THE imaging UPDATE
A SERVICE OF MEDICAL POSITIONING, INC.

FEBRUARY 2003
VOL. 11 NO. 1
SIX DOLLARS

Overview of Stress Echocardiography: Uses, Advantages, and Limitations by John S. Gottdiener is a three-part series.

Look for the second part of the series in the May issue of Imaging Update.

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Overview of Stress Echocardiography: Uses, Advantages, and Limitations

Part One of Three

JOHN S. GOTTDIENER

Responses of the heart to changes in our environment are probably even more important than how the heart functions at rest. Accordingly, stress testing with noninvasive imaging has become important for diagnosis, prognosis, and monitoring the effects of therapy. Echocardiography at rest and with stress permits characterization of global and segmental left ventricular function as well as valvular structure and function. Moreover, echocardiography can be performed during or after a number of different physical or even mental stressors. Advantages of stress echocardiography include its ready availability, relatively low capital cost, and incremental value in that it allows characterization of cardiac anatomy as well as the myocardial response to a potentially ischemic stimulus. Moreover, echocardiography has the potential to image myocardial perfusion along with wall motion and wall thickening. Substantial literature has now been accumulated on the value of stress echocardiography for the diagnosis of ischemic disease, preoperative risk assessment, and assessment of myocardial viability. Echocardiography has compared generally well with nuclear imaging techniques for the detection of angiographic coronary artery disease. Overall sensitivity, however, has been slightly less, particularly for the detection of single-vessel coronary disease, although specificity has been on average somewhat higher than nuclear cardiology techniques. Because of the potential for variability in study acquisition as well as interpretation, careful safeguards need to be employed. Specifically, meticulous technique needs to be applied to obtain high-quality images and to assure that those images are obtained promptly after treadmill exercise stress. Only readers with specific interest and expertise should interpret stress echocardiography studies. Continuing efforts need to be made to assess and minimize variability and to assure continuing quality improvement. Advances in instrumentation, including evolving technology for real time 3-dimensional imaging, and echocardiography contrast assessment of myocardial perfusion will likely improve the sensitivity of echocardiography and further extend its usefulness.

Humans have probably always been aware that the heart responds quickly and vigorously to physical and emotional challenge. Teleologically, our survival has depended more on dynamic responses to environmental challenge than to basal function. Accordingly, responses of the cardiovascular system to naturalistic and laboratory stressors are important measures of cardiovascular function and health. Beginning with the pulse, and subsequently extending to virtually any available measure of cardiac

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pump or electrical function, stress testing has become a key component of cardiovascular diagnosis and prognosis.

Echocardiography has advantages for stress testing not possessed by any other diagnostic modality: It directly assesses left ventricular (LV) contraction, valve function, and intracardiac blood flow. Because echocardiography can identify LV myocardium within known coronary arterial distributions, the discovery of regional wall motion abnormality can identify coronary distributions at risk of ischemic injury as well as those that have already suffered injury. The ischemic cascade (Fig 1) refers to the sequence of events

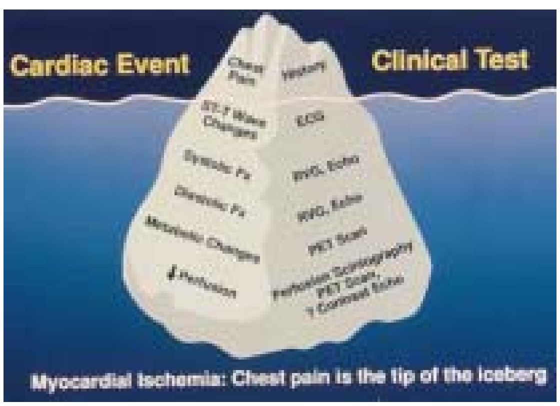

Fig 1. Ischemic pyramid. Diagnostic tests for ischemia will have sensitivity proportional to whether the pathophysiology detected is at the base or the tip of the,pyramid. (Abbreviations: FÑ, function; RVG, radionuclide ventriculography; Echo, echocardiography)

that occur after an event or intervention that decreases myocardial perfusion. Because echocardiography can measure diastolic function, as well as regional and global LV systolic function, it can detect changes several levels below the repolarization changes detectable by electrocardiograms (ECG). More recently, echocardiography has shown potential for becoming a robust technique to assess myocardial perfusion.[1] Importantly, as attested to by the widespread availability of echocardiography, its application is relatively simple and inexpensive.

HISTORICAL BACKGROUND

Although cardiac stress testing cannot determine anatomic narrowing of the coronary arteries, it can determine the physiologic importance of coronary luminal obstruction. Of course, stress testing only addresses the importance of fixed luminal obstruction at the time of the stress test and will not detect the presence of unstable plaque if the obstruction is minor. ECG assessment with exercise provides only indirect assessment of ischemia (Fig 1) and may be of limited sensitivity. Since the demonstration by Tennant and Wiggers[2] that coronary ligation in dogs produced impairment of myocardial performance, direct assessment of regional myocardial performance has been a goal of cardiologists.

