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Short communication

Parametric phase display for biventricular function from gated cardiac blood pool single-photon emission tomography

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Abstract. Complete assessment of biventricular function from planar ECG-gated cardiac blood pool studies has been limited because of the overlap of adjacent activity-containing structures. Theoretically, single-photon emission tomography (SPET) can be used to comprehensively evaluate both ventricles by isolating them from surrounding anatomy. However, an enormous amount of parametric data is generated from gated SPET studies, and much of it is diagnostically irrelevant for ventricular wall motion analysis. To compress this information to a more easily interpretable format, a two-dimensional parametric display has been developed. Fourier analysis of short-axis tomograms from a gated cardiac blood pool SPET study generates three-dimensional, first-harmonic phase data. Circumferential profile data from the parametric tomograms of the right and left ventricle are mapped onto a two-dimensional polar display. This method is demonstrated in a normal patient and in three patients with abnormal ventricular contraction patterns and appears to have potential application for the analysis and characterization of biventricular wall motion.

Key words: Gated blood pool imaging – Heart – Ventricular function – Single-photon emission tomography –Computer processing

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Introduction

An enormous amount of tomographic, three-dimensional parametric data can be derived from gated blood pool single-photon emission tomography (SPET) studies (Fig. 1). When used to clinically evaluate ventricular wall motion, much of this information is diagnostically irrelevant. Only information associated with the left and right ventricular blood pool surfaces reflects endocardial movement, and these surfaces represent a very small fraction of the entire three-dimensional volume being imaged. To reduce this data set to a more manageable size and still maintain the information related to both the tomographic and the temporal parameters, a two-dimensional parametric display for both right and left ventricles has been developed.

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Materials and methods

Gated cardiac blood pool SPET patient studies were acquired on a three-headed SPET camera (TRIAD, Trionix Research Laboratory, Twinsburg, Ohio, USA). Projection images were acquired with a 64×32 matrix size (pixel width=7.12 mm), sampling 360° at 6° increments. The ECG-generated R-R interval was divided temporally into 16 equal-sized frames and, using a gating tolerance of 10%, 60 s of ECG-gated data was acquired at each projection angle.

After processing the projection images with Wiener filter techniques, tomographic reconstruction was performed using conventional filtered backprojection, resulting in 16 three-dimensional tomographic data sets. These 16 tomographic data sets were then reformatted into the major cardiac axis orientation.

Using these reformatted tomographic data, a time-activity curve for each voxel was derived and used for Fourier analysis. For this cardiac phase analysis, the time-activity curve is transformed to the frequency domain using only the first harmonic of a cosine wave, that is, the fundamental frequency. This is analogous to fitting a simple cosine function to each individual voxel's time-activity data. The period of this cosine is equal to the time of the entire R-R interval. The phase angle corresponds to the time of onset of mechanical contraction, with reference to the R-wave gate on the electrocardiogram (Fig. 2).

After Fourier transformation of each voxel's time-activity curve, the real and imaginary components of the first harmonic were placed into two three-dimensional arrays from which amplitude and phase parametric tomograms were calculated.

Circumferential profile data from the first harmonic parametric tomograms were sampled at the left and right ventricular blood pool surfaces and then mapped onto a two-dimensional polar display, analogous to the method used for thallium-201 SPET [1]. The end-diastolic tomograms were used to determine the three-dimensional location of the ventricular blood pool surfaces. The

