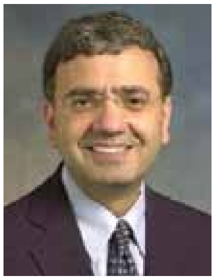

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NEW RECOMMENDATIONS FOR EVALUATION OF PROSTHETIC VALVES WITH ECHOCARDIOGRAPHY AND DOPPLER ULTRASOUND

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Overview

Valve replacement remains common in the adult patient despite advances in valve repair. While a physical examination can alert the clinician to the presence of valve dysfunction, diagnostic methods are often needed to assess the function of the prosthesis. Echocardiography with Doppler is currently the method of choice for the non-invasive evaluation of prosthetic valves. A recently published "Guidelines and Standards" document from the American Society of Echocardiography (ASE)[1] offers a review of echocardiographic and Doppler techniques used in assessing prosthetic valves and, for the first time, provides general recommendations for evaluating prosthetic valve function. The guidelines have been endorsed by prominent national and international professional health organizations including the American Heart Association, the American College of Cardiology, and the European Association of Echocardiography. I was honored to chair the ASE writing group of international experts on prosthetic valves and will review the salient features of these guidelines, particularly pertaining to the commonly implanted valves in the aortic and mitral positions.

Over the last 40 years, a large variety of prosthetic valves have been developed with the aim of improving hemodynamic function, increasing durability, and reducing complications. Nevertheless, there is no ideal valve, and all prosthetic valves are prone to dysfunction. The valve types now implanted include bileaflet and tilting-disc mechanical valves, stented porcine and pericardial xenografts, stentless porcine xenografts, cadaveric homografts, and autografts. Figure 1 shows examples of these valves and their echocardiographic images. The new ASE guidelines outline the importance of a comprehensive evaluation for optimal assessment of prosthetic valve function (Table 1). This involves obtaining pertinent clinical information, blood pressure and heart rate at the time of the examination, date of valve replacement, and type and size of the prosthetic valve since the latter affect valve hemodynamics. Imaging of the valve with transthoracic echocardiogram (TTE) from multiple views, with particular attention to motion of the leaflets or occluder, is recommended along with a comprehensive Doppler evaluation of velocity, gradients, and derivation of effective orifice area, where applicable. Selected indications for transesophageal echocardiography (TEE) to evaluate structural abnormalities, complications, and regurgitation is highlighted (Table 2). Lastly, since most prosthetic valves are inherently mildly stenotic, and velocities and gradients differ significantly among them, a baseline Doppler echocardiographic study is strongly recommended early after surgery for comparison in the serial assessment of valve function.

