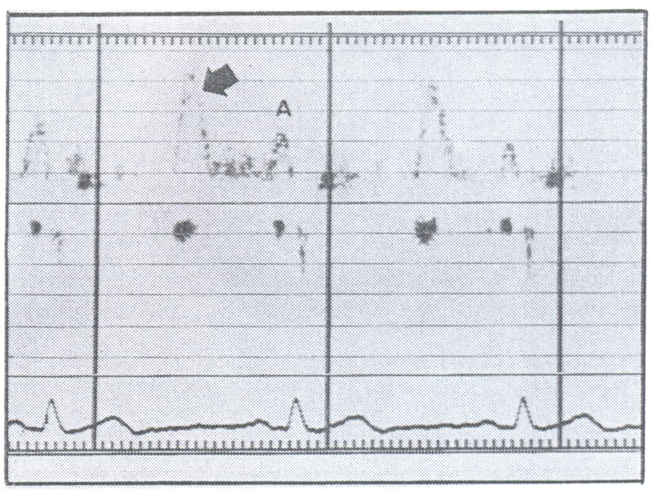
There is a high correlation between the valve area determined by 2-D echocardiography and Doppler and that obtained by cardiac catheterization. Therefore, a patient with mitral stenosis can be operated on without prior catheterization. Further, whether commissurtomy or valve replacement is indicated can be assessed from the mobility of the valve leaflet and degree of calcification. Associated mitral insufficiency and estimation of its degree can also be obtained by Doppler as described in the following section.

Left ventricular out-flow tract is clearly seen with 2-D echocardiography and its size is helpful in determining the type of mitral prothesis (i.e.; ball and cage versus low profile disk valve).

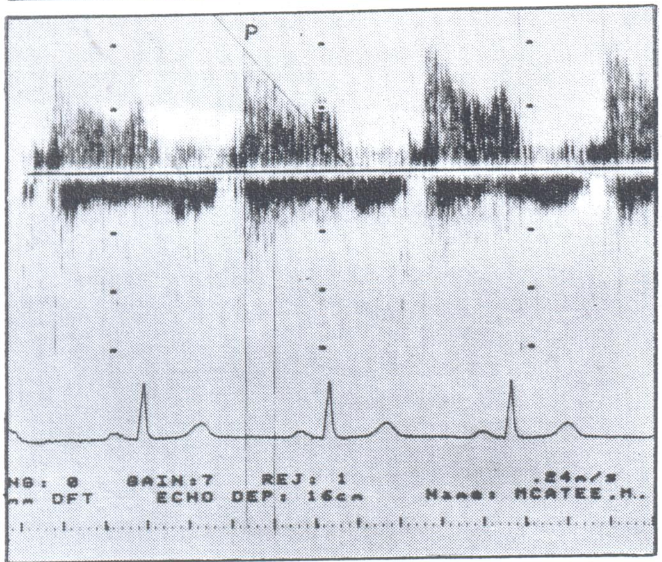
In the follow-up of patients post commissurotomy, Doppler is more helpful than 2-D. The mitral valve area may not appear significantly improved by 2-D, and yet the patient may be



2. Figure 2 — Mitral Stenosis. The figure on the right shows mitral stenosis recorded with M-mode. On the left mitral valve orifice (arrow) is recorded with 2-D echo. The area is planimeterized to calculate mitral valve orifice size.



3. Figure 3 — Normal mitral flow (with pulsed Doppler). Note the early diastolic flow (arrow) and late diastolic flow during atrial systole (A).



4. Figure 4 — Mitral Stenotic Flow. This scan was taken with a continuous Doppler. The lines are drawn to show peak velocity (P) and calculation of pressure half time.

improved symptomatically. Doppler flow appears to correlate better with improvement in symptoms. Catheterization confirmation of this correlation is not yet available. Mitral valve closing index by M-mode has been suggested to be another reliable way to follow patient post commissurotomy [8].

