Fourier Analysis of a Gated Blood-Pool Study During Atrial Flutter

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First-harmonic Fourier analysis of a gated blood-pool study is based on the assumption that the cardiac chambers contract once per cardiac cycle. In atrial arrhythmias this condition may not exist for the atria. We recently studied a patient with atrial flutter and 2:1 atrioventricular conduction. There were predictable alterations in the first-harmonic Fourier phase and amplitude images. The observed changes from first-harmonic Fourier analysis were: (a) very low atrial amplitude values, and (b) absence of identifiable atrial regions on the phase image.

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Characteristic abnormalities in the phase or amplitude images obtained from first-harmonic Fourier analysis of the gated blood-pool study have recently been described for a variety of conditions including bundle branch block (*1–4*), Wolf-Parkinson-White syndrome (*5*), ventricular tachycardia (*6*), and ventricular pacing (*5,7*). In a patient in whom the atrial rate is a fixed multiple of the ventricular rate, it can be predicted that there will be changes in the appearance of the first-harmonic phase and amplitude images. We recently studied such a patient with 2:1 atrioventricular conduction. The purpose of this report is to present the observed changes.

CASE REPORT

The patient is a 70-yr-old white female with a history of rheumatic heart disease and mitral stenosis. A mitral commissurotomy had been performed in 1951. Exertional dyspnea and minimal hemoptysis developed approximately 4 mo before admission. On admission to the hospital she was in normal sinus rhythm with first-degree AV block (PR = 0.24 sec); there was no evidence for intraventricular conduction delay. Chest radiograph showed cardiomegaly with signs of congestive heart failure. Cardiac catheterization revealed isolated mitral stenosis with a calculated mitral valve area of 0.7 cm^2. There was no significant mitral or aortic regurgitation and the coronary arteriogram was normal. The left-ventricular ejection fraction was 67%.

Multigated equilibrium blood-pool imaging was performed the day after cardiac catheterization, at which time the patient was in atrial flutter with 2:1 atrioventricular conduction (atrial rate 172 bpm, ventricular rate 86). The cardiac cycle was divided into 24 frames with data collected for 250,000 counts/frame. The cine display clearly showed the atria contracting twice during the cardiac cycle. The left-ventricular ejection fraction was 85%.

First-harmonic Fourier analysis was performed on the blood-pool study using a program developed at the University of Wisconsin.* Figure 1 shows the 40° left anterior oblique blood-pool image at end-diastole, with regions of interest (ROI) identifying the right atrium (RA), right ventricle (RV) and left ventricle (LV). Figure 2 shows the time-activity curves from the LV (top) and RA (bottom), and confirms that the frequency of right atrial contraction is twice that of the ventricle.

If Fig. 3, the ROIs from Fig. 1 have been superimposed on the first-harmonic amplitude image. There are no significant ampli-

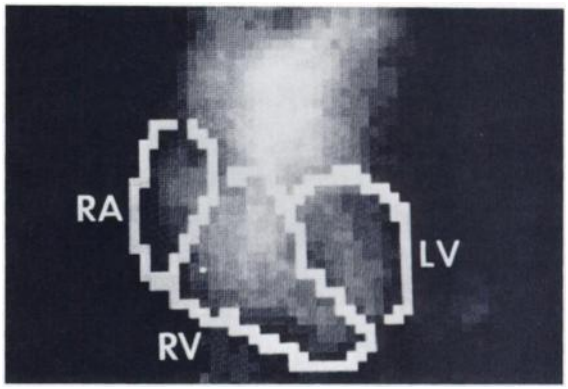

FIG. 1. 40° Left anterior oblique blood-pool image at end-diastole, with regions of interest placed over right ventricle (RV), left ventricle (LV), and right atrium (RA).