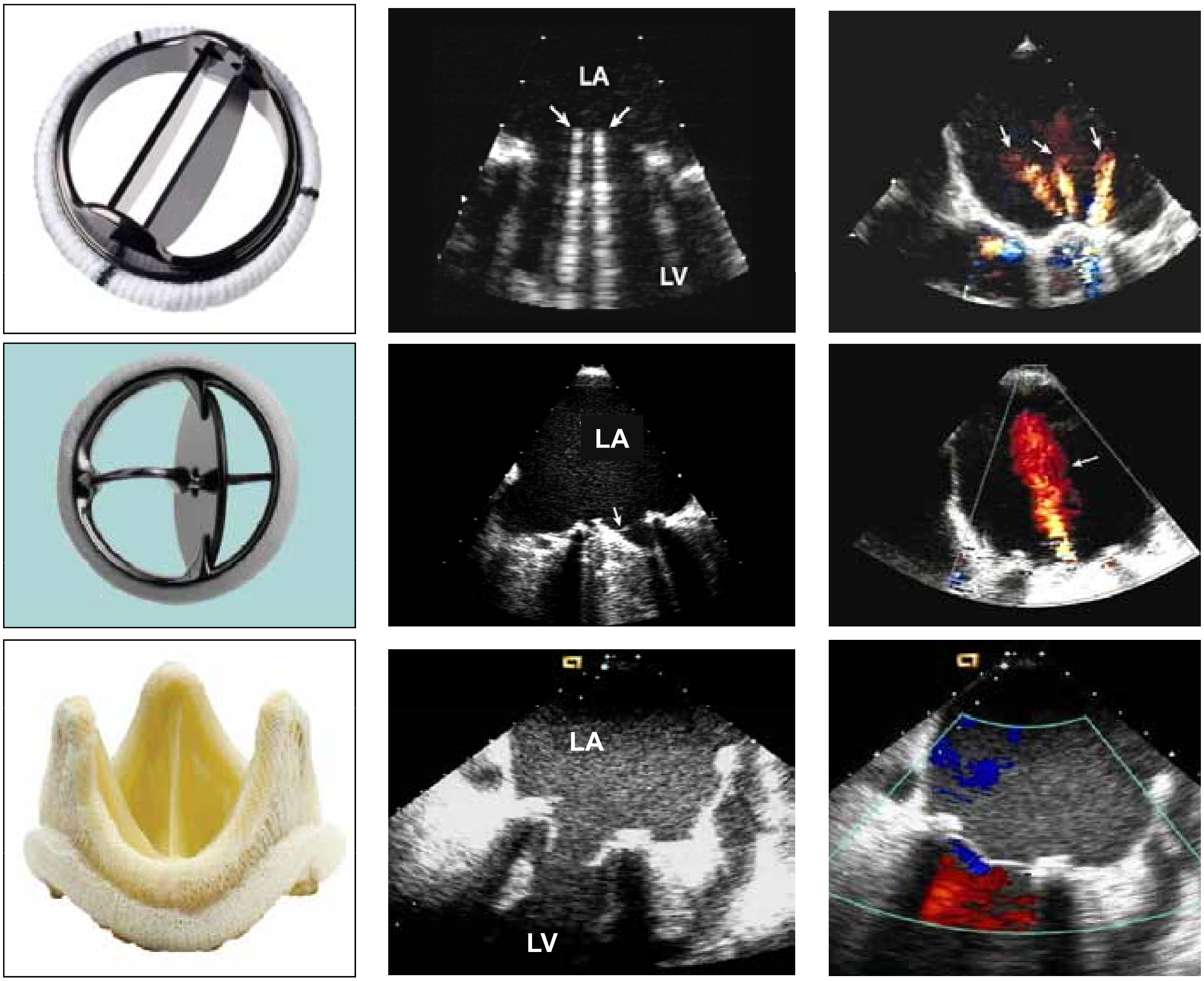

Figure 1. Examples of mechanical and bioprosthesis and their transesophageal echocardiographic characteristics taken in the mitral position in diastole (middle panels) and in systole showing physiologic regurgitation patterns. Modified from Zoghbi et al.[1]

General Considerations for Evaluating Prosthetic Valve Function

A variable amount of normal or "physiologic" regurgitation is visualized by echocardiography in all kinds of mechanical valves, whereas biological valves have minimal or no intrinsic regurgitation at implantation. For example, tilting-disc and bileaflet valves have built-in leakage when the valve is fully closed and can have different regurgitation patterns (Figure 1). The same methods used to evaluate native valvular regurgitation are also applied for prosthetic valve regurgitation.[2] However, three issues are worth highlighting. First, physiologic transvalvular regurgitation must be recognized and differentiated from pathologic regurgitation. Second, the ability of TTE to detect regurgitation depends on the position of the valve. Imaging of mitral or tricuspid prostheses results in acoustic shadowing in the region behind the valve (respective atrium), which compromises image quality as well as Doppler evaluation. In these cases, TEE is frequently needed to assess severity of regurgitation as well as associated structural abnormalities. Lastly, eccentric paravalvular regurgitation from valve dehiscence is frequent and adds complexity to color flow evaluation of regurgitant severity.

Normal prosthetic valves are inherently mildly stenotic compared to native valves. Determinants of gradients include valve type, valve size, and flow. This explains in part the wide range of normal parameters of prosthetic valve function in the literature.[1] In general, gradients across prosthetic valves estimated with

Table 1. Essential parameters in the comprehensive evaluation of prosthetic valve function.

