OBJECTIVES:

At the conclusion of this lecture, the participant will be able to:

1. Identify the types of prosthetic valves and list the advantages and indications for each type of valve
2. Recognize the unique echocardiographic findings associated with each valve type
3. Outline the echocardiographic criteria for diagnosis of abnormal prosthetic valve function

INTRODUCTION

Since the first implantation of the caged-ball (Starr-Edwards) valve in the 1950s, more than 80 models of human prosthetic heart valves have been designed and implanted. Annually, more than 60,000 prosthetic heart valve replacement surgeries are performed in the United States. These prosthetic valves replace the structure and function of the diseased, native heart valve. The valves may be of two types: mechanical or bioprosthetic.

Mechanical valves are classified as caged-ball, single tilting-disc or bileaflet tilting-disc. Biologic, or bioprosthetic valves, may be classified as stented or stentless. Both stented and stentless bioprosthetic valves may be either porcine or pericardial xenografts. Aortic valve and root replacement may also be performed using a cryopreserved homograft (allograft) or an autograft (Ross procedure.) Each valve type has advantages and specific indications for implantation, as well as unique echocardiographic findings.

CHARACTERISTICS OF PROSTHETIC VALVES

The primary concerns in comparing the advantages and indications for mechanical and bioprosthetic valves include: structural valve deterioration (SVD), thrombogenicity, embolization and hemodynamic profile. All prosthetic valves share common complications, both early and late. Early complications include
valvular dysfunction (e.g. paravalvular leak), patient-prosthesis mismatch (PPM), early prosthetic thromboembolism, hemolysis, acute endocarditis and chordal entrapment and obstruction following mitral valve replacement. Late complications include thromboembolism, pannus formation, SVD, hemolysis, dehiscence, endocarditis and pseudoaneurysm formation.

COMPOSITION: MECHANICAL VALVES

The three types of mechanical valves have unique structural characteristics. Caged-ball valves (Starr-Edwards, pictured) contain a silastic or metal ball occluder housed in a wire cage with 3 or 4 struts. The ball occludes central blood flow, which eliminates regurgitant flow but requires greater energy for the left ventricle to eject the blood through the valve. As a result, the blood components endure more trauma, leading to an increased incidence and severity of hemolysis in patients with these valves.1,2

Caged-ball valves excel in durability but are highly thrombogenic. However, some studies have shown there to be a similar incidence of valve thrombosis among all mechanical valves in patients receiving adequate anticoagulation.3

Single tilting-disc valves (Bjork-Shiley, Medtronic Hall (pictured), Omnicarbon and Monostrut) are utilized in the aortic or mitral position. The design incorporates a disc occluder supported by 3 or 4 struts. The disc opens at an angle of 60-80° to form two orifices of different size and shape; this motion improves central flow and prevents backflow.

Overall, the single tilting-disc valves are slightly less durable than other mechanical valve designs. The Bjork-Shiley valve was withdrawn from the market in 1986 after several reports of a valve ring strut fracture, resulting in dislodgement and embolization of the disc. Currently, prophylactic Bjork-Shiley valve replacement is recommended for patients less than 50 years of age who have valves greater than 29mm with a 70° opening angle.4

The bileaflet tilting-disc valve (St. Jude Medical (pictured), Carbomedics and Edwards-Duromedics) is the most frequently implanted type of mechanical prosthetic valve. The differences between the three commercially available bileaflet tilting-disc valves are related to the composition of the carbon, leaflet and pivot design, size and shape of the housing and design of the sewing ring.

All of the commercially available mechanical valves may be implanted in the aortic, mitral or tricuspid position. Bileaflet tilting-disc valves are extremely durable and possess the largest effective orifice area (EOA) of the mechanical valve types. They contain two semicircular leaflets (tilting discs) attached to a circular annulus by 4 hinge points. A sewing ring circumscribes the annulus.
As the leaflets open to an angle of 80° in diastole, three separate orifices are formed. Upon closure during systole, as upstream pressure surpasses downstream pressure, the volume of blood required to “close” the discs washes over the leaflets. These “washing jets” are thought to prevent formation of thrombi within the valve housing.

