QUALITATIVE AND QUANTITATIVE CHARACTERISTICS OF DIAGNOSTIC PET IMAGES

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Abstract: Background: The master's thesis explored the influence of reconstruction parameters (which include inputs to iterative algorithms, additional functions such as PSF) on the qualitative and quantitative characteristics of diagnostic PET images.**Aims of the study**: The aim of the master's work is to assess the influence of reconstruction parameters on the qualitative and quantitative characteristics of diagnostic images.**Methods:**The master's thesis was carried out using a combined PET-CT scanners manufactured by General Electrik (Discovery 710 and two Discovery I. As part of the study, an experiment was performed using a water-filled IEC phantom with six installed spheres of different diameters. This phantom is a model of pathological foci of accumulation of a radiopharmaceutical against the background of physiological accumulation of a radiopharmaceutical (for example, liver metastases). An analysis of the effect of reconstruction parameters was also performed based on real patient studies. Optimal scanning parameters are presented that allow performing studies without losing diagnostic information.**Conclusion:** Taking into account the constant development of diagnostic equipment (PET), as well as the possibilities of its use, in particular, the assessment of the response to treatment, the studies performed in this work will improve the accuracy of the assessment of the received diagnostic information.

Keywords:positron emission tomography, computed tomography, diagnostic imaging, reconstruction algorithm, iteration**.**

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INTRODUCTION

Positron emission tomography combined with computed tomography is one of the most important diagnostic methods in modern medicine, since for the first time it became possible to visualize the course of biological processes "in vivo", allowing to obtain not only a qualitative, but also a quantitative assessment of information. The functional data obtained using PET reflects the vital processes of organs and tissues of the human body at the molecular level.

PET / CT studies provide an integrated image. The hybrid PET-CT method combines the ability to reveal not only metabolic, but also morphological changes in the state of organs and systems of the human body. Today, the PET-CT method provides diagnostics in the field of neurology (temporal lobe epilepsy), cardiology (assessment of myocardial viability), oncology (lymphoma, breast cancer) [1].

It should be noted that the quality of the diagnostic image, as well as the quantitative information (of the radiopharmaceutical accumulated in the pathological focus) are influenced by a number of factors: the calibration of the tomograph, the preparation of the patient for the study, and finally, the software (namely, reconstruction algorithms and various filters). In particular, the quantitative characteristics of the diagnostic image are used to assess the dynamics of the development of the pathological process. And unfortunately, experts do not always pay attention to the SUV deviation when changing the input parameters of reconstruction algorithms or diagnostic protocol. The study of TOF capabilities is of particular interest.

The master's thesis was carried out using a combined PET-CT scanners manufactured by General Electrik (Discovery 710 and two Discovery IQ). This equipment has a wide range of functional capabilities due to the modern detection system in PET and the ability to combine the image with the image obtained on a computed tomography (CT) scanner. The combined image allows to obtain a complete picture of metabolic activity and anatomical information, which makes it possible to accurately localize the foci of accumulation of a radiopharmaceutical.

The accuracy and correctness of the information obtained on PET-CT images largely depends on the technical characteristics of the tomograph and needs timely and periodic control. The current standards of radionuclide diagnostics have rather high requirements for the quality of the resulting image, as well as the radiation load on the patient [2].

It is important to study the influence of the parameters of the diagnostic protocol on the qualitative and quantitative characteristics of the diagnostic image.Image quality can be assessed by the values of the values of contrast and noise. Images can be obtained by various reconstruction methods, which must be evaluated by means of the contrast / noise ratio [3,4].

METHODS

The scanning procedure was performed using a positron emission tomograph combined with a DISCOVERY 710

computer tomograph. The DISCOVERY 710 system is based on LYSO crystals, which allow the TOF method to be implemented. Quality control procedures were previously performed to ensure the reliability of the experiment. The results of tests and calibrations (daily quality control, updating the gain) meet the requirements of the manufacturer's technical documentation The scanning was carried out using the IEC phantom. The cold spheres were replaced by 5 hot spheres with diameters of 34.1 mm, 26.5 mm, 21.5 mm, 14.8 mm, 9.8 mm. The concentration ratio of the spheres and background radiopharmaceutical during the study was 1:16.

To fill the phantom and spheres, a radiopharmaceutical - 18F-FDG was used. Measurements and dosing of RP were performed using an automatic dosing system (KARL 100 automatic injector) and an installed ISOMED activity calibrator.

During the experiment, a series of PET / CT images were obtained. Spheres were contoured on a series of CT images. With the help of the special PROPAGATE function, the contours were transferred to the PET images in order to minimize errors associated with applying the contour "manually". The following parameters were measured:

1. values of the maximum volumetric activities
2. values of the average volumetric activities of the radiopharmaceutical
3. background values
4. standard deviation.