The principal end point of stress echocardiography is the demonstration of new regional wall motion abnormality during or after the stressor, corresponding to 1 or more segmental coronary distributions. The presence of segmental wall motion abnormality presumes inadequate coronary flow relative to myocardial metabolic demand in those arteries responsible for distribution of blood to the involved myocardial segments. The correspondence between segmental decreases in myocardial perfusion and echocardiographically detectable regional wall motion abnormality was shown experimentally 25 years ago by Kerber et al.[3] Decreases in myocardial perfusion, measured in microspheres, produced by partial circumflex coronary artery occlusion resulted in segmental wall motion abnormality. Importantly, adjacent areas of perfused myocardium also evidenced hypokinesis, possibly because of tethering to underperfused segments of the LV wall. Consistent with reperfusion injury, prolonged coronary occlusion followed by reopening of the vessel did not result in improvement of wall motion, Since then, in the evaluation of patients with coronary artery disease

TABLE 1. Stress Echocardiography: Imaging Modalities and Physiologic End Points
Two-Dimensional Echocardiography: Transthoracic, Transesophageal
Segmental wall motion
Segmental wall thickening
Global LV function (ejection fraction)
?Myocardial perfusion
Three-Dimensional Echocardlography
Global function
Regional function
Doppler
Aortic systolic flow velocity
Filling velocity

(CAD), identification of the culprit vessel (which of several candidate coronary occlusions is responsible for the functional alterations of inducible ischemia) has become an important part of clinical practice. Stress echocardiography has shown itself as an appropriate method to achieve that purpose.

Even before the widespread availability of 2-dimensional echocardiography in the early 1980s, M-mode echocardiography showed segmental changes in LV function,[4-6] although limited to the midanterior septum and midposterior wall within the left anterior descending artery and circumflex distributions, respectively. Moreover, the observation in experimental animal models that wall motion changes with ischemia occurred before ECG changes[7] was extended to humans.[8] Hence, the presence of wall motion abnormality was shown to be more sensitive, as well as more specific, for the diagnosis of stress-inducible ischemia. However, the inability of M-mode echocardiography to image more than a limited extent of the myocardium was a serious impediment for the detection of regional wall motion abnormality at rest or with physiologic stressors.

ECHOCARDIOGRAPHIC TECHNIQUES

Assessment of global and systolic function with stress echocardiography is almost universally performed with 2-dimensional imaging to assess effects of stress on wall motion and systolic wall thickening. The imaging modalities and physiologic end points of stress echocardiography are highlighted in Table 1.

Doppler Stress Echocardiography

Doppler echocardiography, used to measure blood flow velocities from recordings of spectral flow profiles and patterns of blood flow (eg, valvular regurgitation) with color flow techniques, can also be used with pharmacologic and exercise stress.[9-10] Responses of ejection velocities and filling velocities to exercise are of interest in the study of patients with CAD. Increase in systolic blood flow velocity and the rate of ejection from the *LV* into the aorta are indicators of the capacity of the *LV* to respond to increased demand. *LV* filling velocities also increase in response to physiologic need. In one study, 10 measurement of peak *LV* ejection velocity, acceleration, and acceleration time in the ascending aorta during dipyridamole stress increased the sensitivity of wall motion changes for detection of angiographic CAD. Doppler measurements of blood flow velocity during exercise or pharmacologic stress have not found widespread application in evaluating patients with ischemic heart disease because of probable limitations in sensitivity. However, dobutamine or exercise stress Doppler echocardiography can be useful in the assessment of valvular function, as will be discussed later.

Tissue Doppler With Stress

Recently, important work has been performed with Doppler echocardiography[11-15] to measure myocardial tissue velocities at rest

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and with stress. Quantification of tissue velocity (Fig 2) may prove to be of use in supplementing analyses of wall motion and is, in principle, less dependent on accurate identification of the endocardium. Regional systolic wall velocities, as well as diastolic filling velocities, can be measured

