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SIGNIFICANCE OF ECHOCARDIOGRAPHY IN VALVULAR HEART DISEASE

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ABSTRACT

Valvular heart disease represents important cause of cardiovascular morbidity and mortality. Echocardiography has become primary non-invasive imaging method for evaluation of valvular heart disease. Generally, patients with stenotic valvular lesions can be monitored clinically until symptoms appear. In contrast, patients with regurgitant valvular lesions require careful echocardiographic monitoring for left ventricular function and may require surgery even if no symptoms are present. Two dimensional echocardiography can provide accurate visualization of valve structure to assess morphologic abnormalities. Doppler is used for assessing the hemodynamic significance of cardiac structural disease, such as the severity of aortic stenosis, degree of mitral regurgitation and flow velocity across the valve. Echocardiography is useful to determine the optimal time for surgical treatment in asymptomatic patient with valvular regurgitation. The parameters like pressure half time, valve area, ventricular ejection fraction, ventricular diameters, pressure gradients across the valves, ventricular outflow tract are to be measured and are useful in clinical decision making based on echocardiography in valvular abnormalities. Doppler color flow imaging is a method for noninvasively imaging blood flow through the heart by displaying flow data on the two-dimensional echocardiographic image. To inexperienced Doppler users, the color flow display makes the Doppler data more readily understandable because of the avoidance of complex spectral velocity displays.

Keywords: Valvular heart disease, Valvular stenosis, Valvular regurgitation, Echocardiography, Doppler color flow imaging, Two dimensional echocardiography
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INTRODUCTION

Valvular heart disease refers to a condition, such as stenosis or insufficiency that may interfere with valvular function and flow of blood through the heart. There are four valves namely mitral, aortic, pulmonary and tricuspid valve. In valvular stenosis, the valve orifice narrows and the valve leaflets become fused together in such a way that the valve cannot open freely. This narrowing of opening causes obstruction of blood flow[1]. Valvular insufficiency also called regurgitation, incompetence or "leaky valve", occurs when a valve does not close tightly[2].

Echocardiography has become the key tool for the diagnosis and evaluation of valve disease, and is the primary non-invasive imaging method for valve stenosis and regurgitation assessment. It assesses valvular motion and pumping action of the heart and measures cardiac chamber size. Clinical decision making is based on echocardiography and also provides the detailed anatomical and functional information that clarifies the mechanism of valve abnormalities. Evaluation of valve abnormalities can be assessed by different types of echocardiographic modalities like M-mode, 2D/3D, transesophageal echocardiography and transthoracic echocardiography.[3,4]

ROLE OF ECHOCARDIOGRAPHY IN VALVULAR STENOSIS

Aortic Stenosis (AS):

Echocardiography has become the standard tool for evaluation of Aortic stenosis (AS) severity. Cardiac catheterization is no longer recommended [5,6,7] except in rare cases when echocardiography is non-diagnostic or discrepant with clinical data. Data should be recorded for quantitation of AS by echocardiogram are Left ventricular outflow tract (LVOT) diameter, LVOT velocity, AS jet velocity, valve anatomy. 3D technique can be used to measure the same data[8].

Exercise testing clearly has no role, and is contraindicated in patients with definitive cardiac symptoms or symptoms those are highly suspicious[9]. Planimetry of Aortic valve area (AVA) using two-dimensional transesophageal echocardiographic images has been reported to be a reliable method for measuring AVA in patients with aortic stenosis**.** Transthoracic two-dimensional echocardiography provides a feasible and reliable method in measuring AVA in patients with Aortic stenosis (Figure 1)[10].

Roshenek et al studied that in asymptomatic patients with moderate or severe valvular calcification, together with a rapid increase in aortic-jet velocity, identifies patient with a very poor prognosis. These patients should be considered for early valve replacement before symptoms appear so, echocardiography is predictor of outcome in severe asymptomatic patient with severe AS. In this Study M-mode echocardiography, two-dimensional echocardiography, and conventional and color doppler ultrasonography was used.[11] A smaller, exercise-induced change in aortic valve area was associated with an increase in mean transaortic gradient. Patients with severe AS who have this kind of response with exercise have fixed severe AS, with a greater leaflet thickness and less valvular compliance (Figure-2).Doppler color flow imaging methods allow for identification of the presence of certain valvular stenotic jets. There are, however, no specific characteristics in the color display of stenotic flows that assist in quantifying the severity of valvular obstruction at the present time[12].

Pellikka et al also used echocardiographic method to predict the long term outcome in asymptomatic adult patient using 2D and doppler echocardiography by left ventricular ejection fraction calculated by measuring the left ventricular short axis continuous-wave. Doppler examinations were performed with a non imaging transducer and multiple windows to obtain the maximal jet velocity. The aortic valve area was calculated from the continuity equation by using the left ventricular outflow diameter and velocity [13]. Patients with severe aortic stenosis and multiple comorbidities not only want to get their aortic valve replaced with a minimally invasive approach but also want to accomplish this more safely than with conventional methods.

Bagur et al propose the use of transesophageal echocardiography (TEE) as a primary imaging technique for transapical transcatheter aortic valve implantation (TAVI) to obviate the need for a hybrid operating room with state-of-the art fluoroscopic imaging equipment[14].

Mitral Stenosis (MS):

Echocardiography, especially Doppler echocardiography, is the procedure of choice for evaluating the degree of mitral stenosis; in most of the patients, echocardiography may be adequate for the planning of therapeutic interventions [15-20].