Mitral Regurgitation

M-mode or 2-D echocardiography is not helpful in diagnosing mitral regurgitation, except indirectly (i.e.; by showing enlargement of the let ventricle and left atrium and hyperactive wall motion which occurs in early stages of significant mitral regurgitation) the so-called volume overload of the left ventricle. When mitral regurgitation is present, however, one can often determine its etiology by echocardiography. For example, mitral valve prolapse, calcified mitral annulus, endocarditis of the valves, rupture of the chordae or cardiomyopathy can be clearly shwon by electrocardiography [9]. The technique is also helpful in assessing left ventricular functin and, therefore, in decision-making regarding the timing of corrective surgery. Thus, if a patient has significant mitral regurgitation but poor left ventricular wall motion, surgery may not be indicated.

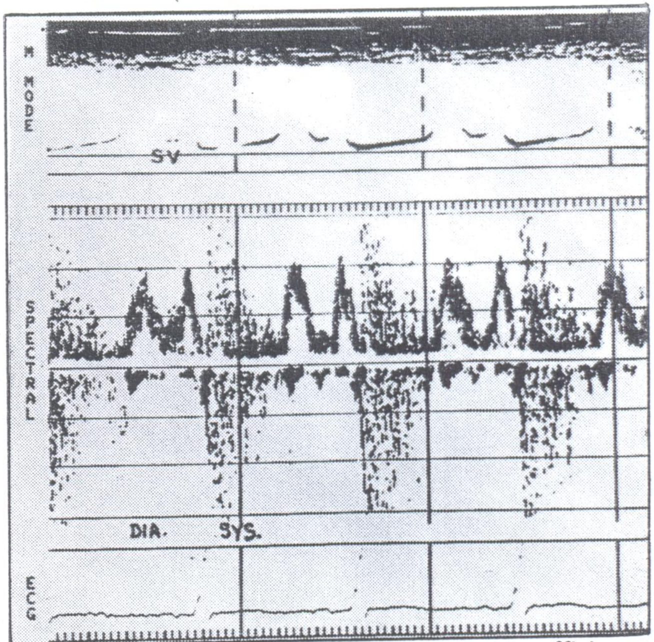
The Doppler is highly sensitive (95%) and specific (97 to 100%) in diagnosing mitral regurgitation [10-13]. More importantly, the severity of mitral regurgitation can be estimated with Doppler [11-12]. Several techniques are used for this purpose :—

1. Left Atrium Mapping [11]

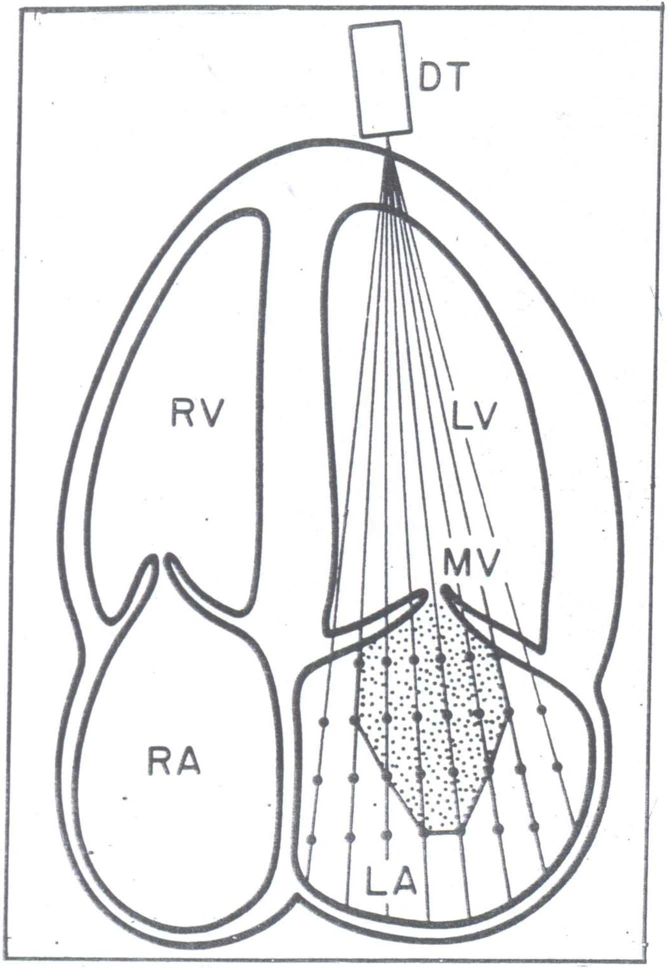
This is a relatively quick method of semi-quantating mitral regurgitation. The sample volume (Doppler sensor) is placed posterior to the mitral valve and mitral regurgtation jet is first detected. Then the jet is followed posteriorly to determine its depth and width. In this way mitral regurgitation may be categorized into mild, moderate, or severe. The further away the jet is detected from the mitral valve, and the wider its distribution, the more severe the mitral insufficiency (Fig. 5-7).