	Parameters
Clinical information	Date of valve replacement
	Type and size of the prosthetic valve
	Height/weight/body surface area
	Symptoms and related clinical findings
	Blood pressure and heart rate
Imaging of the valve	Motion of leaflets or occluder
	Presence of calcification on the leaflets or abnormal echo density (ies) on the various components of the prosthesis
	Valve sewing ring integrity and motion
Doppler echocardiography of the valve	Contour of the jet velocity signal
	Peak velocity and gradient
	Mean pressure gradient
	Velocity-time integral of the jet
	Doppler velocity index
	Pressure half-time in MV and TV
	Effective orifice area*
	Presence, location, and severity of regurgitation**
Previous post-operative study(ies), when available	Comparison of above parameters is particularly helpful in suspected prosthetic valvular dysfunction

Modified from Zoghbi et al.[1]

**Effective orifice area using the continuity equation; needs to be compared to normal Doppler values of the valve type and size.*
***Transthoracic Doppler is less sensitive to detection of valvular regurgitation in mitral and tricuspid prostheses; TEE is frequently needed for a more definitive assessment.*
MV = mitral valve; TV = tricuspid valve.

Table 2. Indications of transesophageal echocardiography in prosthetic valves.

Valvular regurgitation: Mitral and tricuspid valves > aortic valves
Suspected valve obstruction: Assessment of valve motion, thrombus vs. pannus
Evaluation of associated structural abnormalities: Vegetations, thrombi, ring abscess, pseudoaneurysm, fistulae
Atrial, atrial appendage thrombi
Inadequate transthoracic echo study

Doppler by the modified Bernoulli equation (Pressure gradient = $4V^2$) correlate well with catheter-derived gradients, provided that angulation between flow and Doppler is minimal (<20°). Overestimation of gradients with Doppler may occur because of valve design and pressure recovery, particularly in bileaflet valves where a localized gradient is generated at the smaller orifice between the two leaflets. Although overestimation in these valves results in lower derived effective valve areas compared to the hydraulic formula, this is already accounted for in the published normal values.[1]

Another important quantitative parameter in assessing prosthetic valve function is the effective orifice area (EOA, in cm^2) of the prosthesis, derived by the continuity equation. The EOA complements gradient calculation and has the advantage of being less dependent on flow. This is calculated as EOA = stroke volume/TVI_{PrV}, where TVI_{PrV} is the time-velocity integral through the prosthesis determined by continuous wave Doppler. In prosthetic aortic valves, the continuity equation is simplified to the Doppler velocity index (DVI), the ratio of velocity proximal to the valve to the velocity through the valve. This index does not rely on measurement of the LV outflow tract and is much less dependent on valve size. DVI is always less than unity, since velocity will always accelerate through the prosthesis but normally is greater than 0.25.[1]

Complications of Prosthetic Valves

Valvular dysfunction after surgery is usually related to technical challenges during surgery or to early infection. Paravalvular leak is more frequent in older patients and after debridement of calcium and repeat valvular surgery. The incidence and nature of late dysfunction varies more with the type of prosthesis used, its durability and thrombogenicity, and patient factors such as the risk of endocarditis. Thromboembolism is determined by the type of heart valve and by patient-related factors. Mechanical valves are associated with a significant incidence of thromboembolic complications, though critical valve thrombosis is uncommon (Figure 2); the cause is usually inadequate anticoagulation. Both mechanical and tissue valves are also at risk of interaction between the prosthesis and host to create pannus, which can lead to progressive obstruction. Valve degeneration leading to stenosis and/or regurgitation remains the most frequent complication of biologic valves despite advances in valve design. Echocardiography, particularly TEE, offers a powerful tool to assess these various complications.[1] In patients with valve thrombosis, TEE can also assess the size of the thrombus, which helps in the decision to re-operate or use thrombolysis (Figure 2).[3]

Prosthetic Aortic Valve Stenosis

With increasing stenosis of the valve, a higher velocity and gradient are observed along with later peaking of the velocity (longer acceleration time) during systole (Figure 3). Because of the dependence of gradients on flow, other indices that are less dependent on flow should be also evaluated. Table 3 provides the proposed parameters and their cut-offs in assessing prosthetic aortic valve function. The more concordant the parameters are (normal or abnormal), the more confident the diagnosis. Confirmation of an abnormal valve motion, if needed, is undertaken with TEE and/or fluoroscopy and, more recently, with computed tomography. While TEE can help evaluate complications of a valve such as dehiscence, endocarditis, or thrombus formation, leaflet mobility in the aortic position is not optimally assessed