The obtained data were used to calculate the contrast and noise. In this work, the contrast and noise were calculated using formulas (1) and (2):

$$(1):\text{Contrast} = \frac{\text{signal} - \text{bacg}}{\text{bacg}},$$

$$(2):\text{Noise} = \frac{\delta\text{bcg}}{\text{bacg}},$$

where signal is the average value of the volumetric activity (SUV) in the area of interest inside the lesion (in this case, in the spheres); bacg is the average value of volumetric activity (SUV) in an area localized in a homogeneous area outside the lesion focus; δbcg is the standard deviation of the background values. The estimation of noise and contrast changes on the series of reconstructed images was carried out. Signal and bacg values were averaged.

The number of subsets used in the reconstruction of the diagnostic image for noise and contrast was estimated. The study was carried out on PET / CT Discovery 710. Diagnostic protocol parameters: reconstruction algorithm OSEM + PSF, matrix 192X192, the number of iterations varied from 2 to 7 (look along the X axis). The number of subsets varied from 6 to 32.

The influence of the number of iterations and subsets on the contrast value is considered. The contrast was calculated according to formula 1

All image reconstructions were obtained from examinations of real patients. The examinations were carried out on a DISCOVERY 710 apparatus, a positron emission tomography combined with a computed tomography. The detecting system is based on LYSO crystals. All patients were diagnosed with Lymphoma. The study was performed with the drug fluorodisoxyglucose (FDG).

RESULTS

Influence of parameters of iterative algorithms on qualitative and quantitative characteristics of diagnostic pet images on the example of real patients

Reconstructions were performed with a change in the number of subsets used, which varied from 1 to 48. In addition to significant dynamics of visual characteristics, a change in ROI (area of interest), SUV (standardized accumulation indicator), SD (standard deviation) was noted. For a quantitative assessment, two pathological foci were selected, namely in the mediastinum and liver. The measurement data are listed in Table (1).

Table 1. Quantitative data of pathological lesions

Subsets	Mediastinal lymph node			Liver lesion		
	SUVmax, g/ml	STD	ROI, cm^3	SUVmax, g/ml	STD	ROI, cm^3
1	1,44	0,14	38,68	1,27	0,11	38,73
2	2,29	0,24	31,77	2,11	0,22	24,38
3	3,09	0,37	18,3	2,9	0,39	6,43
4	3,84	0,51	8,87	3,64	0,52	3,84
6	4,98	0,71	4,96	5,08	0,74	1,96
8	5,79	0,86	3,91	5,99	0,92	1,78
9	6,02	0,9	3,65	6,56	0,99	1,52
12	6,5	0,98	3,35	7,41	1,11	1,26
16	6,96	1,09	3,09	7,53	1,21	1,35
18	7,09	1,07	3,07	7,98	1,22	1,26
24	7,46	1,13	2,83	8,14	1,29	1,26
32	7,07	1,1	2,83	7,97	1,4	1,35
36	7,35	1,17	2,87	8,07	1,4	1,35
48	7,62	1,2	2,78	7,99	1,43	1,39

The dependence of the standardized index of accumulation of a radiopharmaceutical drug (SUV) on the number of subsets was investigated; plotting and curve fitting were performed. The approximation was performed by quadratic, linear, polynomial and logarithmic dependences. The best value of the approximation reliability R^2 was chosen for a polynomial dependence (polynomial of the 3rd degree, with the approximation confidence value 0.98, Figure (1).

Functional dependence of the standardized accumulation indicator on the number of subsets:

$Y= 0,0003x^3 - 0,0294x^2 + 0,8486x + 0,6849$, $R^2 = 0,9872$ (pathological lesion of accumulation of the radiopharmaceutical in the mediastinum).

$Y=0,0003x^3 - 0,026x^2 + 0,7263x + 1,128$, $R^2 = 0,9823$ (pathological focus of accumulation of the radiopharmaceutical in the liver).

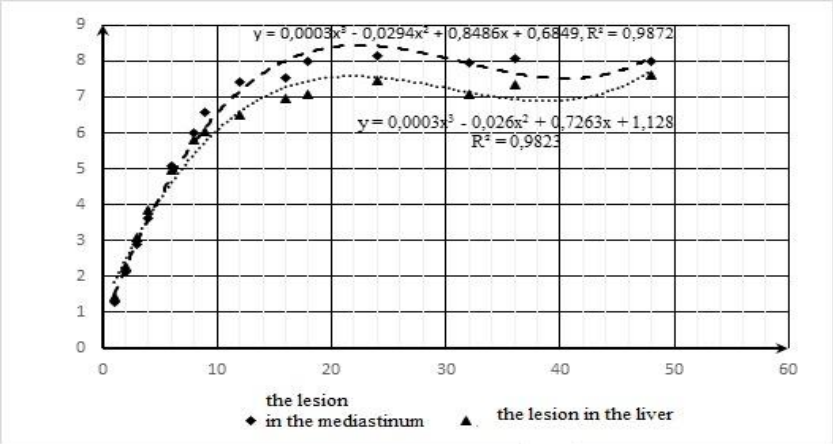

Figure 1: Functional dependence of the standardized accumulation indicator on the number of subsets

