Post Aortic Valve Replacement (AVR):
Are Gradients Important? What Is?

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Aortic valve replacement (AVR) is one of the most commonly performed cardiac surgical procedures. A standardized TEE approach to aortic prosthesis interrogation is helpful but the echocardiographer must also frequently use off-axis imaging and consider additional diagnostic modalities if TEE image quality is suboptimal, if prosthesis visualization is confounded by acoustic shadowing, or if concerning findings cannot be reconciled on the basis of TEE imaging alone. Correct interpretation of the TEE findings also requires knowledge of the different types of aortic valve prostheses. This allows the echocardiographer to compare the actual findings with the expected findings, based on the size and type of prosthesis used.

Two-dimensional imaging

The post-implantation TEE interrogation of an aortic prosthesis logically begins with two-dimensional imaging. Orthogonal imaging planes, such as the ME AV SAX and ME AV LAX views, facilitate visualization of the sewing ring and moving parts (tissue leaflets or mechanical occluders/discs). The prosthesis should be well-seated and free of rocking motion. Rocking, or cyclic back and forth motion of the entire prosthesis during the cardiac cycle, is very unlikely immediately following AVR and usually signifies significant dehiscence of the sewing ring from the annular tissue (sometimes a complication of endocarditis). The degree of acoustic shadowing encountered depends on the type of prosthesis and is typically minimal with stentless biological valves (homograft, intact porcine root, or autograft [Ross procedure]). Increasing acoustic shadowing is seen with stented biological valves (stented pericardial or porcine valves – the most commonly implanted type of tissue prosthesis). In the mid-esophageal views, shadowing degrades imaging of the more anterior aspects of the prosthesis (further from the probe) as well as cardiac structures that are distal to the prosthesis in the imaging sector (such as the pulmonic valve). Such acoustic shadowing may hinder the ability to optimally view the thin, tissue leaflets in both SAX and LAX imaging. Mechanical valves create the greatest degree of shadowing that can obscure visualization of the anterior portion of the sewing ring as well as motion of the occluder discs. Prominent shadowing can also obscure the presence of small regurgitant jets in the LVOT, just below the prosthesis. The presence of a mitral prosthesis (especially mechanical) significantly limits the diagnostic value of mid-esophageal imaging following AVR, as much of the LVOT is lost in acoustic shadowing. To overcome the problem of acoustic shadowing, two-dimensional transgastric imaging of an aortic prosthesis should be a part of every TEE exam following AVR. Both the deep TG LAX and TG LAX views may prove invaluable in confirming normal, symmetrical motion of mechanical discs. Of note, the angle of interrogation from the transgastric position significantly impacts the apparent motion of mechanical discs. Slightly off-axis views may falsely suggest that one or
both discs do not open fully. Before diagnosing prosthesis malfunction, every attempt should be made to ensure that the angle of insonation is as nearly parallel to transvalvular flow as possible. Epicardial or epiaortic scanning are alternatives if mid-esophageal and transgastric imaging suggests a problem with occluder motion, particularly if Doppler findings also reveal concern findings.

**Color Doppler imaging**

Like two-dimensional imaging, color Doppler imaging of an aortic prosthesis should be performed from multiple probe positions (mid-esophageal and transgastric) and should employ orthogonal, and if necessary, off-axis imaging planes. The initial application of a relatively large color box over the LVOT, the aortic prosthesis, and the proximal ascending aorta in a LAX view may provide a quick impression regarding the degree and location of flow acceleration as well as the presence and configuration of regurgitant jets. Virtually all prosthetic valves (and certainly all prosthetic valves with a sewing ring) are inherently stenotic to some degree when compared with normal, native valves. Thus some color Doppler acceleration is expected at the level of the prosthesis. However the finding of turbulence in the LVOT may indicate outflow tract narrowing or elevated flow and warrants pulsed wave (PW) Doppler measurement of the LVOT velocity (see below).

All mechanical valve prostheses display some inherent transvalvular regurgitation. The terms “closing volume” and “washing jets” are sometimes used interchangeably, although closing volume probably better describes the very brief, broad, backward displacement of blood resulting from mechanical disc closure. Washing jets are seen as multiple, symmetric, low momentum jets that often originate near the hinge points of the occluder mechanism. Often two or more such jets can be seen at each side of the prosthesis, near the hinge points. These jets are thought to help prevent thrombus formation. Findings that are suggestive of washing jets include a location within the sewing ring and symmetrical size and location. Often these jets appear to originate at the lateral aspect of the prosthesis and are directed toward the middle of the LVOT. One notable exception is found with the On-X bileaflet mechanical prosthesis. The washing jets of an On-X bileaflet mechanical prosthesis may appear to be oriented inward (toward the center of the LVOT) in one plane, but outward when viewed in an orthogonal plane.

With improvement in imaging quality, a small amount of transvalvular (within the sewing ring) leakage is increasingly recognized with biological prostheses and is almost always benign.