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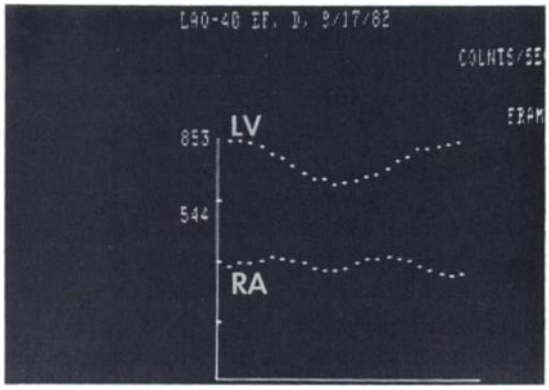

FIG. 2. Time-activity curves from left ventricle (top) and right atrium (bottom). Note that frequency of atrial contraction is twice that of ventricle, consistent with ECG evidence of 2:1 atrioventricular conduction.

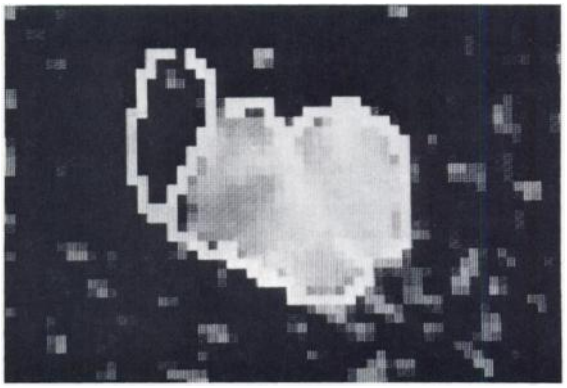

FIG. 4. First harmonic phase image, with Fig. 1 regions of interest superimposed. Phase values of ventricles are unremarkable, but phase values of right atrium are noteworthy for being indistinguishable from those in noncardiac areas. Pixel with no first-harmonic amplitude has random phase value; this explains "salt-and-pepper" appearance.

tude values present in the RA region. In Fig. 4, the ROIs are superimposed on the first-harmonic phase image. While the phase values over the RV and LV are visible and coherent, the random pattern ("salt-and-pepper") of phase values typical of noncardiac structures extends over the right atrium. The unusual appearance of the right atrium in Figs. 3 and 4 arises because the first-harmonic Fourier analysis does not properly characterize that chamber's function in this patient. While these findings could indicate anatomic absence of the right atrium and/or atrial contraction that is not related to ventricular contraction (e.g., atrial fibrillation), Figs. 1 and 2 show anatomic presence of a chamber that has a regular pattern of contraction.

Since the rate of atrial contraction (both by examination of the electrocardiogram and the time-activity curves in Fig. 2) is twice the fundamental frequency, one would expect that chamber's function to be more accurately characterized by a second-harmonic Fourier analysis. We wrote a program to perform such an analysis, and the second-harmonic amplitude image is shown in Fig. 5.

DISCUSSION

First-harmonic Fourier analysis of the gated blood-pool study has recently become a subject of considerable interest, and characteristic patterns in the phase image have been described in a variety of conditions (*1-7*). In this approach, the time-activity curve from each pixel is analyzed as a series of cosine waves, each having a frequency, an amplitude, and a "phase shift" relative to an arbitrary timing point (the R wave of the electrocardiogram). An implicit assumption is that since each of the cardiac chambers contracts once during each cardiac cycle, most of the information regarding contraction is in the first-harmonic term.

In first-harmonic Fourier analysis, all of the cosine terms, except for the term, with a frequency of one (cycle per heart beat) are ignored and the amplitude and phase shift from each pixel are stored in the appropriate location in functional images (the amplitude and phase images, respectively) (*8*). Pixels with flat time-activity curves (e.g., over the lung field) will have low amplitudes and random phase values, giving the lung fields a characteristic "salt-and-pepper" appearance (*3*). In sinus rhythm the atria and ventricles will have relatively large amplitudes and are clearly distinguishable on the phase image because the phase shifts of the atria and ventricles differ by approximately 180° (one half of the cardiac cycle).

