LIVE DEMONSTRATION OF ECHOCARDIOGRAPHY

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INTRODUCTION

In this manuscript we summarize many of the aspects of a typical diagnostic echocardiographic examination that were presented during a live demonstration at the plenary session of the 23rd Annual Review of Progress in Quantitative Nondestructive Evaluation. Ultrasonic imaging of the heart (echocardiography) has become an important tool in the diagnosis of heart disease. Currently most heart patients undergo an echocardiographic examination as part of their diagnostic evaluation. This method of imaging offers the physician a rapid, quantitative, and cost-effective assessment of cardiac anatomy and function. Below we present some of the typical images obtained and discuss some of the measurements performed for diagnostic use in a clinical echocardiographic exam.

ECHOCARDIOGRAPHIC IMAGING SYSTEMS

Echocardiographic imaging systems are available in a wide variety of configurations for clinical use. Many of these systems incorporate a phased-array technology in which the ultrasonic probe consists of a linear array of 64, 128, or more transducer elements. Ultrasonic beams are steered and focused (both on transmit and receive) by applying the appropriate time delay to the transmitted or received ultrasonic signal at each array element.[1] An individual ultrasonic A-line is formed by steering the transmitted ultrasonic pulse in a specific direction and summing the appropriately delayed response from each of the array elements. Two-dimensional, B-mode images are formed by sweeping a series of ultrasonic A-lines, typically over a 90° sector, and scan converting the individual A-lines into an image format. Transthoracic (through the chest) echocardiographic imaging of adults typically employs ultrasonic transducer probes with center frequencies of 2.5 MHz to 3.5 MHz. A Hewlett-Packard Sonos 2500 echocardiographic imaging system (a phased-array system) was used for the echocardiographic demonstration during the plenary session as well as for the images presented in this paper.

DIAGNOSTIC ECHOCARDIOGRAPHY

Two-Dimensional Imaging

One of the most common diagnostic procedures is to obtain two-dimensional ultrasonic B-mode images of the heart. Typically, four standard echocardiographic views (cross-sections) of the heart are obtained. With these views all four chambers of the heart can be visualized and specific regions of myocardium (heart muscle), whose blood is supplied by specific coronary arteries, can be assessed. Cardiologists use these two-dimensional images to look at the gross anatomical features of the heart as well as to assess myocardial wall thickening and valve motion throughout the heart cycle. Figures 1(a) - 1(d) illustrate the four standard views; parasternal long axis, parasternal short axis, apical four chamber, and apical two chamber. Illustrations showing where the ultrasonic probe is placed on the chest to obtain each of these views can be found in Reference [2].
Figure 1(a). Echocardiographic image showing the Parasternal Long Axis view of the heart. RV = Right Ventricle, LV = Left Ventricle, LA = Left Atrium, Ao = Aorta, ECG = Electrocardiogram. The Mitral Valve separates the Left Ventricle and Left Atrium and the Aortic Valve is between the Left Ventricle and Aorta.
Figure 1(b): Echocardiographic image showing the Parasternal Short Axis view of the heart. RV = Right Ventricle, LV = Left Ventricle, ECG = Electrocardiogram.
Figure 1(c). Echocardiographic image showing the Apical Four Chamber view of the heart. RV = Right Ventricle, RA = Right Atrium, LV = Left Ventricle, LA = Left Atrium, ECG = Electrocardiogram. The Mitral Valve separates the Left Ventricle and Left Atrium and the Tricuspid Valve is between the Right Ventricle and Right Atrium.
Figure 1(d). Echocardiographic image showing the Apical Two Chamber view of the heart. LV = Left Ventricle, LA = Left Atrium, ECG = Electrocardiogram. The Mitral Valve separates the Left Ventricle and Left Atrium.
M-mode Imaging

Another imaging mode commonly used in clinical echocardiography is the M-mode (time-motion) display. In this mode, the image from one specific ultrasonic A-line is repeatedly displayed as a function of time. This "icepick" view of the heart can be used to obtain quantitative measurements of myocardial wall thickness, valve motion, and relative timing of events over the heart cycle. Figure 2 shows a typical M-mode display of the motion of the septal and posterior walls of the heart over a number of heart cycles.

