RADIONUCLIDE METHODS APPLICATION IN CARDIAC STUDIES

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Radionuclide methods are one of the most modern methods of functional diagnostics of diseases of the cardiovascular system that requires the use of mathematical methods of processing and analysis of data obtained during the investigation. Study is carried out by means of one-photon emission computed tomography (SPECT). Mathematical methods and software for SPECT data processing are developed. This software allows defining physiologically meaningful indicators for cardiac studies.

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1. INTRODUCTION

1.1. BASIC CONCEPTS

Cardiology is one of the main medical areas of radionuclide methods and SPECT usage. Radionuclide methods in cardiac studies allow to perform functional diagnostics of the cardiovascular system [1 - 2]. Multistage mathematical data processing is an important part of these studies. It incorporates tomographic reconstruction [3], contour segmentation of left and right ventricles, building of functional images [4 - 6], and diagnostic parameters calculation.

Gated SPECT myocardial perfusion imaging (MPI) and gated blood-pool SPECT (GBPS) are modern radionuclide cardiac studies. Improving of the data processing is an actual task.

1.2. MODE OF DATA ACQUISITION

MPI and GBPS are cardiac studies made in a "Gated tomography" data acquisition mode are considered [7 - 8].

This mode is the combination of tomography scanning and synchronization modes. Data acquisition is being run using a signal of an external device – an electrocardiograph (ECG). These studies allow obtaining information about distribution of a radiopharmaceutical at different time points of the cardiac cycle. After tomographic reconstruction we obtain a spatial and temporal distribution $\rho = \rho(t, x, y, z)$ or a sequence of three-dimensional functions

$\rho_1(x, y, z)$, $\rho_2(x, y, z)$, …, $\rho_k(x, y, z)$,..., $\rho_N(x, y, z)$

considering with time discretization of a distribution density of radiopharmaceuticals, corresponding to N intervals of "representative" cardiac cycle, or with discretization of spatial variables − a sequence of three-dimensional arrays

$$\{\rho_{ijk}\}_{ijk}, \quad (1)$$

$$i, j, k = 1, \ldots, n.$$

A goal of data processing is to separate diagnostic important information from a given sequence of three-dimensional arrays and to visualize this information.

2. DATA PROCESSING OF CARDIAC STUDIES

2.1. GENERAL SCHEME OF DATA PROCESSING

Inputs of the data processing are sequence of three-dimensional volumes (1) considered above that was obtained by reconstruction of a projection data.

The stages of data processing of cardiac studies are presented at Fig. 1:

- on the basis of the reconstructed three-dimensional arrays, construction of a three-dimensional phase arrays, which is used afterwards to contour segmentation of ventricles of a heart;
- contour segmentation of right and left ventricles of a heart (RV and LV);
- perfusion, wall motion, systolic thickening (for MPI) polar maps construction;
- phase analysis, phase diagrams and histograms construction;
- plotting ventricular volume graphs;
- calculation of diagnostic parameters.

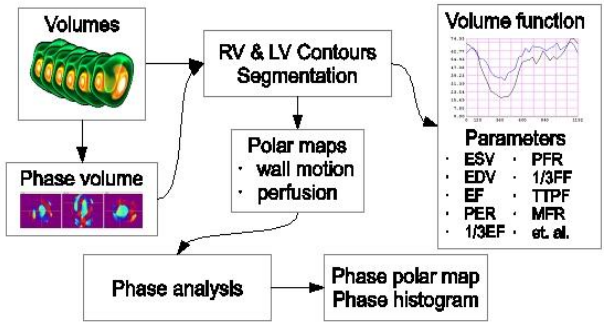

Fig. 1. Scheme of data processing

We note that this scheme is common for studies of MPI and GBPS. The differences lie in algorithms of contour segmentation and functional images construction, calculation of diagnostic parameters, etc.

2.2. GATED SPECT MYOCARDIAL PERFUSION IMAGING

Gated SPECT myocardial perfusion imaging is one of the most important diagnostic studies that allows evaluating a function of a myocardial perfusion. MPI is used for diagnostics and differential diagnostics of an ischemic heart disease, determining the state of the myocardium and the cavity of a left ventricle of a heart, an assessment of a left ventricular myocardium. It is also used to assess results of drug, surgical and rehabilitation of treatment (case follow-up) [1 - 2]. In MPI the three-dimensional distributions of a radiopharmaceutical in an area of a heart at different time intervals of a cardiac cycle are analyzed. These distributions correspond to distributions of blood flow in a myocardium. It should be noted that a myocardium of a right ventricular (RV) is thinner and has a lower blood flow as compared with a left ventricle (LV), it is difficult to visualize. So, usually, in data processing of MPI is limited to the study of LV. In the paper it is offered to investigate perfusion,

function and to determine basic hemodynamic parameters of RV as well [9].

We consider the basic steps of data processing. In Fig. 2 in the top row we see the middle slices of source volume distribution of the radiopharmaceutical in the heart, in the bottom row – the middle slices of the phase volume that constructed on the basis of Fourier analysis.