The typical M-mode and 2D echocardiographic features of rheumatic mitral stenosis are shown in Figure -3. The parasternal short-axis view is used to measure mitral valve area using planimetry [21].
Chiang C.W. and his colleague assessed prospectively 9 clinical and 10 echocardiographic variables for prediction of systemic embolism with mitral stenosis. In this study echocardiography variables were measured using Standard transthoracic echocardiography [22].

Previous retrospective studies have reported that the presence of left atrial smoky echoes by transesophageal echocardiography might favor the occurrence of systemic embolism in patients with mitral stenosis [23,24].

The impact of echocardiographic findings on the prognosis of MS has mainly been studied after balloon mitral commissurotomy. Multivariate analyses performed in studies reporting a follow-up of at least 10 years identified valve anatomy as a strong predictive factor of event-free survival [25,26]. Dobutamine stress echocardiography is also used for risk stratification in rheumatic mitral stenosis. The diastolic mitral valve mean gradient at peak DSE (DSE-MG) was the best predictor of clinical events especially in patients with moderate disease [27].

Tunick et al reported the utility of the assessment of exercise systolic pulmonary pressure (SPP) on clinical decision-making in patients with MS. In this study, those patients with more severe dyspnea and lower exercise capacity presented higher exercise values of SPP [28].

Pitfalls in Doppler estimation of MVA based on the pressure half time (PHT) method may be important in particular situations and cardiologists should be aware of it. Thomas et al elegantly described that PHT is mainly related to the atrioventricular compliance [29,30] This could explain those cases of true severe MS, misinterpreted as mild or moderate as a result of estimating non-severely stenotic MVA because of the presence of a relatively short PHT.

Scwammenthal et al described in a subgroup of patients with MS that the presence symptoms and pulmonary hypertension despite a relatively large MVA (estimated by PHT) may be secondary to reduced atrioventricular compliance. They demonstrated that there is close correlation between SPP and atrioventricular compliance [31]. According to this, patients with a low atrioventricular compliance were more symptomatic. Recently, Firstenberg et al reported validation and pitfalls of PHT method for the estimation of MVA in patients with MS and changes in cardiac output [32]. In this study it was confirmed that in patients with increasing cardiac output, PHT decreased and calculated MVA increased. Thus, MVA estimated by the PHT in exercise is not a reliable parameter to discriminate between severe and moderate MS. The continuity equation should be the method of choice for MVA estimation while performing an SE [33].

Tricuspid Stenosis (TS):

Tricuspid stenosis (TS) is currently the least common of the valvular stenosis lesions. Although tricuspid stenosis is readily detected and assessed hemodynamic ally, the accuracy of Doppler echocardiographic determinations is less well validated but still preferred over other methods [34]. There are reports of quantification of orifice area by 3D echocardiography, the methodology is neither standardized nor sufficiently validated as a method of choice. The tricuspid inflow velocity is best recorded from either a low parasternal right ventricular inflow view or from the apical four-chamber view. For measurement purposes, all recording should be made at sweep speed of 100 mm/s [35]. The hallmark of a stenotic valve is an increase in transvalvular velocity recorded by colour wave Doppler (CWD) (Figure-4 and5) [36]. Peak inflow velocity through a normal tricuspid valve rarely exceeds 0.7 m/s. Tricuspid inflow is normally accentuated during inspiration; consequently, with TS, it is common to record peak velocities that may approach 2 m/s during inspiration. As a general rule, the mean pressure gradient derived using the $4v^2$ equation is lower in tricuspid than in MS, usually ranging between 2 and 10 mmHg, and averaging around 5 mmHg. Higher gradients may be seen with combined stenosis and regurgitation [37-39].

Pulmonary Stenosis (PS):

Echocardiography plays a major role in the assessment and management of pulmonary valve stenosis [40]. In patients with reduced LV function, gradient measurements may appear falsely low, while valve area and resistance measurements will more reliably predict the severity of stenosis. Dobutamine perturbation with Doppler assessment of gradients may also be of use [41]. Pulmonic valve gradients are similarly quantified. Though experimental, contrast injection may allow more accurate recording of stenotic jet velocities and therefore transvalvular gradients [42]. Stenosis of the pulmonary valves usually results in a very diffuse jet like that of aortic stenosis. It is, however, more readily detected than that of aortic stenosis. Most degrees of pulmonary stenosis fill the proximal pulmonary artery with a large mosaic, resulting from both aliasing and turbulence. The pulmonary artery is best investigated using the short-axis approach. Figure-6 shows marked turbulence and aliasing within the pulmonary artery from pulmonic stenosis. Here, abnormal flow is seen up to the bifurcation of the main pulmonary artery [43].

ROLE OF ECHO IN VALVULAR REGURGITATION

Aortic Regurgitation (AR):

AR is common valvular heart disease in which echocardiography play valuable role in assessment and management of patient with AR [44].

Stress echocardiography helps in prediction of prognosis of valve sugary in patient with AR. Bonow et al demonstrated that preoperative exercise capacity in symptomatic patients with AR was predictive of postoperative LV function and long-term prognosis after aortic valve surgery. It has been described that patients who fail to increase LVEF with exercise tend to have a faster progression to symptoms.