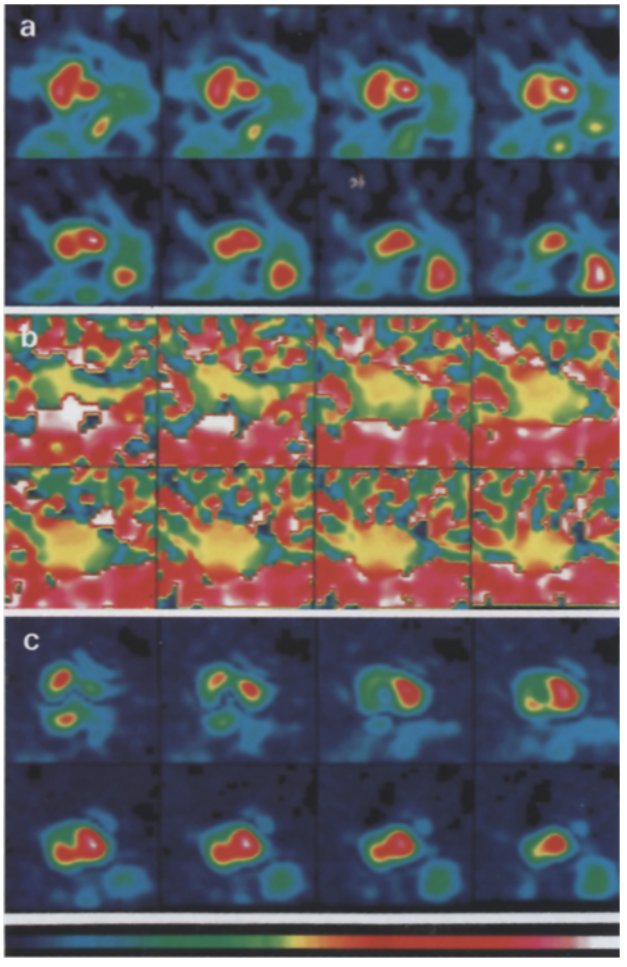


Fig. 1a–c. Gated blood pool SPET. Eight contiguous short-axis tomographic slices from a total of 32 are shown. **a** Tomograms from the end-diastolic portion of the cardiac cycle. **b** Corresponding phase angle tomograms. **c** Corresponding amplitude tomograms

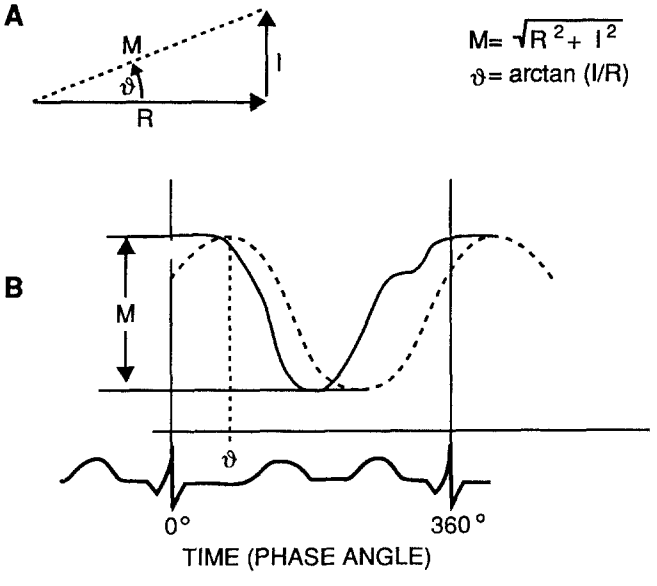
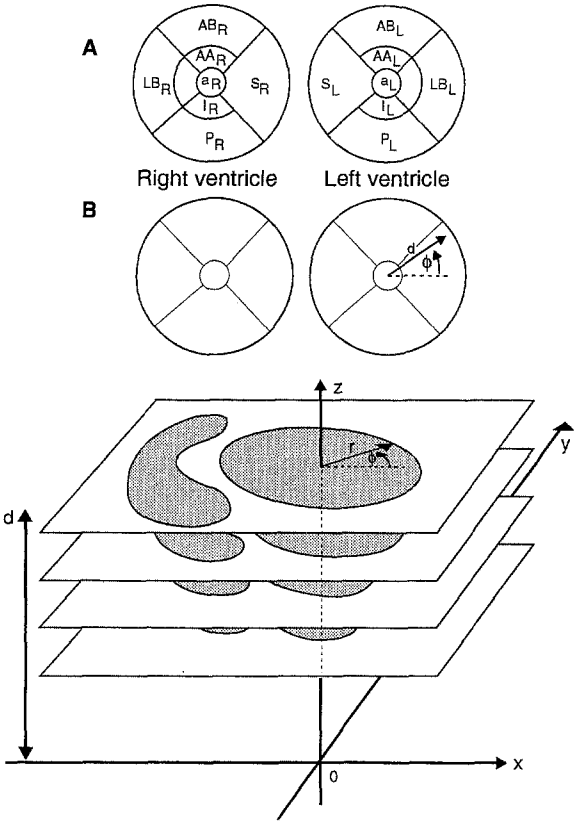


