DATA PROCESSING AND QUANTITATION IN NUCLEAR MEDICINE*

E.D. Kotina, V.A. Ploskikh, St. Petersburg State University, St. Petersburg, Russia

Abstract

Accelerators of charged particles, radiation detectors are widely used in nuclear therapy and nuclear diagnostics. So there is necessity for diagnostic processing of data obtained using these devices. Nuclear diagnostics is based on analysis of radiation passing through the study object emitted from radiopharmaceuticals within the object or from external radiation source. First stage of data processing is presentation of detector signals in 2D or 3D image form. Further processing is based on mathematical modeling of processes within the investigated object. Mathematical modeling of static, dynamic and periodic processes is considered for quantitative analysis of studies in nephrology, osteology, endocrinology and cardiology. The data processing and quantitation software suite is presented. Clinical applications of the developed suite are discussed. Possibilities of software deployment in clinical centers are considered.

DATA ACQUISITION

The NM diagnostic methods study the activity distribution of object.

Nuclear imaging system consists of n_d logical detector units. Detector units need not correspond to physical detectors. Examples of detector unit are Anger camera projection bin at a particular projection angle ($n_d=n_x n_y n_\Theta$), a line of response in PET ($n_d=(n-1)n/2$, where n is a number of detector crystals). Radiation detection hardware registers emission radiation of radiopharmaceutical and forms the flow of registration events. The event carries information about detector unit and time of registration. Registration software during the time of acquisition accumulates events in a projection data array. Exact structure of the array depends on the hardware type and operating mode.

Discrete formulation of the projection problem reads:

$$p=Hx,$$

where x is a column vector of $n_x n_y n_z$ elements corresponding to activity distribution, p is projection data array and H is the system matrix. Each element H_{ij} of H is defined as the probability that emission event occurred in voxel j is detected by i-th logical detector unit.

Depending on studied process temporal nature three basic hardware operating modes can be distinguished [1, 2]:

Static. During the static acquisition it is assumed that the activity distribution function does not vary in time. The goal of static studies is to analyze spatial distribution of radiopharmaceutical.

Dynamics. During the dynamic scan several projection data arrays are formed in sequence. Dynamic studies used to analyze processes of radiopharmaceutical redistribution.

Gated acquisition. Gated acquisition is used in cardiac cycle analysis. The acquisition computer defines the number of time slots to divide the R to R interval of the patient's electrocardiogram. Electrocardiogram guides the acquisition so a projection data array is formed for each time slot.

After acquisition projection data should be corrected for various physical effects: attenuation, Compton scattering, Poisson noise, false coincidences et al.

Planar SPECT projection data is presented as sequence of 2D images. Projection data arrays of tomographic studies are subjected to reconstruction methods and presented as series of 3D data volumes.

For mathematical modeling purposes we consider these series of images as discrete representation of continuous radiopharmaceutical density distribution function $\rho(t, x)$. In 3D case the density distribution function coincides with the source activity distribution function. In 2D case the density distribution function is a projection of the source activity distribution to the detector plane.

DATA PROCESSING

Quantitative analysis is based on computation of various parameters for regions of interest (ROIs). The first step is to extract these ROIs from raw projection data.

Segmentation

In SPECT data processing various region extraction techniques are used. In most cases of static planar processing human-drawing ROI tools is the most simple and flexible method. This method also used in planar dynamic studies in conjunction with patient motion correction methods.

Specialized applications may use organ specific detection methods (fig. 1)

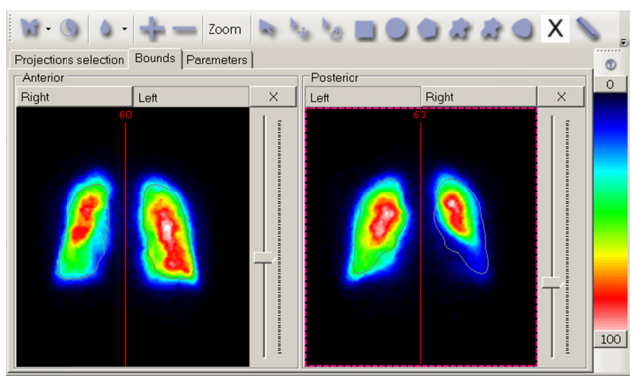

Figure 1: Automatic segmentation in lung perfusion.