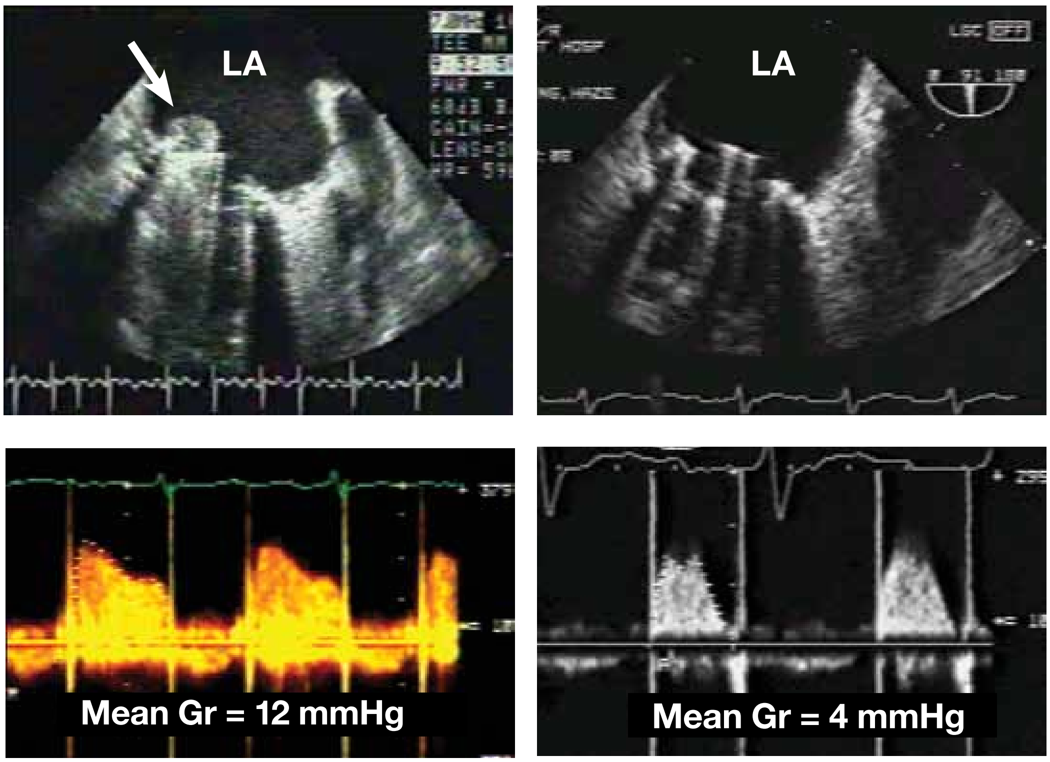

Figure 2. Prosthetic St. Jude valve thrombosis in the mitral position (arrow) obstructing and immobilizing one of the leaflets of the valve. After thrombolysis, leaflet mobility is restored and the mean gradient is significantly decreased. Gr = gradient; LA = left atrium. Reproduced from Zoghbi et al.[1]

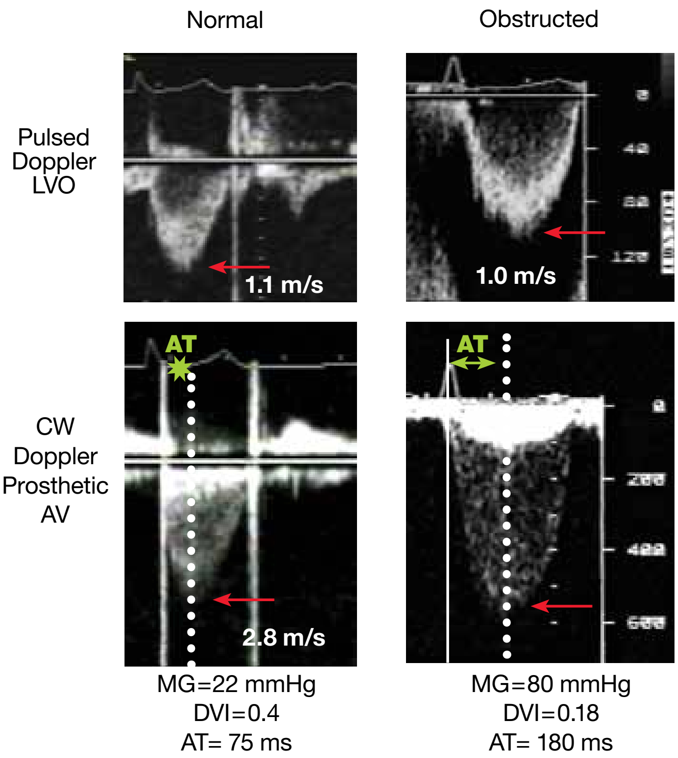

Figure 3. Doppler recordings of a normal and obstructed prosthetic valve in the aortic position. With obstruction, the jet velocity increases and undergoes changes in the contour. AT = acceleration time; MG = mean gradient; DVI = Doppler velocity index, ratio of velocity in the LV outflow to velocity through the prosthesis. Reproduced from Zoghbi et al.[1]