COMPOSITION: BIOLOGIC (BIOPROSTHETIC) VALVES

Stented xenograft valves - porcine or bovine - are the most frequently implanted biologic prosthetic valves. Stented porcine xenografts (Carpentier-Edwards valves - Edwards Lifesciences; Hancock II and Mosaic valves (pictured)-Medtronic) may be an intact porcine valve or a composite constructed from multiple animals. They are composed of a glutaraldehyde preserved porcine aortic valve mounted on a fabric covered wire frame attached to a sewing ring. These valves may be implanted in the aortic, mitral or tricuspid position.

Bovine pericardium is most often used to form the valve cusps of stented pericardial xenografts (Perimount series valves – Edwards Lifesciences). The pericardium is molded into three leaflets that are supported by a wire frame connected to a sewing ring. Xenografts may also differ in the method of valve cusp preservation, anticalcification regimens, and stent / sewing ring design.5

Stentless xenograft valves are formed from a fabric reinforced glutaraldehyde preparation of porcine aorta. They are constructed without the wire frame support, stents or sewing ring. The Medtronic Freestyle (pictured) contains a long aortic root, whereas the St. Jude Medical Toronto valve is designed to fit under the coronary arteries. Durability of the stentless valve may be improved by increased freedom of movement for the valve cusps in the absence of the stents.

Geometric matching of the patient’s sinotubular junction (STJ) diameter with the diameter of the stentless valve is paramount. If the native STJ is greater than 10% of the diameter of the implanted stentless xenograft, altered leaflet coaptation will result and regurgitation will ensue.6 Stentless bioprosthetic valves are used for aortic valve and aortic root replacement.

Recently, there has been a dramatic increase in the number of percutaneous transcatheater aortic valve implantations. (TAVI). The Medtronic CoreValve and Edwards-SAPIEN (pictured), both bovine pericardial bioprosthetic valves, have demonstrated encouraging results for the treatment of high-risk, elderly patients with severe symptomatic aortic stenosis who are not candidates for conventional open AVR.7
STRUCTURAL VALVE DETERIORATION

Durability (longevity) is the major advantage of the mechanical prosthetic valve. Implanted mechanical valves routinely last 20-30 years, with the sparingly used caged-ball valve demonstrating the best durability. Conversely, 30% of xenograft bioprostheses and 10-20% of homograft bioprostheses fail and require replacement within 10-15 years of implantation. For patients less than 60 years of age, mechanical prosthetic valve replacement is nearly always recommended. Exceptions include females planning for pregnancy or a patient whose job or associated medical condition (e.g., seizure disorder) may be a contraindication for anticoagulation.

For patients greater than 60-65 years of age, the decision between mechanical and prosthetic valve replacement is dependent upon life expectancy, associated co-morbid medical conditions (e.g., atrial fibrillation) and willingness to take anticoagulation. Rahimtoola, et al, found the rate of SVD for bioprosthetic valves to be much lower in patients who were at least 65 years of age at the time of implantation. Recent data demonstrates the cumulative 15-20 year risk of SVD for a bioprosthetic valve to be 25% and 34%, when implanted in patients 60 and 55 years of age, respectively. Interestingly, at 55 years of age, the risk of bleeding due to anticoagulation for a mechanical valve is equal to that of subsequent reoperation with a bioprosthetic valve.

Biological valve types that also require aortic root replacement include autografts (Ross principle), allografts (homografts) and stentless xenografts (Edwards Prima Plus; Toronto SPV-St. Jude Medical; Medtronic Freestyle). These valves offer improved EOA due to the absence of the stents (struts) and are often used in aortas less than 20mm in diameter. The rates of SVD for stentless xenografts is similar to stented xenografts. However, recent studies have shown a high operative mortality for redo-aortic root replacements of stentless bioprosthetic valves. Currently, stentless xenografts are primarily used for elderly patients (> 65 years of age) with small aortas.

Allografts (cryopreserved human aortic root homografts) are the valve type of choice in infective endocarditis with abscess or bacteremia. These are available in aortic annulus measurements ranging from 20-26mm. Homografts must be sized-matched appropriately to the recipient to avoid post-implantation aortic regurgitation.

THROMBOGENICITY

Historically, the reported incidence of prosthetic-valve thrombosis is 0.1 – 0.5% per patient-year. Mechanical valves’ major disadvantage is thrombogenicity, with thrombosis occurring more frequently than with bioprosthetic valves. Bileaflet tilting-disk valves carry the lowest thromboembolic risk of the mechanical prosthetic valves, while the caged-ball design carries the highest risk. All mechanical
prosthetic valves require systemic anticoagulation, usually with warfarin. Aspirin may be added to high-risk patients. The major risk factors for thrombosis of a mechanical valve include inadequate anticoagulation, mitral position, left ventricular systolic dysfunction and hypercoagulable state.