*Work supported by SPbGU, grant 9.39.1065.2012

ISBN 978-3-95450-125-0

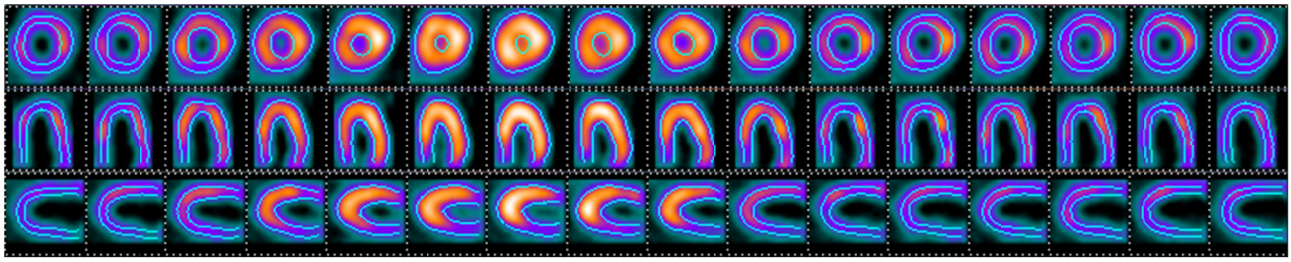

Figure 2: Left ventricle segmentation in gated SPECT.

Volume and gated segmentation techniques incorporate complex automatic and semi-automatic edge-detection algorithms based on detection of isocount surfaces, adaptive thresholds, coordinate transformations, models of mechanical motion, gradient and velocity field analysis.

Mathematical Modelling

In radionuclide studies of the functional state of organs and systems mathematical processing of data is very important. In the interpretation of the data it is necessary to know the features of transport of the radiopharmaceuticals in the study of the physiological system, knowledge of the structure and interactions of the structural elements of the system under study.

For quantitative analysis of the results of radionuclide studies of the functional state of various organs and systems mainly two approaches are presented: the calculation of the complex variety of amplitude and time parameters directly from dynamic curves constructed by regions of interest, the definition of physiologically meaningful parameters that characterize the state of the organ under investigation based on mathematical modeling [3]. Parametric imaging based on the definition of parametric (functional) transformation can also be considered as formal mathematical model of the process, in order to obtain additional diagnostic information.

Since the processing of data uses a model representation of transport indicators describing the system of ordinary differential equations

$$\begin{aligned} \dot{x} &= u(t,x,y), \\ \dot{y} &= v(t,x,y). \end{aligned} \tag{1}$$

Let us consider the following equation together with equation (1):

$$\frac{\partial \rho}{\partial t} + \frac{\partial \rho}{\partial x}u + \frac{\partial \rho}{\partial y}v = 0, \tag{2}$$

under initial condition

$$\rho(t_0,x,y) = \rho_0(x,y), \tag{3}$$

where $\rho_0(x, y)$ is given function and $\rho=\rho(t, x, y)$.

Model representation of radiopharmaceutical transport allows to set the problem of determining the velocity field of the system (1) for a given density distribution of radiopharmaceuticals.

In the case of optical flow system for the determination of the functions u, v has the form [4, 5]

$$\begin{aligned} \alpha^2 \Delta u - \rho_x^2 u - \rho_x \rho_y v &= \rho_t \rho_x, \\ \alpha^2 \Delta v - \rho_y^2 v - \rho_x \rho_y u &= \rho_t \rho_y. \end{aligned} \tag{4}$$

As a result of this approach, the problem of finding the velocity field of (1) by known density $\rho(t, x, y)$ is reduced to the solving of (4) under the corresponding boundary conditions.

The construction of the velocity field, i.e., finding functions u, v can have both intrinsic interests, giving additional visual and quantitative information, and used in various applications.

