In summary, the use of both amplitude and phase images in both LAO and LPO projections provides maximum accuracy of diagnosis of RWMA. This is because inferior wall lesions can be missed in an LAO projection alone, septal or lateral wall lesions can be missed in an LPO projection alone, and conduction abnormalities may be mistaken for contraction abnormalities when a phase image alone is used. In clinical practice, creation of the four Fourier images with existing software requires only about 10 additional minutes of technologist time. Because the accuracy of Fourier analysis is equal to cine display on a segmental basis and is significantly better on a global basis, and because of the rapidity with which the diagnosis can be made and the convenience with which the images can be viewed, archived, and retrieved, we have employed Fourier image analysis rather than cine display for the routine clinical interpretation of the radionuclide ventriculogram for the past 4 yr.

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EDITORIAL

Radionuclide Ventriculography: Should Fourier Analysis Replace the Cine Display?

Nuclear cardiology was, for all practical purposes, born 20 years ago with the description of the radionuclide ventriculogram, a "noninvasive scintophotographic method for measuring left ventricular function in man" (*1,2*). The first studies consisted of only end-diastolic and end-systolic images, but nevertheless permitted evaluation of left ventricular ejection fraction and regional wall motion using manually drawn outlines of the left ventricle and area-length methods. Subsequent application of computer technology has led to the development of multi-image gated studies, easy storage and retrieval of digitized images, semi- or fully-automated methods for detecting left ventricular edges, and count-based methods for measuring left ventricular ejection fraction and other functional parameters, such as left ventricular ejection and filling rates. Increased quantitation provided by the application of computers has been universally recognized as an impor-

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tant advance in nuclear cardiology, as well as in nuclear medicine in general.

Regional wall motion has generally been assessed by displaying the multiple cardiac images of the radionuclide ventriculogram as an endless-loop movie, similar to a contrast cineventriculogram. Abnormalities of regional wall motion, which may be indicative of coronary artery disease or a localized ventricular inflammatory or infiltrative disorder, for the most part are judged qualitatively by carefully examining the motion of the edges of the left ventricle in multiple views. This is the same process followed in assessing regional wall motion from the contrast ventriculogram. Quantitative methods for measuring regional wall motion can be applied to both types of studies, but are considerably easier in the case of the radionuclide study, since the data are already stored in the computer in digitized form. Contrast studies recorded on film, on the other hand, must first undergo time-consuming analog-to-digital conversion, while studies acquired using digital radiographic techniques require large amounts of computer memory.

For most clinical applications, qualitative assessment of wall motion appears to be quite adequate. In patients with acute myocardial infarction, one needs to know the location, extent, and severity of wall motion abnormalities to assess prognosis and guide therapy. The presence of a ventricular aneurysm, which can be easily determined visually, may dictate chronic anticoagulation to prevent intracavitary thrombus formation and subsequent embolization. Extensive wall motion abnormalities and reduced ejection fraction in patients with completed infarcts may condraindicate beta-adrenergic blockers and support the use of digitalis, vasodilators, or angiotensin converting enzyme inhibitors. In patients with non-Q-wave ("incomplete") infarcts, the presence of retained wall motion (hypokinesis rather than akinesis or dyskinesis) in the anatomic distribution of the infarct-related coronary artery may indicate that significant viable myocardium remains at jeopardy. Myocardial revascularization may be in order to prevent recurrent ischemia or infarction in that vascular distribution.

In some clinical situations, however, and for most research applications, more precise quantitative estimates of regional ventricular function are required. A number of approaches have been described including stroke count, ejection fraction, and paradox images (*3*). These functional images utilize the end-diastolic and end-systolic frames from a multi-frame gated study and display volume changes on a pixel-by-pixel basis. Regional ejection fractions can be determined by dividing the left ventricle in the left anterior oblique view into multiple sectors using radial coordinates drawn from the center of the ventricle. Another approach characterizes regional wall motion by the extent of movement of the endocardial boundary along multiple radial profiles, similar to the quantitative analysis of contrast ventriculograms. Both the regional ejection fraction and radial chord shortening approaches have been validated against contrast ventriculograms in animal models and patients, with generally good results considering the differences in methodology.

Fourier analysis of the radionuclide ventriculogram for assessment of regional left ventricular function was first proposed in 1979 (*4*). Temporal Fourier analysis involves mathematically fitting sine and cosine waves to the time-activity data for each pixel over the cardiac cycle. Since most of the changes in activity within the heart occur at the fundamental frequency (the heart rate), the amplitude of the fundamental frequency is proportional to stroke volume and the phase is related to the time in the cardiac cycle when emptying begins. Phase and amplitude images are formed by mapping the calculated values to the corresponding pixel locations in the image matrix. Impaired regional function is characterized by reduced amplitude and delayed phase over a significant number of contiguous pixels. Results in a given patient must be compared to previously determined normal limits, since regional function is normally inhomogeneous, with reduced emptying along the septum and in the area of the outflow tract.