Guidelines for anticoagulation of a bioprosthetic valve recommend low-dose aspirin. Coumadin is recommended for high-risk patients, including those with atrial fibrillation, prior thromboembolism, severe left ventricular dysfunction (ejection fraction < 30%) and a hypercoagulable state.¹⁰

EMBOLIZATION

The incidence of major embolization, resulting in death or permanent neurologic injury, in patients with mechanical prosthetic valves has been reported as 4% per patient-year with no antithrombotic therapy, 2% per patient-year with anti-platelet therapy and 1% per patient-year with Coumadin. Embolization risk increases with mitral position and multiple prosthetic valves.³ Risk factors for embolization are similar to those for prosthetic valve thrombosis. Prosthetic valve thrombosis and endocarditis should be ruled out in the setting of potential prosthetic valve embolization.

HEMODYNAMIC PROFILE

All prosthetic heart valves have published data with regard to normal mean and peak gradients (mmHg) and EOA (cm²). These are given for each valve type and size, as well as implant position. The echocardiographer should be familiar with these values. They may be found in multiple echocardiographic textbooks as well as the 2009 Recommendations for Evaluation of Prosthetic Valves With Echocardiography and Doppler Ultrasound from the American Society of Echocardiography.⁵

The EOA of a prosthetic valve is determined by the formula:

\[
\text{EOA: stroke volume} = \frac{\text{VTI}_{\text{PrV}} \times \text{CSA}_{\text{PROX}}}{\text{VTI}_{\text{PrV}}}
\]

VTI_{PrV} is the velocity-time integral (VTI) calculated by continuous-wave (CW) Doppler through the prosthetic valve.

The stroke volume, for aortic or pulmonary valves, is calculated by multiplying the cross-sectional area (CSA_{PROX}) just proximal to the prosthetic valve by the pulsed-wave (PW) Doppler VTI_{PROX} obtained at that position. Either of these VTI values may be used for mitral valve prostheses, provided there is no significant regurgitation or intra-cardiac shunt.

The EOA of a prosthetic valve determined by the continuity equation is a superior index of valve function to gradient alone.⁵ Low indexed EOA (cm²/m²), the EOA divided by the patient’s body surface area (BSA), has been consistently related to high post-operative gradients and patient-prosthesis mismatch (PPM).¹⁴
PPM, also known as valve prosthesis-patient mismatch (VP-PM), occurs when the indexed EOA of the implanted prosthetic valve is insufficient for the patient’s body size, leading to abnormally high post-operative gradients. Severe PPM after AVR is denoted by an indexed EOA ≤ 0.6 cm²/m²; indexed EOA ≤ 1.0 cm²/m² defines severe PPM after MVR.⁹

PPM has been associated with reduced short and long-term survival, notably in the setting of left ventricular systolic dysfunction.¹⁵ The clinical impact of PPM increases with severity.¹⁴

Cryopreserved homografts possess the largest EOA relative to size. Conventionally, bileaflet tilting-disc valves were thought to have a larger EOA than stented bioprostheses,¹⁴ but recent data have shown no significant difference in EOA at 6 months post-implantation between same-size bileaflet tilting-disc and porcine bioprosthetic valves⁹.

Aortic prosthetic valves are often technically difficult to assess for normal leaflet or occluder motion by 2D echo imaging. Doppler interrogation to ensure a normal transvalvular gradient and EOA is particularly important. The Doppler velocity index (DVI) is a simplified continuity equation and has been validated.¹⁶ The DVI is the ratio:

\[
\text{DVI}_{AV} = \frac{\text{peak LVOT velocity}}{\text{peak transvalvular}_{(AV)} flow velocity}
\]

A normal DVI₈ is ≥ 0.35. DVI has not been validated for the assessment of pulmonary prosthetic valves.

Maslow, et al, validated the use of the double envelope (DE) technique for the assessment of prosthetic aortic valve area, AVA. The DE method simultaneously acquires subvalvular \( (V_1) \) and prosthetic valvular \( (V_2) \) velocities from the same CW Doppler trace. Prosthetic AVA calculated by the DE technique, the ratio of \( V_1/V_2 \), correlates with DVI calculated via the continuity equation and data reported by the manufacturer.