To analyze the distribution of the radiopharmaceutical in different dynamic studies different compartment models are used.

The density distribution of radiopharmaceuticals $\rho=\rho(t, x, y, z)$, which depends on the time t and space coordinates is considered. Next, for convenience we denote $x_1=x$, $x_2=y$, $x_3=z$, and, now $x=(x_1, x_2, x_3)$. It is assumed that the transport of the indicator is based on system

$$\dot{x} = f(t,x), \tag{5}$$

and the function $\rho(t,x)$ satisfies the generalized Liouville equation [6]

$$\frac{\partial \rho}{\partial t} + \frac{\partial \rho}{\partial x} f + \rho \operatorname{div} f = 0, \tag{6}$$

where $\rho=\rho(t, x)$, $f=f(t, x)$ – velocity field of the system (5).

Human organism represented by the sum of related virtual domains (compartments), with the introduction of the following notation: D_i – investigated compartment, $i=1,..,n$, where n – the number of compartments, $q_i=q_i(t)$ - function that characterizes the amount of indicators in the compartment D_i, which is determined by the formula

$$q_i(t) = \int_{D_i} \rho(t,x)\,dx. \tag{7}$$

Considering the density redistribution and, given that the integral of the density by the domain $D=\sum_{i=1}^{n} D_i$ is constant, and also taking into account that the velocity of change of indicator is directly proportional to the amount of indicators in the source compartment, we consider the equations of compartment models

$$\frac{dq_i}{dt} = \sum_{j=1}^{n} a_{ij}(t) q_j, i = 1,2,...,n. \tag{8}$$

The system of parameters $\{a_{ij}\}_{i,j=1}^{n}$ is the transport matrix size, $n \times n$. It is the desired system of unknown clinical and physiological parameters of the model. Also within the framework other mathematical models are considered.

ISBN 978-3-95450-125-0

SOFTWARE SUITE FOR SPECT

In this work program complex for data processing of radionuclide studies is considered, it is intended to perform complex tasks of mathematical SPECT data processing.

The suite could work with various sources of medical

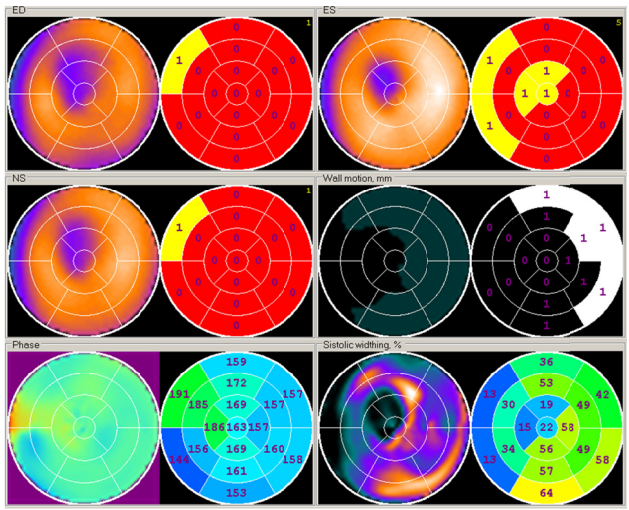

Figure 3: Myocardial perfusion polar maps.

data, based on hardware interoperation, file storages and databases. For interoperability with other software DICOM file format is supported.

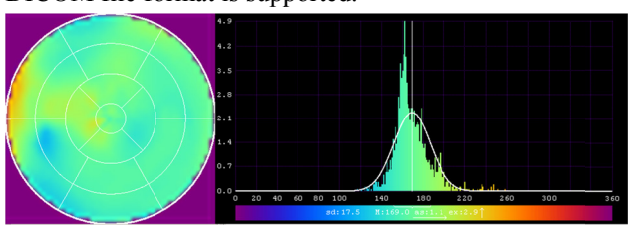

Figure 4: Myocardial perfusion phase analysis.

The designed suite makes it possible to capture and process information in static, dynamic, tomographic, and SPECT gated modes. The data processing applications provide possibility for qualitative and quantitative estimation of the results of radionuclide studies.