2. Volume Determination of Mitral Regurgitation [13].

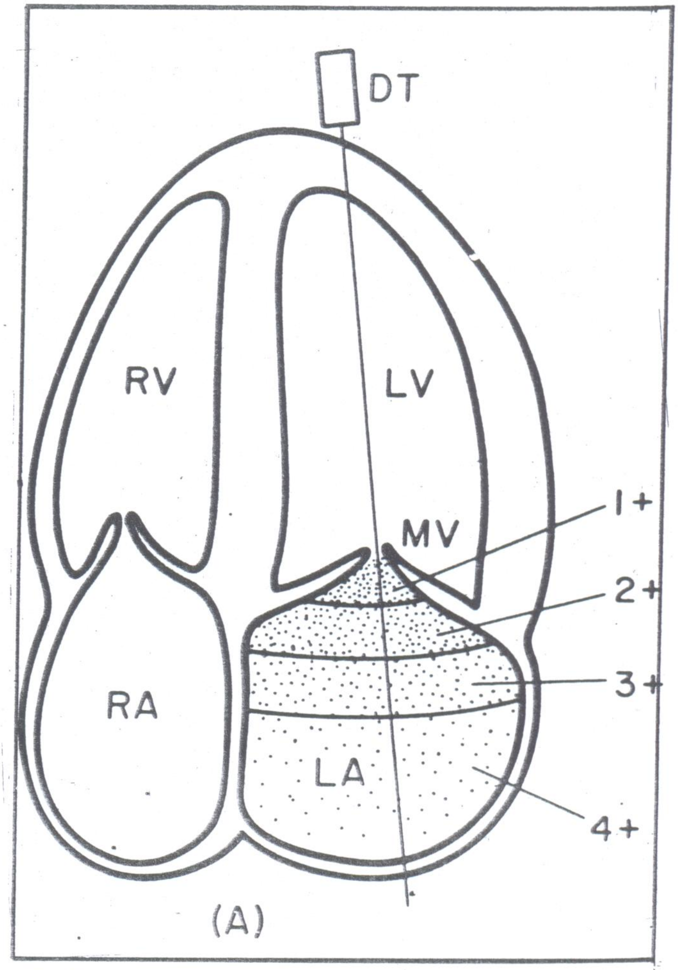
Mitral regurgitation may also be quantiated by calculating the forward mitral flow value (MFV) and comparing it with aortic (AVF) and pulmonic flow (PAF). This is done by Doppler measurement of peak velocity of flow across the respective valves and determining their cross section area by using 2-D imaging. The volume of the forward flow = Velocity Integeral x Valve Area. Then, mitral valve regurgitant volume (RV) = MVF — (AVF + PVF) ÷ 2 and Regurgitant



5. Figure 5 — Mitral valve flow in mitral insufficiency. Note negative systolic flow (sys). SV = Sample volume placed posterior to mitral valve as seen by M-mode echo.



6. Figure 6 — A diagram of 2-D apical four chamber view to show a method of mapping left atrium for mitral regurgitation. RV = Right Ventricle, LV = Left Ventricle, RA = Right Atrium, LA = Left Atrium, MV = Mitral Valve, and DT = Doppler Transducer. Reproduced by permission (12).