Fig. 2a,b. Fourier analysis of a single voxel's time-activity curve. **a** Fourier transformation yields two numerical indices, known as a real (*R*) and an imaginary (*I*) component, which may be thought of as two orthogonal vectors. Vector addition produces a resultant vector with magnitude *M* and direction expressed as a phase angle θ. **b** First harmonic (*dashed line*) compared to time-activity curve (*solid line*). This is analogous to fitting a cosine to the original time-activity curve. The phase angle θ is related to the time of onset of mechanical contraction



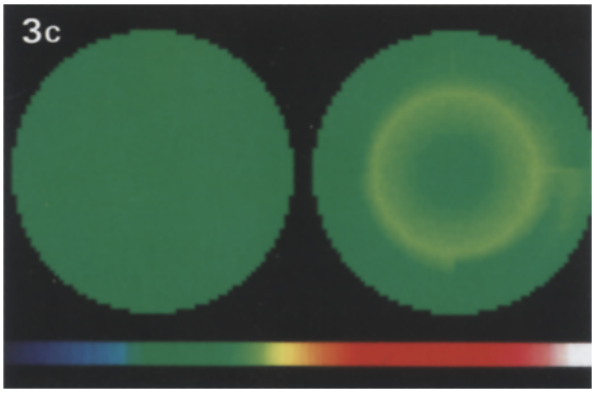
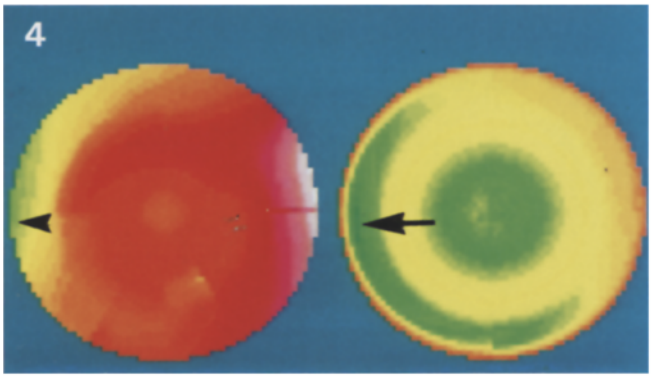


Fig. 3a–c. Construction of biventricular polar display from short-axis tomograms. **a** Format of display. A polar map is made for each ventricle. Parameters from the apex (*a*) are mapped onto the center, and those from the base onto the periphery. A typical point on the display can be described by a vector with magnitude *d* and phase angle ϕ. **b** Corresponding physical location of a polar map vector. Short-axis tomograms are stacked along the *z*-axis related to their distance from the ventricular apex. The parametric tomograms are sampled in slice *d*, at an angle ϕ, at a distance *r* from the long axis located at the blood pool surface. **c** Normal patient study. Ventricular phase angle values are concentrated within a narrow range in this case between 26° and 65°. AB, Anterobasal; AA, anteroapical; S, septal; P, posterior; I, inferior; LA, lateroapical; LB, laterobasal



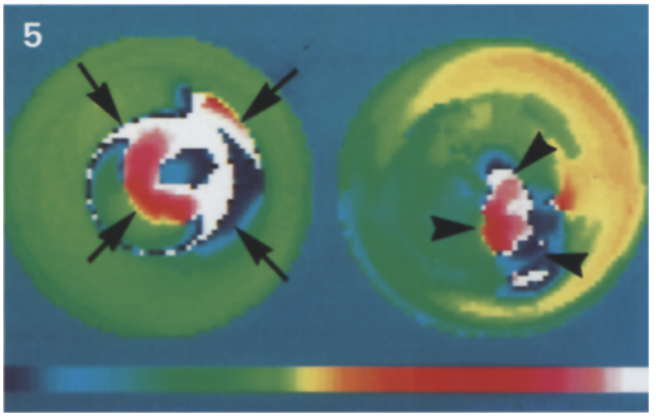
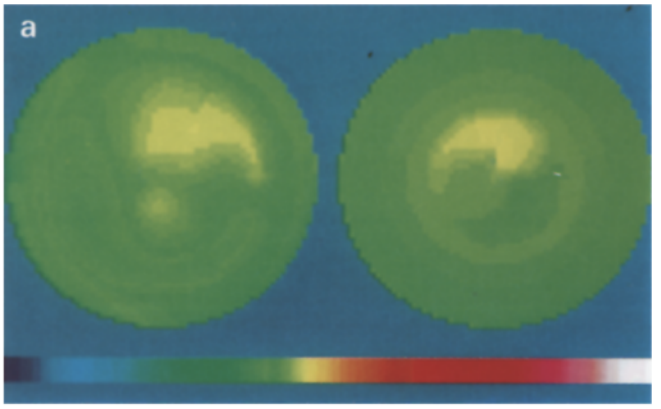


Fig. 4. Right bundle branch block. Overall, the phase values associated with the left ventricle occur earlier than those associated with the right ventricle in this patient. The onset of the wave of mechanical ventricular contraction occurs in the proximal septum of the left ventricle (*arrow*). There is a delay of onset of the right ventricular contraction (*arrowhead*), which then sweeps towards the right ventricular apex and septum

Fig. 5. Inferior wall myocardial infarction and associated right ventricular infarction. There are dyskinetic regions involving the apical region of the right ventricle (*arrows*) and the diaphragmatic region of the left ventricle (*arrowheads*) in this patient with a history of inferior wall myocardial infarction



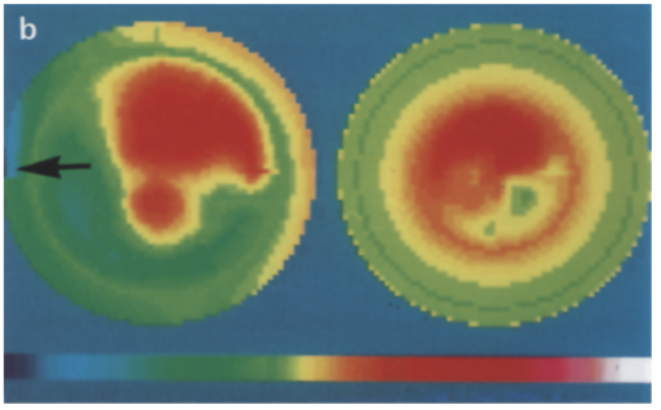


Fig. 6a,b. Wolff-Parkinson-White syndrome. **a** These polar parametric studies, as in the other cases, are displayed by applying a color scale that extends through the entire spectrum of phase values (0–360°). **b** In order to appreciate small differences in phase values within the ventricles, a flexible color scale is used to allow finer angular resolution. There is enhanced appreciation of phase angle differences within the ventricles when the spectrum of phase values is changed to 143–197°. The earliest phase angles, which correspond to the site of the accessory conduction pathway, are in the lateral wall of the right ventricle (*arrow*)

center of each polar map corresponds to the apex of either the right or the left ventricle, respectively, while the periphery corresponds to the basal ventricular segments.

To perform this mapping process, each sample point on the two-dimensional polar map (d, θ) is transformed to three-dimensional cylindrical coordinates (r, θ, d) related to the ventricular blood pool surface (Fig. 3), which are then converted to Cartesian coordinates (x, y, d). Linear interpolation is performed to determine values of the real and the imaginary components of the first harmonic at that spatial location and, by vector addition (Fig. 2a), values for amplitude and phase angle are determined.