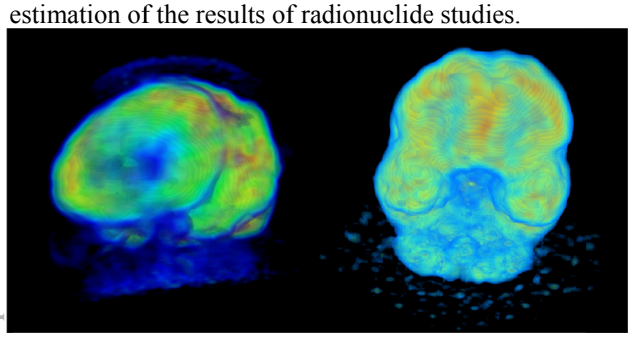

Figure 5: Volume visualization of brain studies.

Data processing of the results of radionuclide studies is performed by clinical software application modules.

The software suite incorporates specialized medical software applications which perform data processing and visualization according to established clinical protocols and methods [7]. Also applications for preliminary data processing (tomographic reconstruction and reorientation, motion correction [5], data view) are included into the suite.

The suite incorporates clinical software applications for data processing in cardiology (fig. 3, 4) [8, 9]; brain studies (fig. 5); in nephrology (fig. 6); in pulmonology (fig. 1); in osteology; in endocrinology; hepatobiliar system analysis; multifunctional application for static and dynamic data processing et al.

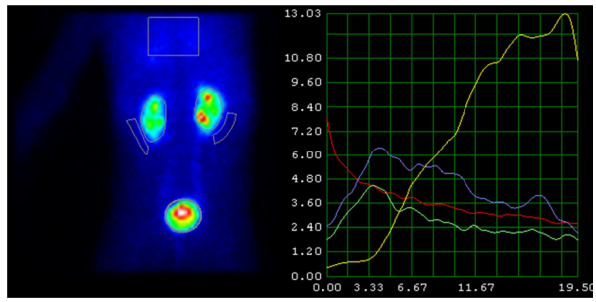

Figure 6: Dynamic nephroscintigraphy.

REFERENCES

[1] E.D. Kotina, A.I. Dzhaksumbaev, D.V. Dezhurnyuk,V.A. Ploskikh "Automated information system for radionuclide diagnostics" Vestnik of St. Petersburg University, Ser. 10, №.1, pp. 110-115, 2006.

[2] M.A. Arlychev, V.L. Novikov, A.V. Sidorov, A.M. Fialkovskii, E.D. Kotina, D.A. Ovsyannikov, V.A. Ploskikh. Two-Detector Single Photon Emission Tomograph EFATOM //Technical Physics, 2009, Vol. 54, No. 10, pp. 1539–1547.

[3] E.D. Kotina "Program complex "Diagnostics", Vestnik of St. Petersburg University, Ser.10, №2, pp. 100-113, 2010.

[4] B.K.P. Horn, B.G. Schunck Determining optical flow // Artificial intelligence. 1981. Vol. 17. Pp. 185–203.

[5] E.D. Kotina, K. M. Maximov "Motion Correction in SPECT and Planar Radionuclide Studies", Vestnik of St. Petersburg University, Ser.10, №1, pp. 29-36, 2011.

[6] D. Ovsyannikov, E. Kotina, "Reconstruction of Velocity Field", ICAP'12, Rostok, August 2012, THSCC2, (2012).

[7] Y.B. Lishmanov, V.I. Chernov et al., National guidelines for nuclear medicine, (Tomsk: STT, 2010), 686.

[8] E.N. Ostroumov, E.D. Kotina, O.R. Senchenko, A.B. Mironkov. Radionuclide methods in the cardiology clinic / / Heart. 2010, № 3. pp. 90 – 95.

[9] G. Germano et al. Quantitation in gated perfusion SPECT imaging: The Cedars-Sinai approach // Journal of Nuclear Cardiology Volume 14, Number 4; pp. 433-54. 2007.

ISBN 978-3-95450-125-0