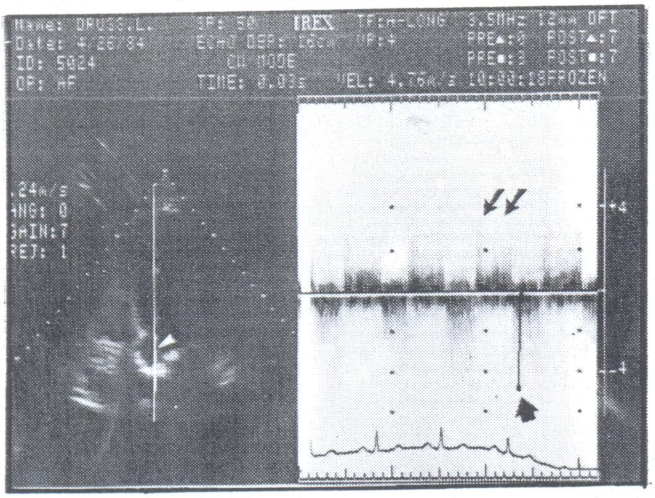
7. Figure 7 — A diagram to illustrate how degree of mitral regurgitation (1+ to 4+) corresponds to the distance covered by mitral regurgitation jet within the left atrium. Abbreviations are similar to those in Figure 5.

Fraction (RF) = RV ÷MVF. The major source of error in this technique is not the measurement of Doppler flow velocity but in the accurate measurement of valve area through which the bloodflow is passing. The estimation of degree of mitral regurgitation by above method is invalid if stenotic lesions are present. Left atrial mapping technique, however, is not influenced by mitral stenosis or aortic valve disease.

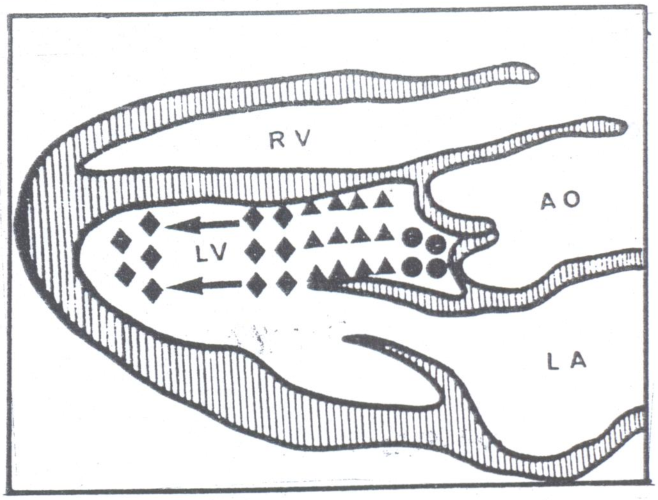
By estimating the degree of mitral regurgitation with Doppler and left ventricular function with 2-D, most of the patients with mitral regurgitation with or without mitral stenosis, can be operated on without cardic catheterization. It should, however, be mentioned that in approximately 10% of cases good quality Echo Doppler studies may not be possible and assessment of mitral regurgitation need to rest on other diagnostic modalities including cardiac catheterization and left ventriculargraphy.

Aortic Stenosis

2-D echocardiography is helpful in diagnosing aortic stenosis [14]. However, the severity of aortic stenosis is often difficult to assess by 2-D imaging because the aortic wall and valve calcification and multiple echoes produced by thickened leaflets, making it difficult to visualize aortic opening. On the other hand, Doppler is very valuable in assessing peak velocity thorough the valve [15-17]. The aortic gradient may be calculated by utilizing a modified Bernoulli



8. Figure 8 — Doppler flow in aortic sterosis and insuffiency. On the left is a 2-D image of opical four chamber view. The sample volume (Doppler sensor) is placed through the aortic valve (white arrow). On the right is shown flow with continuous Doppler. The negative systolic flow (broad arrow) shows velocity of 4.7 m/sec which is approximately 100 mm 1tg. aortic gradient. Diastolic flow (2 arrows) going in opposite directions is due to aortic insuffiency.