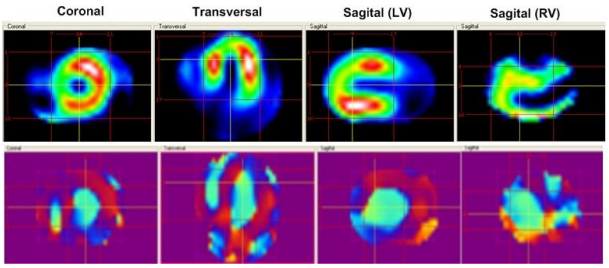

Fig. 2. Middle slices of LV and RV

During ventricular contours segmentation the characteristics of their form are recorded, namely - the division to the top (in this part the spherical coordinates is used) and the remainder (using cylindrical coordinates). We propose a model of simultaneous contouring LV and RV, the coordinate system of the heart is shown in Fig. 3.

Main points of RV and LV segmentation:

- narrowing search bounds:
  - using phase volume;
  - using user specified boundary;
- common septum of LV and RV;
- 4D time-spatial contour detection method.

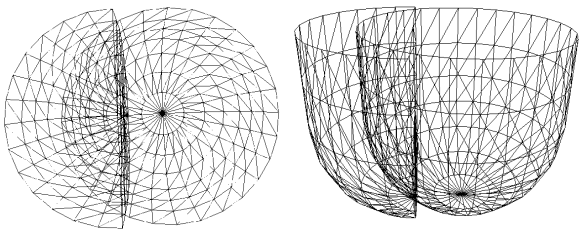

Fig. 3. The coordinate system of the heart

After the segmentation of the ventricles of the heart using the constructing of polar diagrams, sectoral diagrams of myocardium are constructed from the top to the basal parts [10]. On the diagrams the top is displayed in the center, septum on the left, anterior, lateral and posterior walls – respectively at the top, right and bottom. An important parameter of the heart is wall motion, it is visualized as the movement of the endocardium (inner wall of the myocardium) from the end of diastole to the end of systole and it is also displayed in the form of a polar diagram. The thickening of the myocardium from end of diastole to end of systole is visualized in a polar diagram of systolic thickening [11].

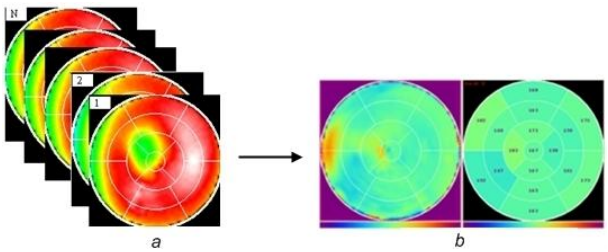

Fig. 4. Building of phase diagrams: a – sequence of perfusion polar diagrams; b – phase polar diagram

The phase polar diagram of LV and RV allow estimating asynchrony of entry into contraction of the various regions of myocardium. These diagrams are based on diagrams perfusion [12 - 14], Fig. 4.

Phase histogram is constructed (Fig. 5) for a more detailed assessment of global asynchrony. The estimation of the phase diagram is made by the basins of the arteries and calculation of parameters that characterize the phase histogram.

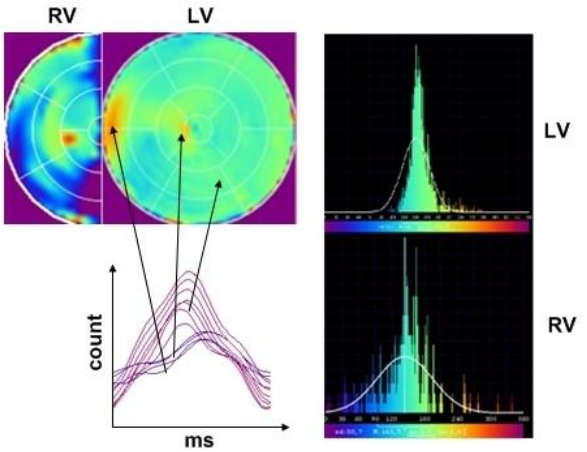

Fig. 5. Phase diagrams and histograms of LV and RV

Design and analysis of phase diagrams and histograms are very important for the estimation of local and global asynchrony for the selection of patients for cardiac resynchronization therapy [15 - 16].

2.3. GATED BLOOD-POOL SPECT

Gated blood-pool SPECT is radionuclide method of heart diagnostics, based on tomography of labeled blood pool, that synchronize with the ECG signal. GBPS allows determining the volume of the ventricles of the heart, their ejection fraction, hemodynamic parameters for the systole and diastole, and to estimate local and global ventricular asynchrony.

Stages of data processing of GBPS are presented in Fig. 1 [17]. Let's consider a more detailed the construction of three-dimensional phase images of the heart and polar phase diagrams.