It has also been reported that lack of improvement in ejection fraction (EF) under exercise has a high sensitivity but a low specificity for predicting poor prognosis after aortic valve surgery. It is important to stress on the relative value of assessing exercise EF as a reliable parameter of LV systolic function based on the limitations of the EF as a real expression of myocardial contractility [45].

The validity of stress echocardiography in predicting outcome of patients with asymptomatic AR is limited by the small number of available studies [46] as compared to the more extensive and consistent results with exercise radionuclide angiography [47–49] With the sparse data supporting the incremental prognostic value of stress echocardiography, this specific application is not recommended for routine clinical use. [5]

2D echo cardiography detects the structural abnormalities causing aortic regurgitation. 2D and M-mode echo findings can be observed in AR if the regurgitant jet impinges on the anterior mitral valve leaflet, a reverse doming (concavity toward the ventricular septum) of the anterior leaflet can be observed on the parasternal long-axis view (Figure-7A)As a result, the leaflet presents a high-frequency fluttering during diastole and its opening can be compromised. The M-mode echo can confirm the fluttering motion of the anterior leaflet (Figure-7 B) [4].

In the setting of AR, current guidelines recommend surgery for asymptomatic patients with a maximal left ventricular end-diastolic diameter (LVDd) of greater than 55 mm or an LVEF of less than 50% [50]. The clinical importance of pre-operative and follow-up echocardiographic studies in patients operated on for chronic severe aortic valve regurgitation is important, Emphasing on the same Corti R et al demonstrated the prognostic significance of M-MODE echocardiography compared with clinical and angiographic data. In this study Age, pre-operative NYHA class and left ventricular systolic function are the main determinants of long-term survival after valve replacement for chronic aortic regurgitation [51].

Mitral Regurgitatrion (MR):

Echocardiography is the most commonly used tool to evaluate the patient with suspected MR. It provides information about the mechanism and severity of MR, the size and function of the left and right ventricle, the size of the left atrium, the degree of pulmonary hypertension, and the presence of other associated valve lesions [52].Doppler evaluation provides quantitative measures of the severity of MR that have been shown to be important predictors of outcome (Figure 8) [53,54].

Echocardiography is useful to identify the predictors of outcome of intervention performed on mitral valve. Iung et al demonstrated in large set of patients that mitral valve intervention can be performed with good late result. Age, mitral valve anatomy, mitral valve area, and flow gradient across mitral valve were the predictors of late results of percutaneous mitral commissurotomy (PMC). Transthoracic echocardiography was used in this study [55].

Akasaka T et al assessed the prevalence of valvular regurgitation in the aged using pulsed doppler echocardiography and found the age as a predictor of regurgitation in aged patients [56].

Leung et al demonstrated the usefulness of preoperative exercise stress echocardiography in predicting LV dysfunction after mitral valve repair for MR. Seventy-four oligosymptomatic patients with non-rheumatic, non-ischaemic, isolated chronic MR and resting normal LVEF were included in the study. Within multivariate analysis, exercise left ventricular end systolic volume (LVESV) resulted predictive of postoperative LV function [57].

Exercise capacity itself is a predictor of the development of symptoms or LV dysfunction in asymptomatic patients with MR. In asymptomatic patients with severe MR, exercise stress echocardiography may help identify patients with unrecognized symptoms or subclinical latent LV dysfunction In symptomatic patients in whom the severity of MR is estimated to be only mild at rest, exercise echocardiography may be useful in elucidating the cause of symptoms by determining whether the severity of MR increases or pulmonary arterial hypertension develops during exercise [58].

The role of Doppler echocardiography in assessing dynamic changes in MR severity with exercise, to identify higher-risk patients for surgery, is the subject of current investigation. The magnitude of ischemic MR varies dynamically in accordance with changes in loading conditions, LV regional wall motion, and annular size and the balance of tethering versus closing forces applied on the mitral valve leaflets [59]. Hence, the severity of MR assessed by Doppler echocardiography at rest does not necessarily reflect the severity of MR that develops during exercise.

Pierard and Lancellotti have proposed that exercise doppler echocardiography can provide useful information in the following patients with ischemic MR: 1) those with exertional dyspnea out of proportion to the severity of MR or the degree of LV dysfunction at rest; 2) those in whom acute pulmonary edema occurs without an obvious cause; and 3) those with moderate MR before surgical revascularization [60,61]. A large prospective multicenter registry of surgery in patients with ischemic MR is underway, designed to assess the role of exercise echocardiography in identifying determinants of adverse outcomes, progressive LV remodeling, and efficacy of treatment [62].

Tricuspid Regurgitation (TR):

The goal of echocardiography is to detect TR, estimate the severity and assess pulmonary arterial pressure and RV function [63].

Chamber enlargement of both the right atrium and the right ventricle does occur with significant tricuspid regurgitation, but the presence of such chamber enlargement is generally the cause of rather than the effect of the tricuspid regurgitation. It is therefore rarely possible to use the chamber dimensions with spectral doppler ultra sound of the right heart to infer the severity of tricuspid regurgitation. Using continuous wave Doppler it is often possible to estimate the peak velocity of regurgitation, which can be used to estimate the right ventricular systolic pressure, but this is of little value in assessing the severity of tricuspid regurgitation [64].