Paravalvular regurgitation (outside the sewing ring) is detected fairly often after AVR (<20%) and is always abnormal. Short axis imaging is helpful in determining that a regurgitant jet is outside the sewing ring, although it may also be seen in long axis views. Sometimes it can be quite difficult to distinguish small paravalvular leakage from transvalvular regurgitation. Fortunately, the clinical course of paravalvular regurgitation is often benign, particularly if the amount of paravalvular leakage is less than moderate.
Spectral Doppler imaging

The two views most commonly used for spectral Doppler interrogation following AVR are the deep TG LAX and the TG LAX. These views usually afford the most parallel alignment of the Doppler cursor with flow across the LVOT and aortic prosthesis. Ideally, measurements should include the peak and mean velocity as well as the VTI obtained with continuous wave (CW) Doppler. The measurement of the LVOT velocity and VTI with PW Doppler is particularly helpful if the continuous wave velocity and gradient are increased beyond the expected values for the size and type of prosthesis. If LVOT velocities are elevated (> 1.5 m/sec), the proximal velocity ($V_1$) should be included in the simplified Bernoulli equation to avoid reporting a falsely elevated valvular gradient.

$$P = 4(V_2^2 - V_1^2)$$

($P = \text{peak pressure gradient}, V_1 = \text{LVOT velocity}, V_2 = \text{prosthesis velocity}$)

Tables containing the expected gradients for various prosthesis types and sizes are widely available in review articles and textbooks.

Elevated prosthesis gradients

The intraoperative finding of an increased transvalvular velocity and gradient is not rare following AVR. Several factors may contribute to elevated velocities and gradients. These causes may be benign (increased cardiac output, increased flow), may be related to the measurement technique (pressure recovery), or may be the result of prosthesis malfunction (immobile disc) or patient-prosthesis mismatch. Awareness of the multiple possible causes and a methodical imaging approach is essential for correct diagnosis.

Increased output/flow

Elevated cardiac output will increase the velocity and measured gradient across a prosthetic valve. Not uncommonly, the flow across a newly implanted aortic prosthesis is increased after cardiopulmonary bypass due to inotrope use, anemia or vasodilatation. Echo clues suggestive of increased flow include the shape of the aortic prosthesis velocity profile and the calculated Doppler velocity index (DVI). A normal prosthesis (which is inherently stenotic compared with a normal native valve) will show a CW Doppler profile that is more triangular in shape (similar to mild valvular AS), with a velocity that peaks relatively early (within 100 msec of
ejection onset – called the “acceleration time.”) On the other, an obstructed prosthesis typically shows a parabolic velocity curve with CW Doppler with a peak velocity occurring later than 100 msec (acceleration time > 100 msec). Therefore even if the prosthesis velocity is elevated (> 3 m/sec), the cause may be increased flow if the acceleration time is < 100 msec.

The DVI is also helpful and is simply the ratio of the LVOT velocity / aortic prosthesis velocity. The respective VTIs can be used in place of velocities. This “dimensionless index” helps account for increased LVOT flow and does not rely on a measured LVOT diameter. DVI values > 0.25 are seen with increased flow states, particularly if the velocity profile and acceleration time are reassuring, although patient-prosthesis mismatch (PPM) cannot be excluded entirely. However a DVI < 0.25 suggests prosthesis obstruction.

Patient-prosthesis mismatch

PPM describes a situation where the effective orifice area (EOA) of a prosthesis is too small relative to a patient’s body size. The flow requirements for an individual of a given BSA lead to abnormally elevated prosthetic velocities and gradients. EOA is calculated by means of the continuity equation, using the calculated LVOT stroke volume and aortic prosthesis VTI as below:

\[ \text{EOA} = \text{CSA}_{\text{LVOT}} \times \frac{\text{VTI}_{\text{LVOT}}}{\text{VTI}_{\text{AVR}}} \]

The LVOT CSA (cross sectional area) should be calculated from a measured LVOT diameter, and should not rely on geometric prosthesis measurements provided by the manufacturer. Typically an indexed EOA is obtained by dividing the result by the BSA. Moderate PPM exists when indexed EOA ranges from 0.65 to 0.85 cm$^2$/m$^2$ with severe PPM present with values below 0.65 cm$^2$/m$^2$. PPM can be difficult to distinguish from elevated flow by initial Doppler assessment as both conditions may have a relatively short acceleration time and a DVI > 0.25.
This underscores the importance of calculating EOA, particularly when elevated prosthesis velocities are present.

Pressure recovery

The calculation of pressure gradient by Doppler is based on measurement of blood velocity. As blood passes through the prosthesis, its velocity increases. Once in the ascending aorta, the blood velocity decreases and the energy associated with the temporary increase in velocity is “recovered” or converted back to pressure distally. The echo machine will calculate pressure gradient based on the highest velocity recorded, not based on the actual pressure in the ascending aorta. Thus, especially with mechanical valves, and particularly if the Doppler cursor is positioned through the central, rather than a lateral orifice, a high velocity and high calculated gradient may result when compared with direct catheter gradients. Typically some component of pressure recovery is accounted for in the reported normal ranges for prostheses, but this may still account for differences seen between Doppler and directly measured (needle transducing or catheter based) gradients in the operating room.

Prosthesis obstruction

Echo clues to prosthesis obstruction include a high prosthesis velocity (> 3 m/sec), a high mean gradient, a DVI < 0.25, and a parabolic CW velocity curve with an acceleration time > 100 msec. Supportive findings would include two-dimensional evidence of abnormal occluder motion or color Doppler evidence of asymmetric jets that may indicate an immobilized occluder.

Suggested reading: