Temporal Fourier Analysis Applied to Equilibrium Radionuclide Cineangiography
Importance in the Study of Global and Regional Left Ventricular Wall Motion

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Abstract. Regional and global left ventricular wall motion was assessed in 120 patients using radionuclide cineangiography (RCA) and contrast angiography. Functional imaging procedures based on a temporal Fourier analysis of dynamic image sequences were applied to the study of cardiac contractility. Two images were constructed by taking the phase and amplitude values of the first harmonic in the Fourier transform for each pixel. These two images aided in determining the perimeter of the left ventricle to calculate the global ejection fraction. Regional left ventricular wall motion was studied by analyzing the phase value and by examining the distribution histogram of these values. The accuracy of global ejection fraction calculation was improved by the Fourier technique. This technique increased the sensitivity of RCA for determining segmental abnormalities especially in the left anterior oblique view (LAO).

Introduction
Among noninvasive approaches to the evaluation of left ventricular performance, RCA has been shown to be of particular value. Its contribution to the study of global and regional left ventricular wall motion (and particularly the latter) has been previously reported [2, 7, 10, 12, 13, 14]. Presently available methods can however be improved by applying temporal Fourier analysis to the variations in radioactivity observed during the cardiac cycle.

In this study, regional and global left ventricular wall motion was assessed in 120 patients using RCA with temporal Fourier analysis and contrast angiography to determine the value of temporal Fourier analysis applied to RCA.

Material
The study group consisted of 120 patients, 86 males and 34 females, hospitalized in the Cardiac Unit between February 8, 1980 and March 31, 1981. The average age was 55 years (range 28-69 years). All patients were in normal sinus rhythm and presented no intraventricular conduction abnormalities. All underwent cardiac catheterization with angiography. Ninety-four patients had coronary heart disease, 21 had valvular heart disease and 5 had other cardiopathy. Left ventricular performance was evaluated in 57 of the patients. The remaining 63 with chronic coronary artery disease were assessed for segmental contraction abnormalities only.

All contrast ventriculographic studies were performed 24 h after the equilibrium gated radionuclide evaluation. Both analyses were carried out in postprandial periods and without premedication. Data for the radionuclide method was collected and processed using a Picker 4c gamma camera and a 64 K-word 16-bit Simis III Informatek central memory computer. The cardiac cycle was decomposed into 16 frames using a 64 x 64 matrix. Each frame contained 500,000 counts. The superimposing of cardiac cycles was synchronized using the peak of the R wave. Following cycles presenting a deviation of 10% from the mean were rejected.

Methods
Temporal Fourier analysis can be applied in the evaluation of radionuclide images [6, 11, 14, 15]. In this study, two functional images were constructed by taking the phase and amplitude values of the first harmonic of the Fourier transform for the time-activity curve of each pixel. By means of the Fourier transform, any periodic function can be represented as the sum of a series of sine functions. The Fourier transform is given by:

\[ F(t) = \sum A_i \sin(\omega t + \phi_i) \]

where \( \omega \) is the pulse, inversely proportional to cardiac frequency, \( A_i \) is the amplitude of each harmonic, and \( \phi \) the corresponding phase. When dealing with a stationary and periodic phenomenon presenting nearly sinusoidal variations, the first harmonic alone provides almost all the information required.

The 'amplitude' image (in counts) represents maximum variation in activity for each pixel over a given cycle. The 'phase' image (in degrees) visualizes the relative delay in activity change at each given point. These two functional images allow delineation of the end-diastolic perimeter with a high degree of accuracy [6].

The computer is able to display four 128 x 128 images on a color TV screen. The dots appear at the same coordinates in the four different images [4]. To establish the end-diastole region of interest, the dots move along the same paths on the two functional images ('amplitude' image and 'phase' image) and end-diastole cardiac image. The observer is thereby able to integrate all available data, the validity of the outline being continually assessed in relation to both images. The end-systolic
Fig. 1 a and b. Temporal Fourier analysis applied to radionuclide cineangiography. The "phase" image represents the relative chronology of activity change (see text). The valvular area is well isolated. a: LAO, b: RAO.

Fig. 2. Phase histogram for the left ventricle. Normal subject: the curve shows only one peak.

The left ventricular ejection fraction was calculated from activity at end-diastole and end-systole using the following formula:

$$\frac{[C_{TD} - (BF \times SD)] - [C_{TS} - (BF \times SS)]}{C_{TD} - (BF \times SD)}$$

where $C_{TD}$ is activity at end-diastole, $C_{TS}$ is activity at end-systole, $SD$ is end-diastolic surface of left ventricle, $SS$ is end-systolic surface of left ventricle, and $BF$ is the average punctual value of activity in a zone contained between end-diastolic and end-systolic outlines and located at the lateral wall of the left ventricle in the LAO projection and at the anterior and apical region in the RAO (right anterior oblique view).

Regional left ventricular wall motion was studied by analyzing the phase value for left ventricular contraction and by examining the distribution histogram of the phase values for the left ventricular images. To do this, the phase image for left ventricular contraction was isolated. The phase was quantified using a color scale of 256 levels representing values ranging between the peak phase value and the superior limit of the phase as shown on the distribution histogram (Figs. 1 and 2).

For each ventriculographic study, ventricular volumes and the global ejection fraction were determined in the RAO using the method of Chapman [5]. Regional wall motion was studied in RAO and LAO view using a radial model that corrected left ventricular systolic translation by superimposing the mass centers of the end-diastolic and end-systolic images and that also corrected left ventricular systolic anticlockwise rotation by aligning end-diastolic and end-systolic apices [1].

Regional wall motion was quantitatively analyzed in 20 angular sections as the percentage of systolic shortening of the mean axis of each section and was compared on a section-to-section basis with values obtained for 16 normal subjects. A section was considered hypokinetic when shortening was at least 20% below the inferior limit of the confidence interval for 99% of the healthy population. A section was considered akinetic when the percentage shortening approached zero and paradoxal when systolic expansion was observed. This method was applied in both RAO and LAO.

Fig. 3. Segmentation of a contrast ventriculogram in RAO and in LAO. In RAO, the anterior region is comprised of angular sections A4–A9, the apical region is comprised of sections A3–I3 and the inferior region is comprised of sections I4–I9. The sections adjacent to the aortic region were not considered. In LAO, the lateral region contains the sections A3–A9, the inferoapical region contains sections I3–A3 and the septal region contains sections I3–I9. The sections adjacent to the aortic region were not considered.