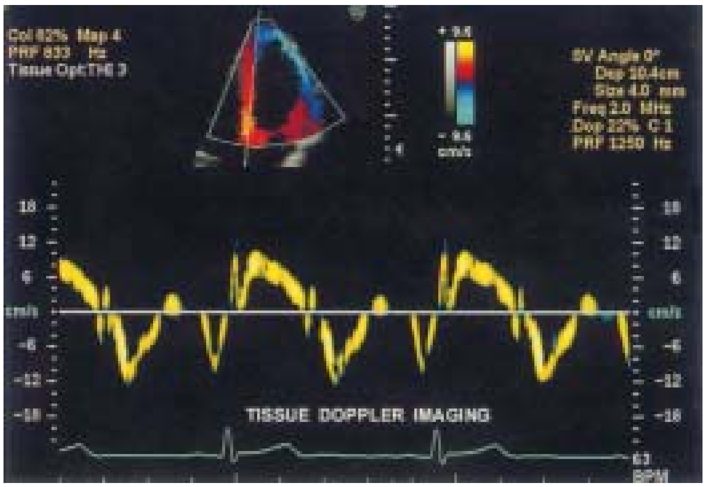

Fig 2. Tissue velocity spectral Doppler. A new method for assessment of segmental LV function. Encoding LV wall Doppler shift permits both enhanced imaging of regional wall motion with color flow display of LV wall Doppler velocities as well as quantification of segmental motion by spectral Doppler. (Image courtesy of ATL Ultrasound, Bothell, WA.)

and compared. Additionally, encoding the tissue velocities as images may improve the qualitative assessment of segmental LV function. The usefulness of this approach in clinical practice needs to be established in appropriately designed clinical trials.

Two-Dimensional Echocardiography

Real-time 2-dimensional echocardiography records cross-sectional images of the heart obtained by receiving reflected ultrasound signals transmitted through various locations (echocardiography windows) on the chest wall. The quality of those images, however, is affected by a number of factors. Vigorous cardiac con-traction increases translation and rotation of the heart throughout the scan sector such that different segments of the LV may be imaged in a given portion of the scan plane thoughout the cardiac cycle. Respiration changes both the position of the heart relative to the scan plane and the adequacy of the echocardiography window as the interposition of air-filled lung, cyclic with respiration, interferes with insonification of the heart. Before the availability of digital echocardiography techniques, which allowed selection of single beats gated to the cardiac cycle for cine-loop display, interpretation of real-time tape recordings of 2-dimensional echocardiography with exercise was limited because of a constantly moving image, as well as the difficulty of assessing regional wall motion at rapid heart rates. Currently, commercially available equipment on echocardiography machines and on offline units have greatly simplified the acquisition and interpretation of stress echocardiography, Digitized images can be presented for side-by-side comparison of prestress and poststress (or intrastress) images at synchronized display rates. Nonetheless, difficulties with rotational and translational effects, respiratory artifact, and echocardiography dropout, particularly of anterior and lateral wall endocardium, can interfere with the accuracy of stress echocardiography.

Transesophageal Stress Echocardiography

In some patients, it is difficult to acquire transthoracic echocardiographic images of sufficient quality for reliable assessment of regional wall motion. The principal reasons for this have included lung disease and aging in which the imposition of the lung between the chest wall and the heart limits the echocardiographic windows in which imaging can be effectively performed. Obesity can also limit echogenicity because impositition of adipose tissue between the transducer and the heart attenuates the ultrasound beam, decreasing signal/noise ratio. Although current echocardiographic instrumentation is capable of obtaining good quality images at greater depths from the signal source than heretofore possible, there is still a substantial number of obese patients in whom image quality is not adequate for diagnostic stress echocardiography. Unfortunately, in some cases of substantial obesity, nuclear stress testing may also not be possible because these patients may not fit under the camera. In such cases, transesophageal echocardiography (TEE)[16-19] with pharmacologic stress, most commonly dobutamine, will usually provide good quality diagnostic images (Fig 3). Apical foreshortening may occur from the esophageal window and may limit the accuracy of stress TEE. However, the sensitivity and specificity of dobutamine stress TEE have been shown to be equivalent or superior to other stress testing modalities, including treadmill exercise thallium scintigraphy.[18] Because TEE requires conscious sedation, dobutamine stress echocardiography (DSE) is probably not appropriate for routine use. However, in selected cases, dobutamine stress TEE may be the only way to obtain functional information on inducible myocardial ischemia.