Influence of reconstruction parameters on the metabolic volume of the pathological focus

Based on the analysis of the dependence of the metabolic volume of the pathological focus on the number of subsets (Fig. (2), it can be concluded that the metabolic volume decreases with an increase in the number of subsets. It is noted that a change in the number of used subsets affects the formation of the shape of the accumulation focus, as well as the contrast.

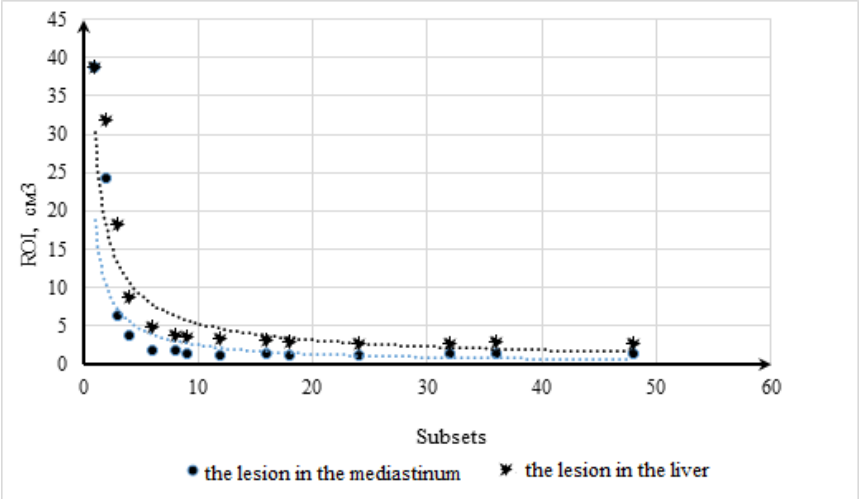

Figure 2: Dependence of ROI on the number of subsets

The following functional dependences of the metabolic volume on the number of subsets were obtained, with the corresponding approximation coefficients:

$y = 30,243x^{-0,752}$, $R^2 = 0,8446$ (the lesion in the mediastinum) - power-law functional dependence;

$y = 18,804x^{-0,871}$, $R^2 = 0,7695$ (the lesion in the liver) - power-law functional dependence.

Also, a visual analysis of the images obtained, together with doctors of radionuclide diagnostics, showed that the results obtained using subsets in the amount from 1 to 3 are incorrect for further evaluation for the following reasons:

- the minimum contrast required for correct viewing;
- deformation of the focus;
- a significant increase in size, which can subsequently lead to "merging" with other foci.

Dependence of quantitative parameters on the number of iterations

Analysis of the dependence of quantitative data (SUV, ROI), as well as visual assessment of lesions on the reconstructed images with the algorithm VPHD + PSF on the number of iterations performed. Lymphoma was selected due to the presence of a large number of small pathological foci that need to be differentiated. Reconstruction parameters: no Z-axial filter, 12 subsets, VUE point HD algorithm.

Reconstructions were performed in the interval from 1 to 30 iterations Table (2).

Table 2. Results of quantitative analysis of lesions

Lesion 1 (mediastinum)				**Lesion 2 (liver)**		
Iterations	SUVmax, kBq/ml	SUV,av	ROI, cm^3	SUVmax, kBq/ml	SUVav, kBq/ml	ROI, cm^3
2	22,98	14,12	1,6	12,77	6,97	10,18
3	29,91	18,66	1,26	14,82	8,37	7,28
4	29,91	18,66	1,26	14,82	8,37	7,28
5	35,65	21,99	1,21	17,58	9,82	5,42
6	37,82	23,07	1,17	18,45	10,41	4,9
7	39,36	23,62	1,17	19,12	10,55	4,77
8	40,51	24,01	1,17	19,64	10,77	4,64
9	41,39	25,25	1,04	20,06	10,99	4,46
10	42,08	25,51	1,04	20,40	11,10	4,46
12	43,07	25,88	1,04	20,94	11,29	4,46
14	43,74	26,14	1,04	21,34	11,52	4,33
16	44,23	26,34	1,04	21,65	11,68	4,29
18	44,60	26,16	1,08	21,91	11.81	4,29
20	44,8	26,2	1,08	21,91	11.81	4,29
22	45,16	26,38	1,08	22,32	12,14	4,12
24	45,37	26,47	1,08	22,48	12,24	4,12
26	45,56	26,55	1,08	22,63	12,45	3,94
28	45,72	26,94	1,04	22,76	12,53	3,94
30	45,87	27,01	1,04	22,87	12,61	3,94

Visual analysis:

Images reconstructed with the number of iterations from 2-5 are characterized by smooth contours, lack of coarse grain. Images reconstructed with the number of iterations from 6-10 are also suitable for description, however, in the case of liver metastases, the correct assessment will be difficult due to noise.