9. Figure 9 — A diagram of a cross section of the heart showing a method of estimating the severity of aortic insufficiency; (arrows indicate direction of regurgitation flow), circles = mild, triangles = moderate, and diamonds = severe aortic inefficiency. Reproduced by permission (Ref.).

equation, i.e.; peak gradient across the valve = 4 $(V)^2$ where the V is the peak velocity by Doppler [17] (Fig. 8). Thus, if V is 4 meters per second, then the gradient across the valve equals $4 \times (4)^2 = 64$ mm Hg. It has been recently shown that the gradient by Doppler correlates with the mean gradient better than peak to peak gradient [18].

The gradient, however, may be slightly over estimated in presence of increase flow, such as concommitent aortic insufficiency. On the other hand, gradient may be relatively low because of a low cardiac output and yet the patient may have significant aortic stenosis. Therefore, non-invasive measurement of the aortic valve area has been proposed which uses cardiac output determined by Doppler [19].

Aortic Insufficiency

Just as in the case of mitral regurgitation, aortic insufficiency may be diagnosed indirectly by echocardiography (i.e., dilated left ventricle, with hu]eractive wall motin and diastolic fluttering of mitral valve). Left ventricular function can be assessed at the same time. Doppler on the other hand is highly sensitive and specific in diagnosis of aortic insufficiency. Estimation of severity of aortic insufficiency can also be obtained with Doppler [20-22]. Again, a number of techniques can be used including flow mapping of the left ventricle (Fig. 9). Volume determinatin of aortic insufficiency has been recently proposed and shown to have good corrleation with noninvasive techniques. In this method aortic and pulmonary flow (AF and PF) is measured by Doppler. It is assumed that excess of AF compared to PF is due to aortic regurgitant flow (RF): Thus, RF% = (AF − PF) ÷ AF x 100 [23].

When to operate on the patient with pure or dominant aortic insufficiency is a difficult question. If one waits until the heart failure is evident, then it may be too late, as surgical outcome is not satisfactory. On the other hand, a patient with aortic insufficiency may go on without significant symptoms for many years and too early an operation for severe aortic insufficiency is not desireable either. It has been suggested that since aortic insufficiency causes volume overload of left ventricle which is accompanied by increase of left venticular wall motion, normal to reduced wall motion by echocardiography may indicate an early sign of left ventricular dysfunction. Similarly, end systolic dimension of left ventricle 55mm or more (indicating left ventricle dysfunction) has been suggested to be a helpful guide to undertake valve replacement [24]. However, no single parameter is accurate in timing the aortic surgery [25]. It is generally agreed that a reduction of left ventricle ejection fraction during exercise may be one of the ways to time aortic valve replacement [26].

Triscupid/Pulmonary Valve Stenosis and Insufficiency

Echo Doppler is also helpful in the diagnosis and assessment of severity of the right-sided valve lesions in a similar fashion as the left-sided valves [27-28].

Surgery Without Cardiac Catheterization

It may be seen from the above discussion that Echo Doppler techniques are highly accurate in the diagnosis of valvular disease and quite accurate in assessing severity of valve stenosis and insufficiency. The question has been asked why not use Echo Doppler, which is noninvasive and relatively inexpensive in selecting patients for cardiac surgery? Why use cardiac catherterization, which is potentially hazardous and much more expensive and requires highly skilled and trained personnel? This questions has been studied by a number of investigators [29-31]. There are those who feel that using Echo Doppler along with careful clinical evaluation is quite adequate to select most of the patients for cardiac surgery. The exceptions are those patients who have less than optimum Echo Doppler studies, those with multiple valve lesions not easily assessed with Doppler methods and patients older than 40 to 50 years who may have associated coronary artery disease. Even if coronary angiography is deemed necessary, a limited cardiac catheterization study to assess the coronary arteries may be adequate. Knowing left ventricular function by echocardiography, no extra contrast medium needs to be injected to obtain a left ventriculorgram. Further, if one would like to confirm the degree of the aortic or mitral insufficiency, a saline contract injection may be given in the aortic root or left ventricle.

The degree of valve insufficiency may then be assessed by contrast echocardiography during cardiac catheterization, thus limiting the amount of radiopaque contrast medium which can be toxic to heart and kidneys. As experience is being gained in these noninvasive techniques, more cardiologists feel confident in advising cardiac surgery, in selected patients, without cardiac catheterization. The potential fiscal impact of this change is evident.

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