TR using color flow imaging is readily recognized from parasternal tricuspid inflow view, short axis view, and apical or subcostal four chamber cross sections. Regurgitant jet area correlates roughly with severity of regurgitation, being less than 5 cm^2 in mild, 6-10 cm^2 in moderate and greater than 10 cm^2in severe cases. The spectral Doppler image of TR represents pressure gradient between right ventricle and right atrium through systole. The shape of TR velocity profile using continuous wave doppler provides a clue to this relationship. The regurgitation profile is generally parabolic except in severe cases, where high right atrial "C-V" waves result in rapid equalization with right ventricular pressure giving a profile with rapid deceleration, also described as 'V' wave cut off sign (Figure- 9) [65].

There are conflicting reports on the prenatal validity of echocardiographic indexes used to assess tricuspid valve malformations (TVM) in postnatal life. Andrews ER et al demonstrated some echocardiographic factors which are of most prognostic significance in prenatally-diagnosed TVM. Factors significantly associated with increased mortality included increased cardiothoracic ratio, Celermajer index, and right–left ventricular ratio, reduced/absent pulmonary valve flow , and retrograde duct flow. These are the predictors of outcome of TVM diagnosed during fetal life [66].

Hornherger L K et al also studied the tricuspid valve disease in fetal life and identified that tricuspid valve abnormalities with tricuspid insufficiency can be identified echocardiographically in the fetus and should be searched for in the presence of right aerial enlargement. All fetuses had been evaluated using third generation, high resolution linear array or electronic sector scanners with doppler capabilities. Fetal echocardiographic imaging of the two-dimensional cardiac anatomy and pulsed or continuous wave Doppler interrogation were performed [67].

Pulmonary Regurgitation (PR):

Detection of PR relies exclusively on colour flow imaging, PR is diagnosed by documenting the diastolic jet in RV outflow tract directed towards the RV. Although the vena contracta width is probably a more accurate method than the jet width to evaluate PR severity by colour doppler, it lacks validation studies (Figures 10 and 11) [4].

There are now more adults living in US with congenital heart disease than children and most of the former arrive there via successful pediatric surgical interventions. Progressive PR is common in these adolescents and adults. Initially, the RV responds well but variably, to severe PR. However, at some point, the RV will fail. This 'point of no return' seems to be an RV end-systolic volume index (ESVI) of greater then 150 ml/m^2 [68].

CONCLUSION

Great progress has been made in improving rates of morbidity and mortality in patients with valvular heart disease. Successful management of patients with valvular heart disease requires an evidence-based approach to echocardiography and to surgical intervention. Echocardiography should assess not only the valvular lesion but also the compensatory changes of the heart in response to the lesion. Data should be recorded for quantitation of AS by echocardiogram are LVOT diameter, LVOT velocity, AS jet velocity, LVEF, valve anatomy. 3D technique can be used to measure the same data. A smaller, change in AVA with increase in transaortic gradient is also useful to determine the severity or quantification of AS. In the setting of AR, surgery is recommend for asymptomatic patients with a maximal LvdD of greater than 55 mm or an LVEF of less than 50%. Aortic jet regurgitant is also useful for detection of AR. In mitral stenosis M-mode echocardiogram is helpful for detection of abnormal motion of anterior mitral valve leaflet by EF slope. Diastolic mitral valve mean gradient is the best predictor in moderate MS. The hallmark of a stenotic valve in TS is increases in transvalvular velocity recorded by colour wave doppler.The mean pressure gradient derived using the $4v^2$ equation is lower in tricuspid than in MS, usually ranging between 2 and 10 mmHg, and averaging around 5 mmHg. Higher gradients may be seen with combined stenosis and regurgitation. In PS, LV function reduced and gradient measurement appear falsely low. Functional MR due to LV dysfunctions associated with a poor outcome when MR is more than mild. When effective orifice area is >20 mm^2, MR is quantified as a severe. In TR regurgitant jet area correlates roughly with severity of regurgitation, being less than 5 cm^2 in mild, 6-10 cm^2 in moderate and greater than 10 cm^2in severe cases. PR is diagnosed by documenting the diastolic jet in RV outflow tract directed towards the RV.

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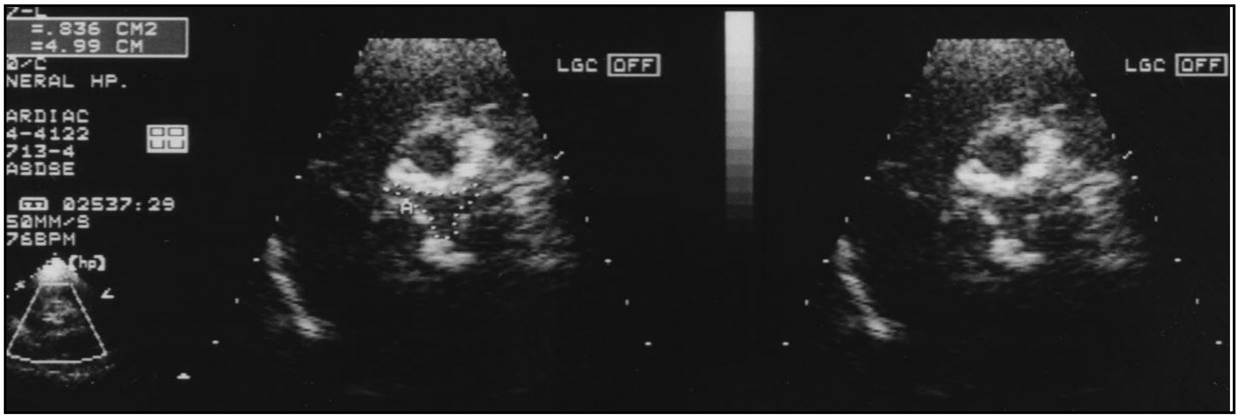