**TEE EVALUATION OF PROSTHETIC VALVES**

Multiplane Transesophageal Echocardiography (TEE) is the diagnostic modality of choice for identification of prosthetic valves, interrogation and assessment of valve function and diagnosis of prosthetic valve dysfunction.¹⁸ TEE provides high-resolution 2D imaging, along with color flow and spectral Doppler, for an unmatched assessment of prosthetic valve structure and hemodynamic function. Unfortunately, mechanical valves and the stents of bioprosthetic valves possess poor acoustic properties, exposing the limitations of ultrasound echocardiography. These limitations include the inability to pass through the metallic and polymer components found in both types of prosthetic valves. The resulting highly specular echocardiographic image impairs the imaging of distal structures because of
shadowing, dropout and reverberation artifacts. Minimizing the transmit gain may improve the imaging of tissue adjacent to non-biologic materials. Assessing a prosthetic valve from multiple positions and angles is essential to performing a proper TEE examination.

Clinical indications for TEE include evaluation and interrogation of the native valves to ensure accurate diagnosis, evaluation and interrogation of the newly implanted prosthetic valve and assessment of any suspected post-operative prosthetic valve dysfunction. A comprehensive evaluation of a prosthetic valve should include relevant clinical information (height, weight, BSA, symptoms, heart rate and blood pressure), 2D imaging and Doppler interrogation. Left and right ventricle size and function, left and right atrial size, presence of concomitant valvular disease and estimation of pulmonary artery pressure should be determined.

2D imaging of the valve should be performed using multiple views and planes. Key examination points include:

1) opening and closing motion of the moving parts of the valve (bioprosthetic leaflets or mechanical occluders)
2) presence of leaflet calcifications or abnormal echo dense structures attached to the sewing ring, occluder, leaflets, stent or cage
3) sewing ring appearance, particularly areas of apparent separation from the native annulus or any “rocking” motion of the prosthetic valve.

Doppler echocardiography of the valve should assess mean pressure gradient, peak velocity and peak pressure gradient via CW Doppler. The contour of the jet velocity signal should be assessed. EOA should be calculated, along with DVI for aortic valves. The presence, location and severity of any regurgitant flow should also be determined.

The four basic tasks in assessing prosthetic heart valves with TEE are:

1) confirm normal leaflet motion
2) confirm proper valve seating
3) confirm normal blood flow patterns, specifically the absence of pathologic transvalvular and paravalvular regurgitation
4) calculate valve gradients (mean and peak) and EOA

MECHANICAL HEART VALVES

*Caged-ball valves:* The ball or silastic occluder will cast a large acoustic shadow requiring assessment of its motion in the long axis of the valve. Short axis imaging reveals the ball inside the wire struts. CFD (color flow Doppler) will demonstrate flow through the valve, around the perimeter of the ball and within the cage. There is typically a small closing volume and very little or no regurgitant flow.

*Single leaflet tilting-disc valves:* The TEE examination should confirm proper tilting motion of the disc in the long and short axis planes. Strut fracture should always be ruled out. Inside the sewing ring, the Bjork-Shiley valve has small jets where the closed disc meets the housing. The Medtronic Hall valve demonstrates the same trivial transvalvular jets, plus an additional jet through a hole in the disc occluder.5
Bileaflet tilting-disc valves: TEE examination should confirm opening and closing of the two discs. Short axis examination should reveal two linear shadows inside the sewing ring. Mitral prosthetic valves are best assessed in the mid-esophageal long-axis view. Acoustic shadowing is often present with bileaflet discs in the aortic position, precluding adequate assessment of leaflet motion in the mid-esophageal views. Trans-gastric long axis and deep trans-gastric long axis views allow unobstructed assessment of the discs via the left ventricle.

The bileaflet valves will demonstrate regurgitant flow from closing and leakage backflow. Closing backflow is the closing blood volume required to close the two discs. Leakage backflow jets originate from the 4 hinge points of the leaflets. These jets are centrally directed with a small CFD profile and short duration. Leakage or “washing jets” are seen best with TEE in the long axis of the valve, at a multiplane angle parallel to the discs.

BIOPROSTHETIC VALVES

Bioprosthetic valves possess favorable acoustic properties and are well visualized by TEE examination. They may be interrogated with the same techniques used to examine native cardiac valves.