The use of wavelet analysis is proposed for the building of three-dimensional phase volume $\Phi(i, j, k)$, $i, j, k = \overline{1, n}$ and subsequent analysis of GBPS data. Two families of complex wavelets with the following basal functions are considered:

1. Morlet wavelet

$$\psi(t) = \exp\left(-\frac{t^2}{2}\right).$$

2. B-spline wavelet

$$\psi(t) = \exp\left(\frac{\sin(t/2)}{t/2}\right).$$

The input data for finding the volume Φ are a sequence of three-dimensional distributions of the RFP ($P_s, s = \overline{1, N}$), corresponding to intervals of the cardiac cycle. The curve «activity / time» is constructed to find the value of the element (*i, j, k*) volume Φ. This curve is a graph of a periodic function *f* (*t*), whose values are known at *N* points ($f_s = \Phi(i, j, k), s = \overline{1, N}$).

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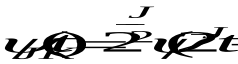
Wavelet series for function $f(t)$ is as follows:

where the coefficients a_{JK} and b_{JK} are calculated by the formulas



(J – scale, K – displacement), a ψ^*_{JK} – function, the complex conjugate of the function ψ_{JK}. As a result, the elements of phase volume Φ can be found by the formula

(2)

Constructed phase volume is used in the LV and RV contours segmentation, as it allows separating the atria from the ventricles, which contract in different phases. Fig. 6 shows an example of to clarify bounds of LV by the phase image. We can note also that the use of the approaches described in [18] can be perspective for the construction of the contours of LV and RV. These approaches are based on the determination of the velocity field and can be used in the problems of data processing of radionuclide images.

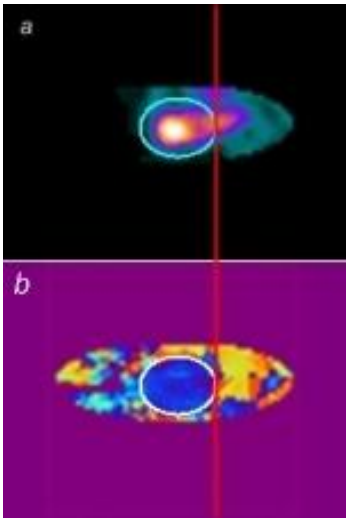


Fig. 6. Construction of contour LV for sagital projection: a – slice of source volume LV; b – corresponding phase image is based on the B-spline wavelet

For the construction of phase images of RV and LV represented as polar diagrams, wavelet analysis is also used. The phase polar diagram is based on the sequence of the polar diagrams of perfusion using the formula (2), written for the two-dimensional case.

Fig. 7 are phase images of RV based on the first harmonic of the Fourier and wavelet analysis. Wavelet analysis using more accurate approximation of curves «activity / time» allows getting a more detailed phase images.

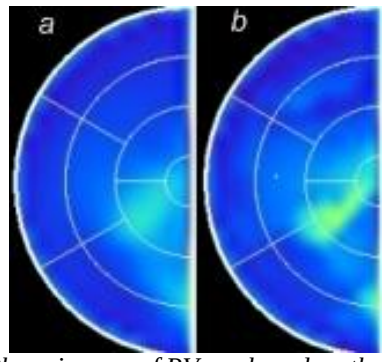


Fig. 7. Phase images of RV are based on the first harmonic of the Fourier series (a) and B-spline wavelet (b)

CONCLUSIONS

The software for data processing of tomographic radionuclide cardiac studies was developed. The article describes the main stages of processing MPI and GBPS. For the studies of MPI the method of simultaneous segmentation of the LV and RV was used. For the construction phase matrices and polar diagrams for GBPS is considered with using of wavelet analysis.

The developed software is installed and operated at «Federal Research Center of Transplantology and Artificial organs named after Academician V.I. Shumakov», «Federal Research and Clinical Center of specialized types of health care and medical technology of the Federal Medical and Biological Agency».

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ПРИМЕНЕНИЕ РАДИОНУКЛИДНЫХ МЕТОДОВ В КАРДИОИССЛЕДОВАНИЯХ

Е.Д. Котина, В.А. Плоских, А.В. Бабин

Радионуклидные методы являются одними из самых современных методов функциональной диагностики заболеваний сердечно-сосудистой системы, которые требуют использования математических методов обработки и анализа данных, полученных в ходе исследования. Исследование проводится с помощью однофотонной эмиссионной компьютерной томографии (ОФЭКТ). Разработано математическое и программное обеспечение для обработки кардиологических исследований в ядерной медицине. Данное программное обеспечение позволяет определять физиологически значимые показатели перфузии и функции сердца, а также оценивать асинхронию желудочков сердца.

ЗАСТОСУВАННЯ РАДІОНУКЛІДНИХ МЕТОДІВ У КАРДІОДОСЛІДЖЕННЯХ

О.Д. Котіна, В.А. Плоскіх, А.В. Бабін

Радіонуклідні методи є одними з найсучасніших методів функціональної діагностики захворювань серцево-судинної системи, які вимагають використання математичних методів обробки та аналізу даних, отриманих у ході дослідження. Дослідження проводиться за допомогою однофотонної емісійної комп'ютерної томографії (ОФЕКТ). Розроблено математичне та програмне забезпечення для обробки кардіологічних досліджень в ядерній медицині. Це програмне забезпечення дозволяє визначати фізіологічно значущі показники перфузії і функції серця, а також оцінювати асинхронію шлуночків серця.