Figure-1 Measurement of AVA by transthoracic echocardiography in a patient with moderate aortic stenosis. The parasternal short-axis image of the aortic valve orifice was visualized during peak systole (**right**). Orifice area determined by planimetry was 0.84 cm2 (**left**).[10]

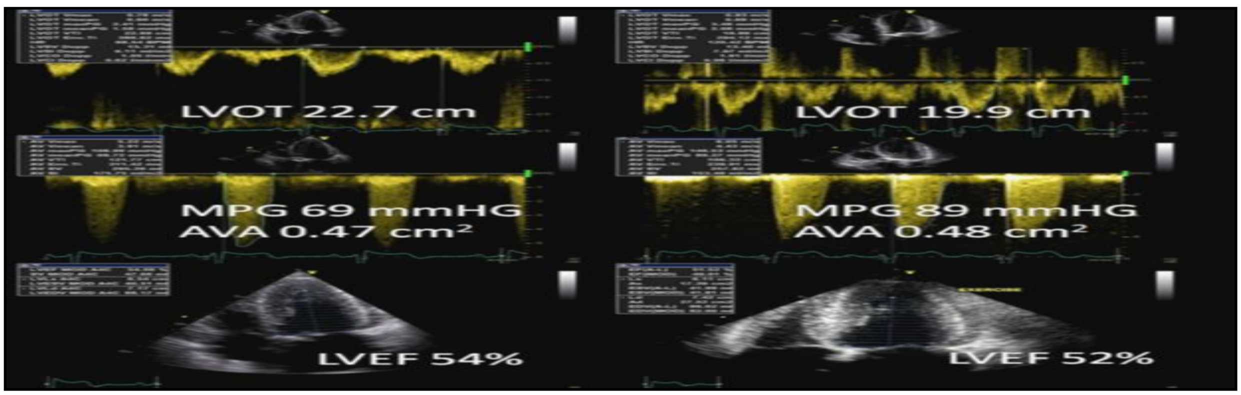

Figure-2 Two-dimensional echocardiography, Doppler findings by two-dimensional strain method **Left**: rest recordings with LVEF > 50%, high transaortic pressure gradients and altered longitudinal function. **Right**: exercise recordings demonstrating absence of increase in LVEF, increase in mean transaortic pressure gradients (20 mmHg).[12]

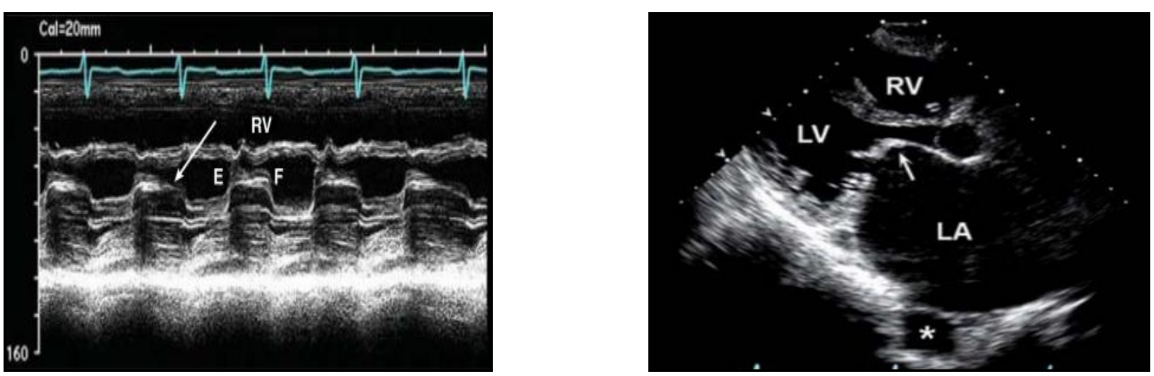

Figure-3 (Left) -M-mode echocardiogram of a patient with mitral stenosis. Note the abnormal motion of the anterior mitral valve leaflet as demonstrated by the E-F slope (arrow).**(Right)**-2D echocardiogram of parasternal long-axis view during diastole of a patient with mitral stenosis. The mitral valve leaflets are thickened and have the typical "hockey-stick" appearance (arrow). Left atrium (LA) is enlarged. LV=left ventricle; RV=right ventricle; *=descending thoracic aorta [21]

