Surgical Echocardiography of Heart Valves: A Primer for the Cardiovascular Surgeon

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Echocardiography is the primary noninvasive tool for evaluating the structure and function of cardiac valves and has become an essential diagnostic test in pre-, intra-, and postoperative management. Standard echocardiogram reports include several measurements and findings important to most cardiovascular and cardiothoracic surgeons. These measurements are derived from multiple standard imaging techniques, such as M-mode, 2-dimensional (2D), spectral Doppler and color Doppler which are employed in transthoracic (TTE) and transesophageal (TEE) echocardiography. As an ensemble, these techniques provide a comprehensive assessment of primary valve pathology and its secondary effects. In this review, we describe the use of these techniques in the imaging of the mitral, aortic, tricuspid and pulmonic valves. In addition, we highlight the clinical uses of real-time 3-dimensional echocardiography (RT3DE) to evaluate valvular pathology, and the emerging use of a new matrix array 3D TEE probe.

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Echocardiography is the primary noninvasive tool for evaluating the structure and function of cardiac valves. During the last 50 years, echocardiography has yielded new insights into normal and abnormal valve function and the natural history of valvular disease. Echocardiography has revolutionized the detection and characterization of valvular pathology and has become a crucial component of the preoperative evaluation of patients undergoing valvular procedures, with findings on echocardiography guiding the timing and type of surgery. Standard echocardiogram reports include several measurements and findings important to most cardiovascular and cardiothoracic surgeons. Routine echocardiographic studies incorporate M-mode, 2-dimensional (2D), spectral Doppler, and color Doppler techniques. Many new techniques are available but are not yet part of standard examinations. One of these techniques that has achieved increased application to the imaging of heart valves is real-time 3-dimensional echocardiography (RT3DE). Used together, these techniques provide a comprehensive assessment of primary valve pathology and its secondary effects. Echocardiography provides a variety of different ways to measure valve dysfunction, each with its own associated pitfalls. A detailed discussion of the strengths and weakness of each measurement technique is beyond the scope of this review. Suffice to say that none of these measures should be used in isolation but instead should be integrated into a composite picture of valve performance.

ECHOCARDIOGRAPHIC TECHNIQUES

M-mode involves sending out a single beam of ultrasound from the imaging transducer. The waves travel into the body and are reflected back to the transducer by cardiac structures, producing a single scan line of reflected images which can be plotted to show movement in the structures over time (the "M" in "M-mode" refers to "motion"). M-mode provides very high temporal and spatial resolution and can be used to detect and track fine movements and make measurements of cardiac chambers. The accuracy of these measurements, however, is often limited by

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inability to achieve a truly perpendicular M-mode interrogation angle. The "diagonal" measurement from M-mode is often an overestimate.

2D imaging expands the view of echocardiography. 2D images are composed from a series of dense scan lines sent out and received by the transducer over an arc of 90°. The real-time images constructed from these lines are displayed at a certain frame rate. The greater the frame rate, the better the temporal resolution of the image and the better the ability to accurately display the motion of cardiac structures. 2D echocardiographic images are composed of 256 shades of gray, allowing differentiation of tissue from blood, and of normal tissue from areas of fibrous and calcific degeneration.

Doppler imaging analyzes the shift in frequency of transmitted ultrasound waves and converts this shift into velocity measurements. Velocities can be converted to gradients by the use of the modified Bernouille equation $PG = 4v^2$ (where PG = pressure gradient and v = velocity). Spectral Doppler displays velocities going toward the transducer as above a zero crossing line and velocities going away from the transducer as below the line. There are 2 forms of spectral Doppler. Pulsed-wave (PW) Doppler imaging transmits discrete pulses of ultrasound energy which allow the recording of velocities at specific locations within the heart. The ability to resolve fast velocities is limited. Continuous-wave (CW) Doppler involves the continuous transmission and reception of the ultrasound signal. This form of spectral Doppler allows measurement of the range of velocities along the interrogation beam, including very fast velocities, but cannot be used to measure the velocities at specific locations. Both techniques can be used to measure velocities of blood flow and generate a curve of velocities plotted over time. Integrating these velocity curves can be used to calculate mean gradients, stroke volumes and regurgitant volumes across valves.

Color Doppler imaging is a variant of PW Doppler imaging and displays a color representation of direction and speed from several hundred PW sample volumes, superimposed on a 2D image. Applied to blood flow across valves, color Doppler uses color flow maps to code flow of blood away from the transducer as blue and flow toward the transducer as red. Velocities greater than a certain threshold cause aliasing and are registered as the opposite color (eg, flow going away from the transducer colored red). When the color of flow direction varies from what is expected, machine settings called variance maps will color these areas yellow, orange or green. These colors, therefore, represent areas of high velocity and can be used to detect turbulence.

ECHOCARDIOGRAPHIC VIEWS

The standard transthoracic echocardiographic (TTE) imaging protocol generally starts with the transducer placed to the left of the sternum to produce the parasternal long-axis (PLAX) view. The transducer is then rotated 90° to yield the parasternal short-axis (SAX) view. The transducer is then placed at the apex of the heart to produce the apical 4, apical 2, and apical long-axis views. The subcostal view, imaged from the epigastrium, is often not helpful in assessing valves because the transducer is farther away from the valves than in other views. When other imaging windows are nondiagnostic, however, it may provide the only available transthoracic images. When the transducer is placed in the suprasternal notch, the valves are not visualized, but Doppler flow interrogation can help to characterize aortic valve (AV) disease.

The transesophageal echocardiographic (TEE) probe consists of an ultrasound transducer mounted on a scope. The distal portion of the probe can flex or extend and move side to side to steer the ultrasound beam. In addition, the beam itself can be rotated 180°. Because the transducer is positioned in the esophagus just posterior to the heart, ultrasound waves have a shorter distance to travel to reach the heart and do not need to pass through fat and lung tissue. Images are therefore generally of greater quality. M-mode, 2D, and spectral and color Doppler imaging modes are all available on modern TEE systems.

The standard TEE examination generally begins with the transducer positioned in the mid-esophagus and the rotational plane set at 0°, displaying a 4-chamber view of the heart, upside down relative to that of TTE imaging. The rotational angle is then increased to image the heart from different views, which are analogous to those obtained by rotating the TTE transducer at the apex (2 chamber at 60°, long axis at 120°). The imaging probe can then be advanced into the stomach. From transgastric imaging planes, a vertical mirror image to that obtained by the SAX view on TTE is seen at 0°. At 90°, an orthogonal view provides a long-axis image of the heart. In addition to these standard views, the maneuverability of the ultrasound beam ensures that alternate views can be obtained to image most of the cardiac structures.

TEE can provide visualization of cardiac structures obscured by difficult transthoracic imaging windows, but in most cases it should be regarded as complimentary to TTE, not superior. Often, TTE im-