Images reconstructed with the number of iterations from 20-30 are characterized by a large amount of "noise", bright pathological lesion.

The figure (3) shows the functional dependence of the SUV on the number of iterations.

The following equations were obtained for the dependence of the standardized indicator of the accumulation of a radiopharmaceutical in the pathological focus on the number of iterations:

$Y = -0.0493x2 + 2.1127x + 24.35$ ($R^2 = 0.8878$; second-degree polynomial) – the lesion in the mediastinum;

$Y = -0.0202x2 + 0.9125x + 12.681$ ($R^2 = 0.9231$; second degree polynomial) - the lesion in the liver.

Considering that SUV is used to assess the dynamics of the development of a pathological process, it should be borne in mind that a comparison of diagnostic images reconstructed with a different number of iterations can lead to an error.

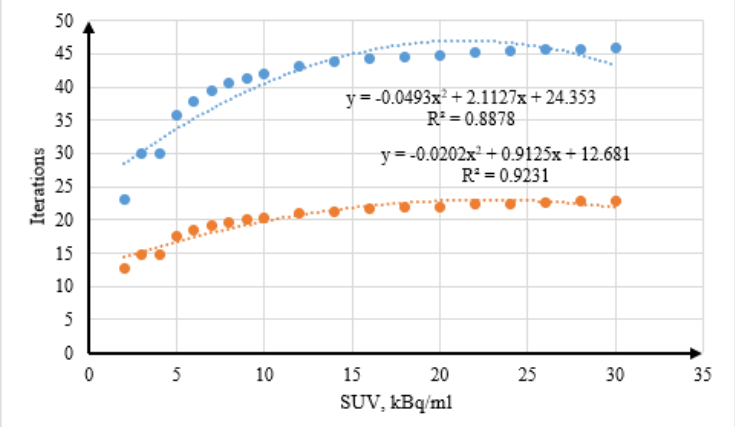

Figure 3: SUV versus number of iterations

The figure (4): shows the dependence of the metabolic volume on the number of iterations. As a result of the study, it was revealed that the metabolic volume of lesions with a diameter of less than 6 mm (measured by CT) is subject to significant fluctuations as a result of changes in the number of iterations. Both the standardized accumulation rate of the radiopharmaceutical and the metabolic volume can vary up to 20% over the iteration interval 1-3.

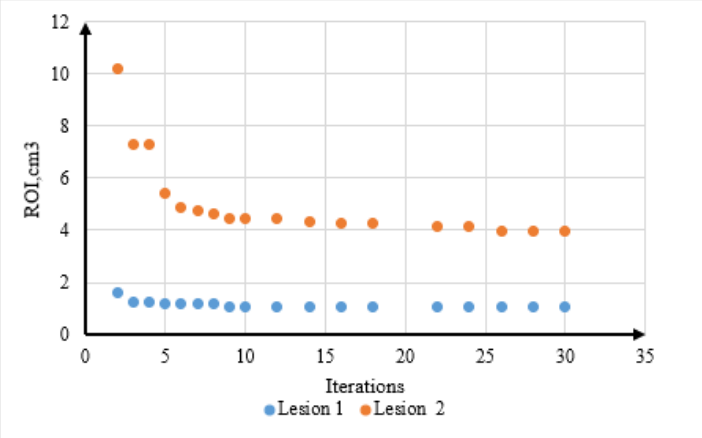

Figure 4: Dependence of ROI on the number of iterations

CONCLUSION

The analysis of the influence of the input parameters of the reconstruction algorithm on the quantitative characteristics of the diagnostic image based on the study of real patients was carried out in order to confirm the results obtained on the basis of studies performed using a water-filled phantom.

An increase in the number of iterations is also accompanied by a decrease in metabolic volume, an increase in the SUV value, and an increase in the standard deviation.

An increase in the number of subsets is accompanied by a decrease in metabolic volume, an increase in the SUV value, and an increase in the standard deviation.

Using a low number of subsets (from 1 to 8) allows obtaining images with a low noise level, but this is impractical because the consequence of using a low number of subsets may be the loss of diagnostic information.

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