By flagging small portions of the color bar sequentially and displaying the polar phase images of the right and left ventricles either serially or cinematically, an appreciation of the temporal and spatial relationships of the wave of onset of mechanical contraction for both ventricles is obtained.

Results

Figure 4 shows the results, displayed as described above, from a 59-year-old man with a history of chronic obstructive pulmonary disease and coronary artery disease, who has a right bundle branch block (RBBB) confirmed by ECG. In this patient with RBBB, notice that the onset of the wave of mechanical ventricular contraction occurs in the proximal septum of the left ventricle (Fig. 4, arrow), which is the typical, expected site. The wave of contraction spreads down towards the left ventricular apex and across the free left ventricular wall to the left ventricular base. There is a delay of onset of right ventricular contraction (Fig. 4, arrowhead), which then sweeps towards the right ventricular apex and septum. The wave of mechanical contraction is finally seen to move along the right ventricular outflow tract and proximal pulmonary artery in an orderly fashion.

Figure 5 displays the data from a 70-year-old woman with a history of an inferior wall myocardial infarction and an associated right ventricular infarction. Right ventricular infarction is generally associated with obstructive lesions of the right coronary artery and frequently complicates a left ventricular infarction of the inferoposterior wall [2]. In this patient study, dyskinetic regions are noted involving the apical region of the right ventricle (Fig. 5, arrows) and the diaphragmatic region of the left ventricle (Fig. 5, arrowheads).

Figure 6 shows a study from a 51-year-old woman with a history of tachycardia associated with the Wolff-Parkinson-White syndrome. In Fig 6a, the polar parametric phase study is displayed by applying a color scale that extends through the entire spectrum of the cardiac cycle (0–360°), in a manner similar to the other two cases. In order to appreciate small differences in phase values within the ventricles, an expanded color scale is used to allow finer phase angle contrast. Enhanced appreciation of the phase angle differences is noted when the spectrum of phase angle values is changed to the range of 143–197° (Fig. 6b).

In this patient study, the earliest phase angles, which correspond to the site of the accessory conduction pathway, are seen in the lateral wall of the right ventricle (Fig. 6b, arrow). The wave of contraction then spreads across the free wall of the right ventricle towards its apex before the onset of left ventricular contraction. Notice in this case that the septal portions of both ventricles are the last segments to begin contraction.

The location of the accessory conduction pathway was confirmed by electrophysiological studies, and the patient underwent successful catheter ablation of the accessory conduction pathway.

Discussion

Several cases have been presented here which demonstrate the use of this parametric phase display for biventricular function. Although several investigations have shown the utility of gated cardiac blood pool SPET parametric displays for evaluation of the left ventricle [3–6], these case examples stress the importance of right ventricle functional analysis in several commonly encountered clinical situations. There is an obvious functional relationship between both cardiac ventricles. In many pathologies, the primar disease of one ventricle can have functional manifestations on the other.

A direct application of the parametric phase display is in patients with conduction abnormalities. Since, in general, electrophysiologic excitation has a close correlation with mechanical contraction and movement of the myocardium [7], the parametric phase display provides the three-dimensional propagation pattern of mechanical ventricular contraction.

This display may be useful for the localization of abnormal foci of excitation in patients with episodic sustained ventricular tachycardia. The same method can also be applied, as demonstrated in Fig. 6, to patients with Wolff-Parkinson-White syndrome to localize the accessory conduction pathway emergence.

For the assessment of regional kinetic abnormalities in coronary artery disease or cardiomyopathies, this phase display can condense, in a single image, the information which summarizes the temporal and spatial relationships of ventricular wall motion. In the field of ischemic heart disease, wall motion abnormalities are common and characterization of their location, size, and behavior is of immense, practical clinical importance. An intriguing potential application of three-dimensional phase analysis, for example, may be the localization and quantification of ischemic wall motion abnormalities during either stress-induced ischemia or myocardial infarction.

To compress the amount of parametric data derived from gated cardiac blood pool SPET, a two-dimensional display has been developed. This method is an effective technique that integrates four-dimensional functional information for diagnostic interpretation.

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