*Stented porcine xenografts:* demonstrate three leaflets supported by stents that in short axis open to form a central opening. In long axis, the struts are orientated downstream and the valve leaflets open and close symmetrically, coapting at the center of the valve.

*Stented bovine pericardial valves:* possess similar imaging characteristics, but have a lower profile.

*Stentless bioprosthetic valves:* nearly identical on 2D imaging to native aortic valves. Trace or mild central aortic regurgitation is common after implantation.

ECHOCARDIOGRAPHIC ASSESSMENT OF PROSTHETIC VALVE DYSFUNCTION

Prosthetic valve dysfunction is the result of valvular regurgitation, valvular stenosis, endocarditis or left ventricular outflow tract obstruction. TEE is the modality of choice for assessing the patient presenting with suspected prosthetic valve dysfunction.

PROSTHETIC VALVE REGURGITATION

Understanding regurgitant blood flow patterns is essential for performing an accurate TEE examination of prosthetic valves. Regurgitant flow patterns, as assessed by CFD and Doppler echocardiography, are classified as physiologic or pathologic and transvalvular (within the sewing ring) or paravalvular (outside of the sewing ring).

Minor physiologic regurgitation is normal in all prosthetic valves. Usually, a closing volume of regurgitation is seen. This is a small displacement of blood caused by closing of the occluder mechanism used in mechanical valves. Trivial
Regurgitation may also occur at the hinges of the occluder. These normal, minor regurgitant jets are always transvalvular, small in size on CFD and short in duration.

Bioprosthetic valves usually exhibit minor, central regurgitation. CFD often reveals a small, narrow regurgitant jet originating from the central coaptation point. Stentless valves, homografts and autografts are more likely to demonstrate these jets. The percutaneous aortic valves nearly always exhibit these central jets, along with mild to moderate paravalvular regurgitation. As with all minor regurgitant jets, they are low in momentum with aliasing confined to the base of the jet.\(^5\)

Regurgitant jets originating outside of the sewing ring are paravalvular and always pathologic. Paravalvular regurgitant jets are found in the immediate post-implantation period between 5-20% on TEE examination. In the absence of endocarditis, these leaks are usually clinically and hemodynamically insignificant; however, there may be an increased risk of hemolytic anemia.\(^{19,20}\) Pathologic paravalvular regurgitation jets will normally be high velocity (less with severe systolic dysfunction), with a large CFD profile and significant aliasing. The CFD jet will frequently track along the wall of the receiving chamber.

Pathologic transvalvular regurgitation will have a large CFD profile and be long in duration. Immediately after implantation, this finding represents abnormal leaflet or occluder motion. Intraoperative causes include retained tissue (e.g. subvalvular apparatus in MVR), misplaced suture or debris causing leaflet or occluder dysfunction. Bioprosthetic valves may undergo chronic degenerative changes (structural valve deterioration, SVD) leading to leaflet thickening and calcification with reduced mobility or leaflet destruction resulting in significant transvalvular regurgitation.

Indices for assessing the severity of prosthetic valve regurgitation have been formulated; examples include:\(^5\)

- **Prosthetic aortic regurgitation (AR):** grading is dependent upon valve structure and motion, jet density and deceleration rate, presence of flow reversal in the descending aorta, regurgitant volume and fraction.
- **Prosthetic mitral regurgitation (MR):** dependent upon patient presentation (62% of large leaks associated with NYHF class III/IV\(^{21}\)) vena contracta (VC) width, and CFD appearance of jet in the left atrium. Severe MR is defined by systolic flow reversal in the pulmonary veins and effective regurgitant orifice area (EROA) ≥ 0.5cm\(^2.\)\(^{22}\)
- **Prosthetic tricuspid regurgitation (TR):** severe when holosystolic reversal of hepatic venous flow is present. CW Doppler interrogation demonstrates a dense, early peaking jet contour. VC width is usually > 0.7cm.
- **Prosthetic pulmonary valve regurgitation:** severe when the jet width is > 50% of pulmonary annulus, PW Doppler reveals pulmonary flow to be much greater than systemic flow and there is diastolic flow reversal in the pulmonary artery.
PROSTHETIC VALVE STENOSIS

All prosthetic valves are mildly stenotic relative to the native valve. The gradients vary depending upon the valve type and size, and the hemodynamic status of the patient. All prosthetic valves have expected mean and peak pressure gradients for a specific annulus size and implant position; these may be found in the package inserts.