In this issue of the *Journal*, Brateman et al. (*5*), compare the ability of the conventional cinematic display and Fourier image analysis of radionuclide ventriculograms to detect regional wall motion abnormalities as identified by biplane contrast ventriculograms in patients with suspected coronary artery disease. They found that the Fourier images had higher sensitivity and accuracy for identifying abnormal wall motion and concluded that for this reason, as well as ease of archiving and advantages of hard copy, "Fourier analysis . . . is the preferred display method for clinical interpretation of the radionuclide ventriculogram." In other words, they suggested that Fourier analysis could replace the cine display for routine clinical purposes.

Although the authors made a serious attempt to validate the radionuclide methods against the contrast studies, practical constraints prevented a precise matching of contrast and radionuclide views. The contrast ventriculograms were performed in standard fashion with acquisition of 30° right anterior oblique and 60° left anterior oblique views. The radionuclide views, although said to be "similar," were actually 40° left anterior oblique and left posterior oblique. These differences, although seemingly small, may be very important because the visual detection of wall motion abnormalities by both types of cinematic displays depends primarily on motion of the ventricular edges. If the views do not match precisely, different areas of myocardium are represented on the edges of the left ventricular blood pool. Validation studies in animal models employing truly matched views have demonstrated that abnormal wall motion produced by regional myocardial ischemia can

generally be assessed equally well by cine display of contrast and radionuclide ventriculograms (*6,7*). When the ischemic region is small (<4 g), however, the contrast ventriculogram is more sensitive, probably because of the better spatial resolution available with the radiographic technique (*6*).

Fourier image analysis, on the other hand, displays regional volume information perpendicular to the camera face ("the Z-axis"). The detection of regional wall motion abnormalities is based on reduced or delayed volume changes in that region rather than on motion of the ventricular edges alone. It may therefore not be surprising that when the ventriculographic views are not matched, Fourier analysis agrees better with the contrast study than does the radionuclide cine display. Strictly speaking, the Brateman study demonstrates that Fourier analysis is somewhat better than the cine display for detecting wall motion abnormalities, as defined by a contrast study recorded at different projection angles. The study clearly shows that Fourier amplitude and phase analysis of two radionuclide views is better than analysis of a single view. It does not address whether other methods of quantitation of regional function, such as regional ejection fraction or measurement of radial chord shortening, are as good as Fourier analysis.

Quantitation of wall motion aside, there are many reasons why it is essential to view the cine display of a radionuclide ventriculogram. The cine display provides information about the quality of the study: the adequacy of blood-pool labeling, the positioning of the patient, and the degree of separation of the cardiac chambers. Without an assessment of the quality of the "original data," one cannot be confident about the validity of the processed data, including Fourier analysis or regional ejection fraction calculations. Such analyses may provide misleading information about regional function where the right and left ventricles overlap, or where the left atrium is not clearly separated from the left ventricle. The cine display also allows assessment of the position of the heart in the thorax, the size of the cardiac chambers, and the presence of left ventricular hypertrophy or pericardial effusion. Right ventricular enlargement or dysfunction can easily be identified from the cine display, and occasionally the diagnosis of hypertrophic cardiomyopathy, intracardiac mass lesion, aortic aneurysm, or thoracic tumor can be made. The information contained in the cine display is critical for a full evaluation of cardiac function and cannot be replaced by a few functional Fourier images. Despite the relatively large amounts of space required for archiving of cinematic data, it does represent the "original data" and should therefore be saved for future reference. It is always possible to repeat the Fourier analysis if the original data set is available, but the true raw data cannot be reconstructed from the Fourier images. The increasing availability of optical disc storage should make the archiving of radionuclide ventriculographic data considerably easier.

In summary, Fourier analysis cannot replace the cine display, but it can enhance the reading of radionuclide ventriculograms by calling attention to subtle areas of abnormal wall motion that might have been missed by visual analysis alone. Abnormal myocardial segments located "inside" the left ventricular blood-pool image and not represented on the edge of silhouette in a particular view should be detected more readily by Fourier analysis. Usually these areas become visually apparent when examined carefully. Quantitation should not be a replacement for visual analysis, but instead should represent an important adjunct. This is probably a good general rule to keep in mind for all nuclear medicine studies.

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