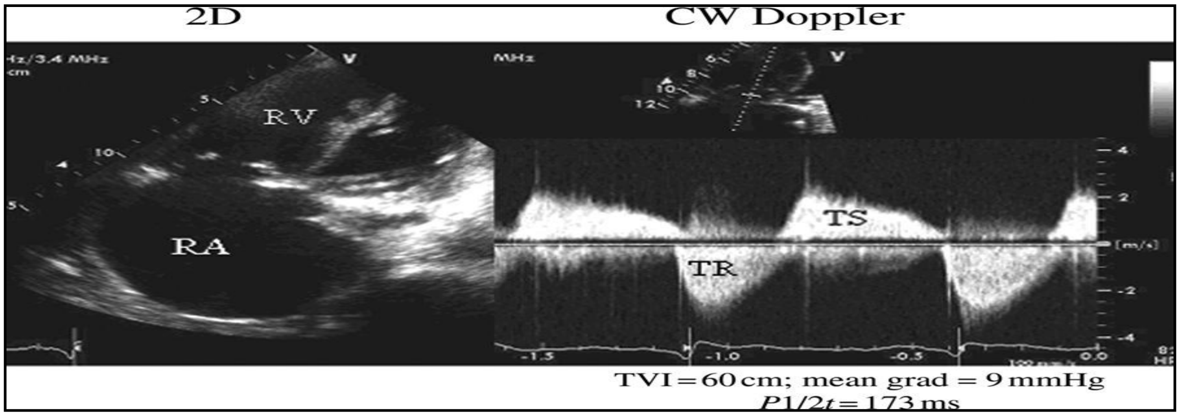

Figure-4 The left panel illustrates a 2D echocardiographic image of a stenotic tricuspid valve obtained in a modified apical four-chamber view during diastole. Note the thickening and diastolic doming of the valve, and the marked enlargement of the right atrium (RA). The right panel shows a CW Doppler recording through the tricuspid valve. Note the elevated peak diastolic velocity of 2 m/s and the systolic tricuspid regurgitation (TR) recording. The diastolic time–velocity integral (TVI), mean gradient (Grad), and pressure half-time (*T*1/2) values are listed.[36]

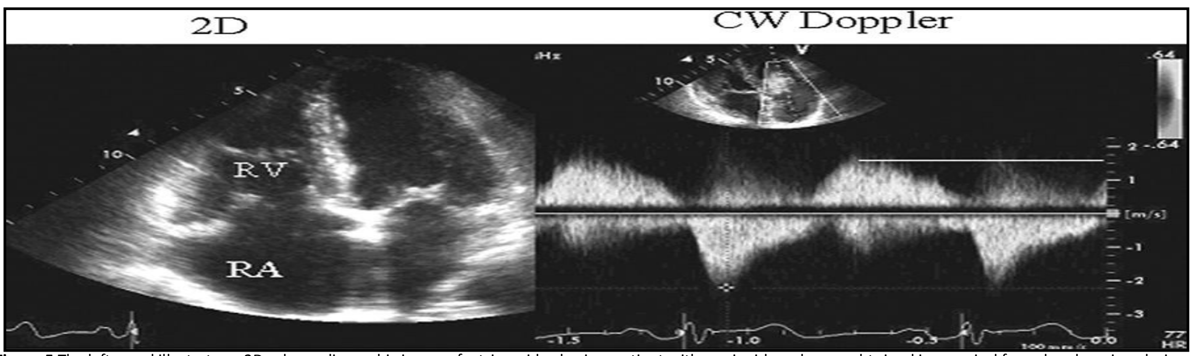

Figure-5 The left panel illustrates a 2D echocardiographic image of a tricuspid valve in a patient with carcinoid syndrome, obtained in an apical four-chamber view during systole. Note the thickening and opened appearance of the valve. The right panel shows a continuous-wave Doppler recording through the tricuspid valve. Note an elevated peak diastolic velocity of 1.6 m/s and the systolic TR recording.[36]

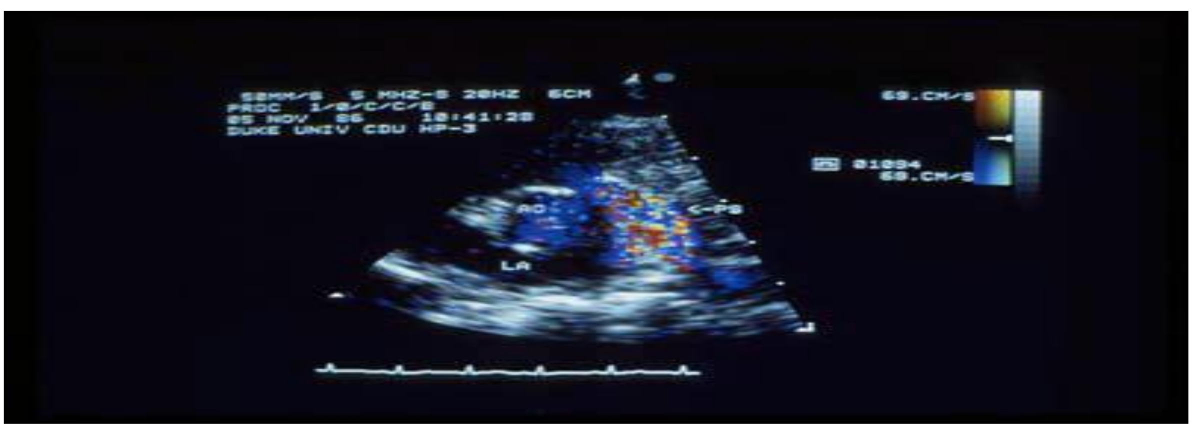

Figure-6 Short-axis view at the level of the aortic root, demonstrating turbulent flow in the main pulmonary artery due to pulmonic stenosis. A variance map was used.[43]