in mechanical valves. In the latter situation, fluoroscopy and CT are very helpful in visualizing mobility of the occluder. As stated earlier, performance of a baseline Doppler echo study is among the most valuable and essential tests in the serial evaluation of prosthetic valve function, particularly for the aortic position. This becomes crucial when the implanted valve size is small, resulting in prosthesis-patient mismatch, which produces high gradients and parameters of valve function that may be difficult to distinguish from valve obstruction.

Prosthetic Aortic Regurgitation

As in native valves, evaluation of aortic regurgitation (AR) is based on an integrated approach of color flow and conventional pulsed and continuous wave Doppler.[1, 2] These include color flow evaluation of the spatial distribution of the regurgitant jet, particularly its width at the origin, the intensity of the signal, pressure half-time by continuous wave Doppler, magnitude of diastolic flow reversal in the descending aorta, and measurement of regurgitant fraction by pulsed Doppler. Acoustic shadowing — problematic with the mitral prosthesis — is less of an issue for prosthetic AR. Assessing the severity of AR is generally more difficult than in native valves because of the high prevalence of paravalvular regurgitation and eccentric jets in mechanical prostheses. The integrative approach recommended for native aortic valve regurgitation is applied to prosthetic AR, with few modifications[1] relating to eccentric jets where traditional color Doppler parameters may be less reliable. TTE may be adequate for most of the qualitative and quantitative information needed to evaluate AR severity. TEE complements the transthoracic approach in technically difficult studies, in mapping the extent of annular involvement, and in evaluating the etiology of AR and associated complications.

Prosthetic Mitral Valve Stenosis

Similar to native mitral stenosis, parameters used for the assessment of prosthetic mitral valve function include maximal inflow velocity, mean gradient, pressure half-time (PHT), and effective orifice area derived with the continuity equation. Table 4 shows the proposed parameters and their cut-off values for normality and for suspecting stenosis.[1] In contradistinction to prosthetic aortic valves, heart rate has a major influence on mitral gradients. Therefore, heart rate should always be reported during the evaluation of prosthetic mitral valve function, and gradients interpreted accordingly. To correct for the effect of flow and heart rate, PHT and effective orifice areas are calculated. In valve stenosis, the time that it takes for the initial pressure gradient to decrease by half (PHT) is longer. PHT, however, is affected by several factors including atrial and ventricular compliance, ventricular relaxation, and loading conditions. Despite limitations, PHT provides a good index of valve function in the majority (85-90%) of cases. The use of effective areas is usually reserved for situations in which PHT is inaccurate to measure (e.g., short filling period) and in cases of discrepancy between information obtained from gradients and PHT.[1]

Prosthetic Mitral Valve Regurgitation

Detection and quantitation of prosthetic mitral valve regurgitation is difficult by transthoracic echocardiography because of the acoustic shadowing that occurs in the left atrium, although this phenomenon is less prominent with bioprosthetic valves compared to mechanical valves. Thus, in addition to incorporating clinical findings, one has to rely on indirect clues from the transthoracic echo-Doppler that suggest significant regurgitation.[4] These include:

Table 3. Doppler parameters of prosthetic aortic valve function in mechanical and stented biological valves*

	Normal	Possible Stenosis	Suggests Significant Stenosis
Peak velocity$^{\psi}$	< 3 m/s	3-4 m/s	> 4 m/s
Mean gradient$^{\psi}$	< 20 mmHg	20-35 mmHg	>35 mmHg
Doppler velocity index	≥ 0.30	0.29-0.25	< 0.25
Effective orifice area	> 1.2 cm^2	1.2-0.8 cm^2	< 0.8 cm^2
Contour of the jet velocity through the PrAV	Triangular, Early peaking	Triangular to Intermediate	Rounded, symmetrical contour
Acceleration time	< 80 ms	80-100 ms	> 100 ms