Doppler Imaging

Clinical assessment of blood flow throughout the heart chambers as well as in blood vessels is often accomplished by employing Doppler-based imaging techniques. These techniques utilize Doppler frequency shifts in the backscattered ultrasonic signals from blood to measure the velocity (both direction and speed) of blood flow.[1] Figure 3 illustrates the type of quantitative blood-flow information that is obtained using Pulsed-Wave Doppler imaging. This figure illustrates the flow of blood through the mitral valve between the left atrium and left ventricle over a period of a few heartbeats. In this figure, the horizontal axis represents time (over a few seconds) and the vertical axis represents the blood velocities contained within the Pulsed-Wave Doppler sample volume. Velocities above the baseline in the figure represent flow toward the ultrasonic transducer and velocities below the baseline represent flow away from the transducer. At each instant of time there is a distribution of blood velocities present in the Pulsed-Wave Doppler sample volume (spectral Doppler). A broad distribution of velocities is indicative of turbulent blood flow whereas a narrow distribution of velocities represents relatively laminar blood flow. Analyses of the spectral Doppler information can help in diagnosing specific heart pathologies.

Another Doppler-based echocardiographic technique commonly used in clinical diagnoses is Color-Flow Doppler imaging. In Color-Flow Doppler imaging the flow velocities over a relatively large region of a two-dimensional image are measured. These measured velocities are color-coded and the Color-Flow Doppler information is superimposed on the two-dimensional grayscale image of the heart. This mode of displaying blood flow information allows the cardiologist to quickly assess any blood flow abnormalities.

Assessment of Global Cardiac Function

Assessment of global cardiac function (i.e., assessment of the pumping ability of the heart as a whole) represents another important aspect of the diagnostic information that can be obtained echocardiographically. Often these measurements are performed by cardiologists off-line using sophisticated image analysis of 2D echocardiograms. Hewlett-Packard Sonos imaging systems, such as the one used in the live demonstration, can be equipped with an Acoustic Quantification cardiac assessment package that provides real-time quantitative measurements of parameters related to assessment of heart function. For example, Figure 4 illustrates a real-time estimate of the left-ventricular chamber volume based on Acoustic Quantification analysis of the left-ventricular chamber area from the two-dimensional image. This figure illustrates how the volume of the left ventricle changes over the heart cycle. Parameters that describe global cardiac function, such as the ejection fraction (i.e., the ratio of the volume of blood ejected from the left ventricle during systole or the "squeezing" part of the heart cycle to the volume in the left ventricle at end-diastole or "relaxation" part of the heart cycle), can be determined from this type of information.

Stress Testing

To better diagnose certain forms of heart disease it is often beneficial for the heart to be assessed while it is stressed (i.e., forced to work hard) and compare the information obtained with that obtained from the heart in a resting state. Thus echocardiographic stress testing has become an important clinical diagnostic tool. Two common methods of stressing the heart are through patient exercise or through pharmacologically induced stress. Typically, the cardiologist will compare the thickening of the myocardium (heart wall) over the heart cycle
Figure 2. M-mode image showing the septum, left-ventricular chamber, and posterior wall of the heart. LV = Left Ventricle, SEP = Interventricular Septum, PW = Posterior Wall.
Figure 3. Pulsed-Wave Doppler spectra showing the distribution of blood velocities through the Mitral Valve over approximately three heartbeats. Velocities above the baseline represent flow toward the ultrasonic transducer and velocities below the baseline represent flow away from the transducer.
Figure 4. Estimates of the left-ventricular chamber volume based on Acoustic Quantification analysis of the left-ventricular chamber area from an apical four chamber view of the heart. This figure illustrates how the volume of the left ventricle changes over approximately five heart cycles.
during rest and during stress testing. In comparing these two sets of images, the thickening of the myocardium is normally seen to be significantly greater in the stressed heart. A non-uniform increase in thickness in a particular segment of the stressed heart image could indicate a reduced flow of blood to that segment and aid the cardiologist in the diagnosis.

SUMMARY

Echocardiography has rapidly become a major tool in the diagnostic procedures that are commonly applied to patients. Because this method of imaging offers the physician a rapid, quantitative, and cost-effective assessment of cardiac anatomy and function it is ideally suited for the current healthcare environment.

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REFERENCES