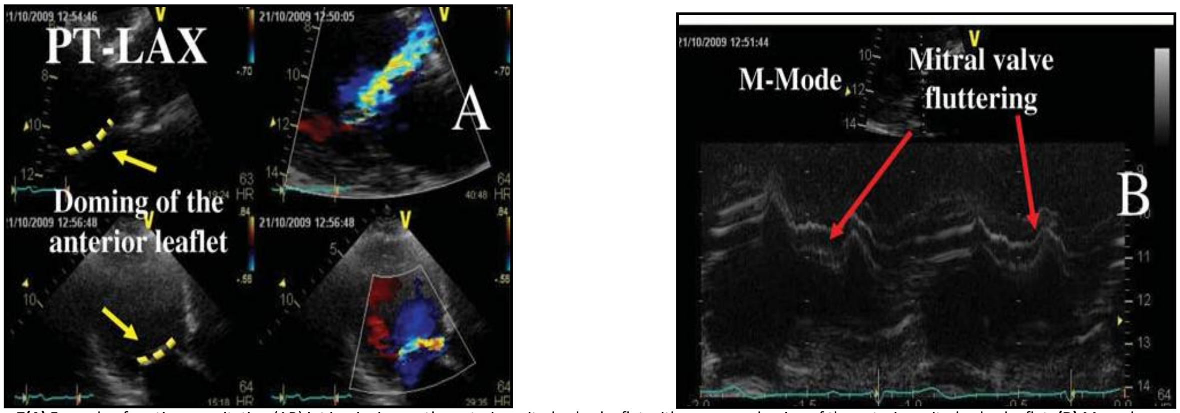

Figure-7(A) Example of aortic regurgitation (AR) jet impinging on the anterior mitral valve leaflet with a reverse doming of the anterior mitral valve leaflet; **(B)** M-mode recording showing the fluttering motion of the anterior mitral leaflet in a patient with severe AR.PT-LAX-parasternal long axis view.[4]

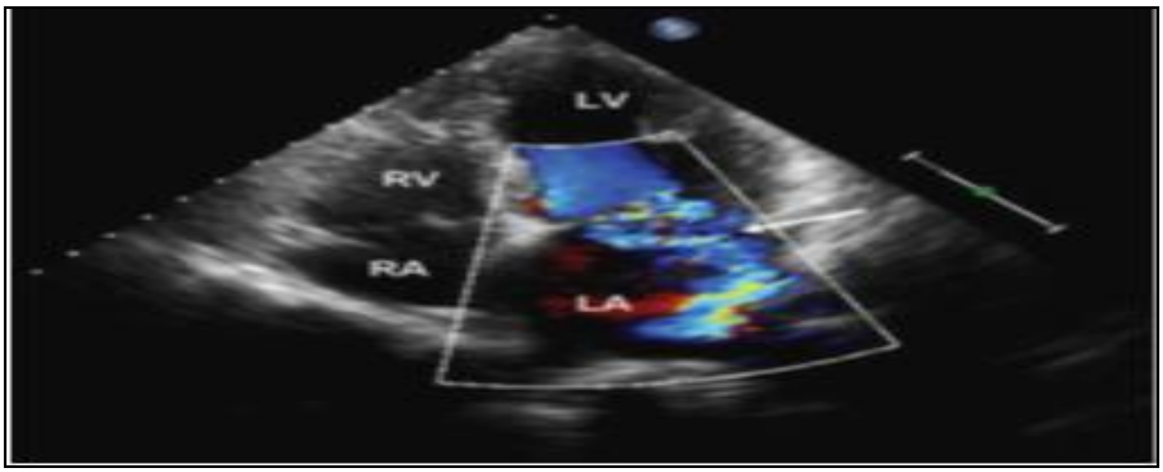

Figure-8 Apical 4-chamber echocardiographic view with color-flow Doppler imaging in a patient with mitral valve prolapse and severe mitral regurgitation (arrow). LA = left atrium; LV = left ventricle; RA = right atrium; RV = right ventricle [54]

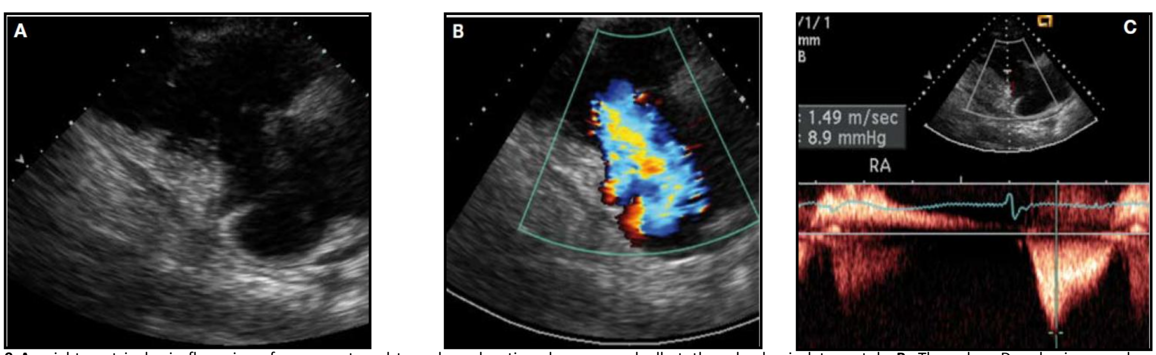

Figure-9 A- right ventricular in flow vi ew from parasternal transducer location shows a markedly tethered valve in late systole **B-** The colour Doppler images shows slow accelerating and severe tricuspid regurgitation jet without turbulence **C-** Continuous wave doppler shows early peaking systolic profile associated with high right artial pressure which was estimated to be 25 mmHg. The peak tricuspid regurgitation velocity is measured at 9mm Hg and thus indicate the right ventricular systolic pressure to be 34mmHg (9+25)[67]