Modified from Zoghbi et al.[1]

* *In conditions of normal or near-normal stroke volume (50-70 ml) through the aortic valve.*
$^{\psi}$ *These parameters are more affected by flow, including concomitant aortic regurgitation.*
PrAV = prosthetic aortic valve

Table 4. Doppler Parameters of Prosthetic Mitral Valve Function

	Normal	Possible Stenosis	Suggests Significant Stenosis
Peak velocity$^{\psi \xi}$	< 1.9 m/s	1.9 – 2.5 m/s	≥ 2.5 m/s
Mean gradient$^{\psi \xi}$	≤ 5 mmHg	6-10 mmHg	> 10 mmHg
VTI_{PrMV}/VTI_{LVO} $^{\psi \xi}$	< 2.2	2.2-2.5	> 2.5
EOA	≥ 2.0 cm^2	1-2 cm^2	< 1 cm^2
PHT	< 130 ms	130- 200 ms	> 200 ms

Modified from Zoghbi et al.[1]
$^{\xi}$ *Slightly higher cut-off values than shown may be seen in some bioprosthetic valves.*
$^{\psi}$ *These parameters are also abnormal in the presence of significant prosthetic mitral regurgitation.*
EOA = effective orifice area; PHT = pressure half-time.

Figure 4. Transesophageal images in a patient with severe paravalvular (arrow) mitral regurgitation in whom regurgitation was barely visible by transthoracic echocardiography.

- Signs of increased mitral inflow volume (peak early velocity more than 1.9 m/s, mean gradient >5 mmHg, without signs of obstruction, i.e., PHT <130 ms)
- Decreased systemic output despite normal left ventricular function, with ratio of left ventricular outflow time-velocity integral to the time-velocity integral of the mitral inflow (TVI_{PrMV} /TVI_{LVO} ≥ 2.5)
- Systolic flow convergence in the left ventricle towards the mitral valve
- Unexplained pulmonary hypertension

Currently the best method for detection and quantitation of prosthetic mitral valve regurgitation is TEE (Figure 4). From the esophageal level, TEE provides an unobstructed view of the mitral valve and the left atrium. It demonstrates the site, mechanism, direction, and severity of the regurgitant jet by color flow imaging, evaluates flow velocity pattern in the pulmonary veins, evaluates the density and contour of the regurgitant jet by continuous wave Doppler, and may demonstrate flow convergence on the ventricular side. Integration of these findings from TTE and TEE to assess severity of the regurgitation is needed.[1, 2]

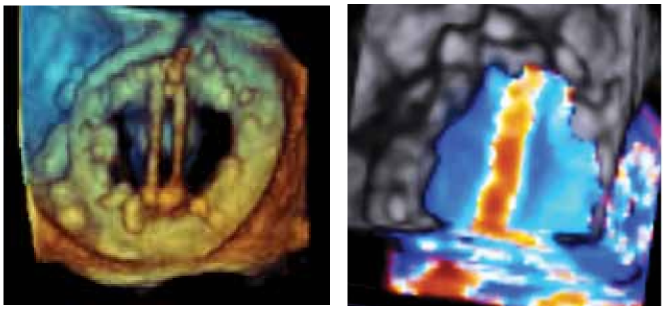

Figure 5. Examples of 3-dimensional echocardiography and Doppler images of a bileaflet mechanical valve in the mitral position from the left atrial view, showing the whole valve apparatus and flow through the valve, with higher velocity
between the leaflets.

Summary

Echocardiography with Doppler is currently the modality of choice for evaluation and management of prosthetic heart valves and native cardiac valves. In general, assessment of prosthetic valve function is more challenging due to the variability of inherent mild obstruction observed, emphasizing the need to document the type and size of the inserted valve. Serial comparison with a baseline postoperative study is also essential in facilitating accurate assessment of valve function. Recent advances in real-time 3D imaging from the transthoracic and more importantly from the transesophageal approach offer an important additional dimension in the echocardiographic evaluation of prosthetic valve function. 3D provides a powerful tool to image, for the first time with ultrasound, the motion of the entire valve apparatus and its annulus (Figure 5). This will undoubtedly enhance our appraisal of prosthetic valve function and application of innovative percutaneous interventions.[5]

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