The modified Bernoulli equation, pressure \( P = 4(V_2^2 - V_1^2) \), usually disregards the proximal velocity, \( V_1 \), due to its insignificant value. In the presence of an aortic valve prosthesis, high cardiac output state or small LVOT, Doppler estimation of the gradient should consider the velocity proximal \( (V_1, \text{if}> 1.5 \text{ m/s}) \) to the native valve or prosthesis. Otherwise, overestimation of the gradient may occur, particularly with caged-ball and bileaflet tilting-disc valves, leading to a falsely reduced EOA.

The phenomena of pressure recovery, which is beyond the scope of this text, should also be considered in the presence of caged-ball and small (< 19mm) bileaflet tilting-disc valves.  

Peak transvalvular gradient for valves in the mitral position average 4mmHg with an average EOA of 2.5-3.0cm²; peak gradients in the aortic position average 15-20mmHg with average EOA ranging 1.5-2.0cm².

Thrombus, pannus, vegetation, suture or retained subvalvular tissue may cause stenosis of a mechanical or bioprosthetic valve. Differentiating thrombus from pannus determines the appropriateness of thrombolytic therapy. Bioprosthetic valves may also be stenotic due to chronic degenerative changes (structural valve deterioration, SVD) leading to leaflet calcification, thickening and reduced mobility. 2D TEE imaging will reveal these changes.

Indices for assessing the severity of prosthetic valve stenosis have been formulated; examples include:\textsuperscript{5}

- **Severe aortic stenosis** (AS): mean gradient > 35 mmHg, DVI < 0.25, EOA < 0.8cm², jet contour is rounded and symmetrical
- **Severe mitral stenosis** (MS): peak velocity > 2.5 m/s, mean gradient > 10mmHg, EOA < 1cm²
- **Severe tricuspid stenosis** (TS): peak velocity > 1.7 m/s, mean gradient ≥ 6 mmHg, EOA not yet validated
- **Severe pulmonary valve stenosis**: peak velocity > 3 m/s through prosthesis, or > 2 m/s through homograft

ENDOCARDITIS

Prosthetic valve endocarditis (PVE) is an endovascular, microbial infection occurring on a prosthetic heart valve (PHV) or a reconstructed native heart valve.\textsuperscript{25}
PVE occurs in 2-6% of patients following valve replacement surgery and has a mortality rate of 20-80%. The incidence of PVE is increasing and now comprises 20-30% of all episodes of infective endocarditis. TEE remains the diagnostic gold standard for evaluating PVE.

Detecting the size and location of any vegetation is essential for determining appropriate therapeutic decisions, such as duration of antimicrobial therapy or urgent surgical therapy. It is important to use both mid-esophageal and transgastric views to completely evaluate the periannular tissue, investigating for the presence of an abscess, dehiscence or fistula of both sides of the prosthetic valve.

LEFT VENTRICULAR OUTFLOW TRACT OBSTRUCTION

Left ventricular outflow tract (LVOT) obstruction is a rare cause of subvalvular aortic stenosis following mitral valve replacement (MVR) surgery. The chordal sparing approach is now favored when performing MVR, allowing residual leaflet or chordal tissue to remain in the LVOT causing subvalvular stenosis. In small left ventricles, the stent of a porcine bioprosthetic valve in the mitral position may impair blood flow out of the LVOT, thus causing subvalvular stenosis.

Transgastric long axis view of the left ventricle allows imaging of the subvalvular apparatus and the LVOT after MVR. Doppler echocardiography should be employed in this view to estimate the LVOT gradient.

5. Zoghbi WA, Chambers JB, Dumesnil JG, et al. Recommendations for evaluation of prosthetic valves with echocardiography and doppler ultrasound: a report From the American Society of Echocardiography's Guidelines and Standards Committee and the Task Force on Prosthetic Valves, developed in conjunction with the American College of Cardiology Cardiovascular Imaging Committee, Cardiac Imaging Committee of the American Heart Association, the European Association of
Echocardiography, a registered branch of the European Society of Cardiology, the Japanese Society of Echocardiography and the Canadian Society of Echocardiography, endorsed by the American College of Cardiology Foundation, American Heart Association, European Association of Echocardiography, a registered branch of the European Society of Cardiology, the Japanese Society of Echocardiography, and Canadian Society of Echocardiography. J Am Soc Echocardiogr 2009;22:975-1014; quiz 82-4.