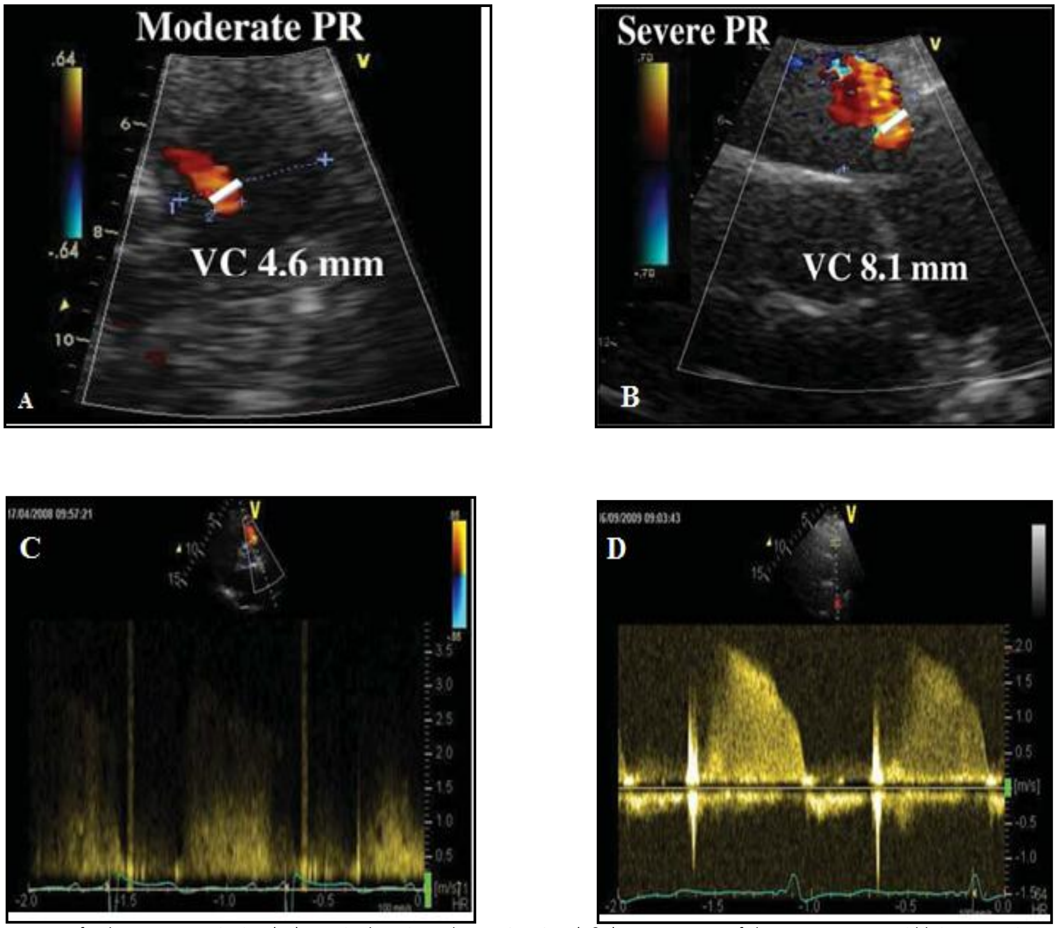

Figure-10 Assessment of pulmonary regurgitation (PR) severity by using colourow imaging. (A&B) Measurement of the vena contracta width in two patients with PR (left: moderate, right: severe). (C&D) Continuous-wave doppler recordings. [4]

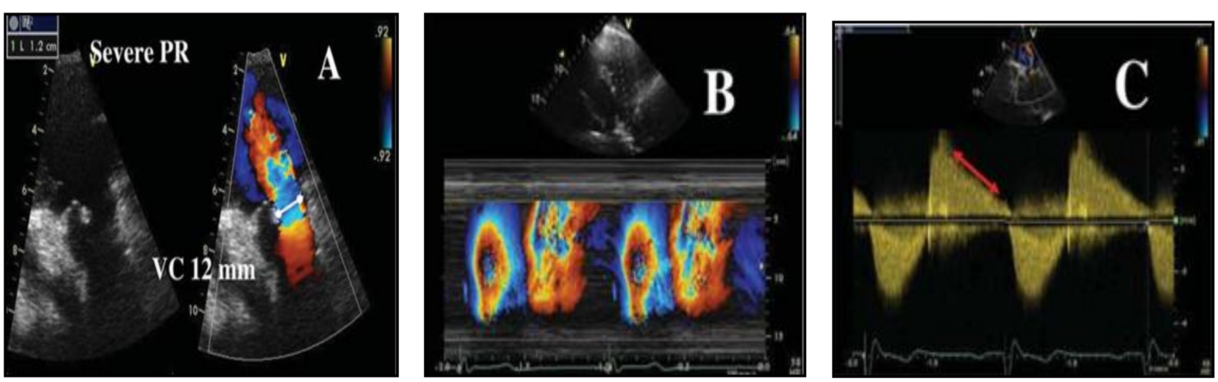

Figure-11 Example of a patient with a severe pulmonary regurgitation (PR). (A) Complete lack of valve coaptation (left) and measurement of the vena contracta width (VC) (right); (B) colour-coded M-mode d epicting the time dependency of flow signal during the heart cycle; (C) continuous Doppler recording of PR showing a rapid flow deceleration during the diastole (red arrow) and increased systolic flow velocity [4]