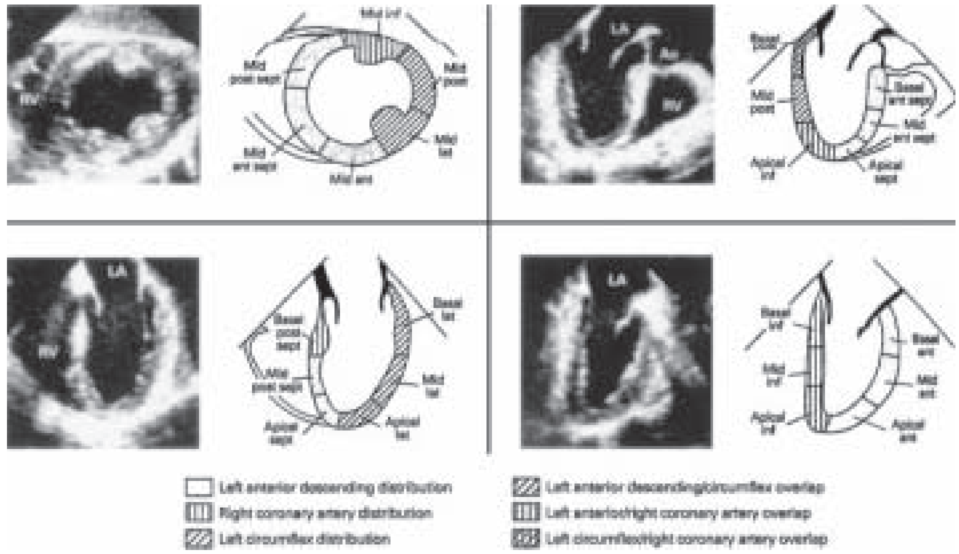

Fig 3. LV wall segments as visualized by TEE. All 3 coronary branch distributions are imaged, making this technique suitable for pharmacologic stress echocardiography. (Abbreviations: ant, anterior; lat, lateral; post, posterior; sept, septal; inf, inferior; LA, left atrium; RV, right ventricle; Ao, aorta. Reprinted with permission from the American College of Cardiology [J Am Coll Cardiol, 1994, 24, pp 12801287][16])

Three-Dimensional Echocardiography

Two-dimensional echocardiography performed after exercise requires the sonographer to sequentially obtain cross-sectional images from 4 to 5 views in 2 principal positions (echocardiography windows) on the chest wall. It takes time to get the patient from the treadmill to a left lateral decubitus position on the examination bed and still more time to obtain the several beats for 4 to 5 views in the 2 echocardiography windows. Substantial experience is required to be able to move the transducer from one window to another and recapture good quality images of the rapidly beating heart. Even with experienced and capable sonographers, it may take 30 to 90 seconds to acquire a complete image data set, during which time the postexercise heart rate may decrease substantially. Recently, 3-dimensional echocardiographic technology has been developed, including a promising system (Volumetrics, Durham, NC) for real-time 3-dimensional acquisition. Acquisition of only a few beats from a single window, which can be performed in 4 to 5 seconds, allows complete reconstruction of the heart in 3 dimensions. Hence, assessments could, in principle, be performed at higher workload and with more complete interrogation of the LV

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than is possible with 2-dimensional techniques. Although the feasibility of this technique has been shown[20] future research will determine whether 3-dimensional exercise echocardiography improves the accuracy of stress echocardiography for detection of ischemia.

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0033-0620/01/4304-0005$35.00/0

doi:10.1053/poad.2001.20502

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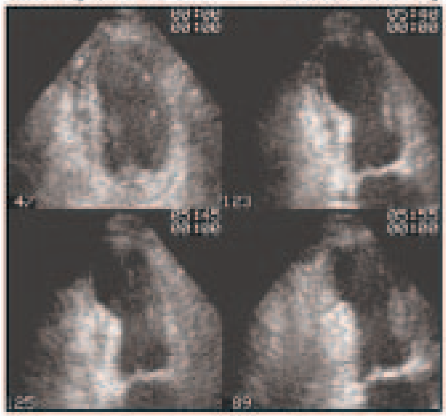
The Results Are In...

peak imaging vs post exercise

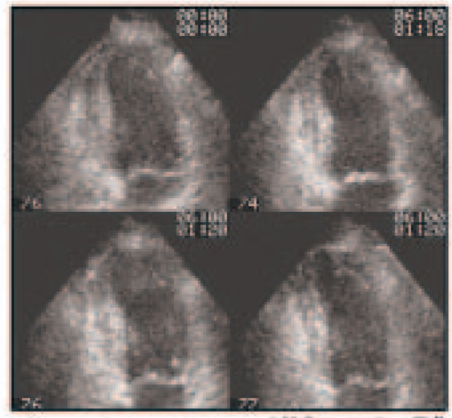
Rest end-systolic frame

5:40 significant wall motion abnormality

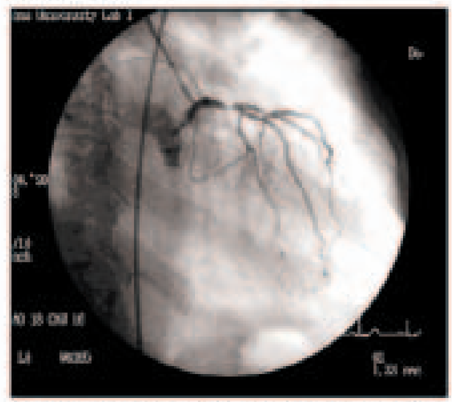


5:45 peak exercise heart rate of 125; test was stopped

5:55 10 seconds post exercise; heart rate down to 89 and notable improvement in wall motion



1:20 Post exercise - Wall motion abnormality completely resolved!



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