If a chamber is contracting twice in each cardiac cycle, the time-activity curve for this chamber will be characterized by the *second* Fourier harmonic rather than the first. Since the first-harmonic term will not describe the chamber's time-activity curve, the amplitude of the first-harmonic term will be negligible and the first-harmonic phase value will be random. This resembles the first-harmonic results over the lung field. As shown in Figs. 3, 4,

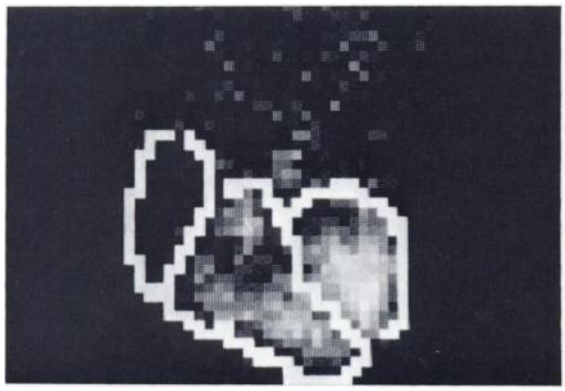

FIG. 3. First-harmonic amplitude image, with regions of interest from Fig. 1 superimposed. Amplitude values in right atrium are negligible in comparison with ventricular amplitudes.

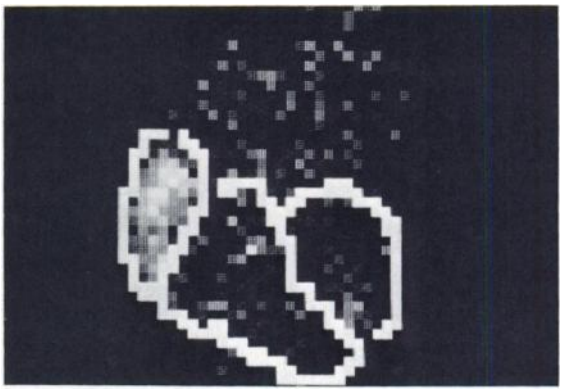

FIG. 5. Second harmonic amplitude image with regions of interest from Fig. 1 superimposed.

and 5, these expected results were observed in this patient with atrial flutter and 2:1 atrioventricular conduction.
* DEC Clinical Applications Package.

REFERENCES

1. LINKS JM, DOUGLASS KH, WAGNER HN JR: Patterns of ventricular emptying by Fourier analysis of gated blood-pool studies. *J Nucl Med* 21:978-982, 1980
2. SWIRYN S, PAVEL D, BYROM E, et al: Sequential regional phase mapping of radionuclide gated biventriculograms in patients with left bundle branch block. *Am Heart J* 102: 1000-1010, 1981
3. BOTVINICK E, DUNN R, FRAIS M, et al: The phase image: its relationship to patterns of contraction and conduction. *Circulation* 65:551-560, 1982
4. FRAIS MA, BOTVINICK EH, SHOSA DW, et al: Phase image characterization of ventricular contraction in left and right bundle branch block. *Am J Cardiol* 50:95-105, 1982
5. BOTNIVICK EH, FRAIS MA, SHOSA DW, et al: An accurate means of detecting and characterizing abnormal patterns of ventricular activation by phase image analysis. *Am J Cardiol* 50:289-298, 1982
6. SWIRYN S, PAVEL D, BYROM E, et al: Sequential regional phase mapping of radionuclide gated biventriculograms in patients with sustained ventricular tachycardia: close correlation with electrophysiologic characteristics. *Am Heart J* 103:319-332, 1982
7. RABINOVITCH MA, STEWART J, CHAN W, et al: Scintigraphic demonstration of ventriculo-atrial conduction in the ventricular pacemaker syndrome. *J Nucl Med* 23:795-798, 1982
8. ADAM WE, TARKOWSKA A, BITTER F, et al: Equilibrium (gated) radionuclide ventriculography. *Cardiovasc Radiol* 2:161-173, 1979