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ORIGINAL ARTICLE

OPTIMIZATION OF PLANNING RADIONUCLIDE DIAGNOSTIC TESTS IN OSTEOSCINTIGRAPHY

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ABSTRACT

Purpose of the study. Determining maximum possible number of high-quality radionuclide studies by days of the generator operation.
Materials and methods. We studied the factors influencing the capacity of radionuclide diagnostic tests in osteoscintigraphy (OSG) by days of service life of a ^{99m}Tc generator GT-4K. The OSG capacity, the required resource of ^{99m}Tc and its efficiency in OSG were calculated. The optimal days for the generator delivery were determined.
The Pirfotech ^{99m}Tc radiopharmaceutical (RFP) prepared with the generator was used for OSG.
Scanning, data collection and processing of results were carried out on gamma-cameras of the systems Signature Series, Symbia T16 Siemens, and syngo M1 Applications VB10 Siemens.
Parameters of the radioactivity of ^{99m}Tc were processed by mathematical methods using the Excel program.
Results. We revealed specific factors influencing the OSG capacity: 1) three-hour accumulation of RFP after its administration to the patient; 2) generator activity by days of its operation; 3) the day of the week of the generator delivery. We calculated quantitative indicators of the maximum possible OSG capacity during the generator operation (maximum number of OSG procedures by days of operation, total capacity, preferred day of the week for the generator delivery).
Conclusion. The most significant factors in optimal OSG planning by days of the generator operation are the generator specifications, quantity and frequency of generator supply, provision of gamma-cameras.
The described technique for scheduling diagnostic procedures can be useful for the efficient use of the generator system which ensures the maximum amount of high-quality RFP from the generator eluate and contributes to the objectification of the cancer process in order to choose the treatment tactics.

Keywords:
radionuclide research, osteoscintigraphy, generator ^{99m}Tc, radiopharmaceutical, OSG planning, pirfotech, capacity.

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ОРИГИНАЛЬНАЯ СТАТЬЯ

ОПТИМИЗАЦИЯ ПЛАНИРОВАНИЯ РАДИОНУКЛИДНЫХ ДИАГНОСТИЧЕСКИХ ИССЛЕДОВАНИЙ ПРИ ПРОВЕДЕНИИ ОСТЕОСЦИНТИГРАФИИ

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РЕЗЮМЕ

Цель исследования. Определение максимально возможного числа качественных радионуклидных исследований по дням срока эксплуатации генератора.
Материалы и методы. Для достижения поставленной цели изучались факторы, влияющие на пропускную способность радионуклидных диагностических исследований остеосцинтиграфии (ОСГ) по дням срока эксплуатации генератора ^{99m}Tc типа ГТ-4К (генератор). Рассчитывалась пропускная способность ОСГ, необходимый ресурс ^{99m}Tc и эффективность его использования при проведении ОСГ. Определялись оптимальные дни поставки генератора. Для проведения ОСГ применялся радиофармацевтический препарат «Пирфотех, ^{99m}Tc» (РФП), приготовление которого обеспечивалось с помощью генератора.
Сканирование, получение данных и обработка результатов осуществлялась на гамма-камерах систем e.cam Signature Series, Symbia T16 “Siemens, syngo M1 Applications VB10 “Siemens”.
Обработка показателей параметров радиоактивности ^{99m}Tc осуществлялась математическими методами с помощью программы Excel.
Результаты. Выделены специфические факторы, влияющие на пропускную способность ОСГ: 1) трехчасовое накопление РФП после введения его пациенту; 2) активность генератора по дням эксплуатации генератора; 3) день недели поставки генератора. Рассчитаны количественные показатели максимально возможной пропускной способности ОСГ в период эксплуатации генератора (максимальное число ОСГ по дням эксплуатации, суммарная пропускная способность, предпочтительный день недели поставки генератора).
Заключение. Наиболее значимыми факторами оптимального планирования ОСГ по дням срока эксплуатации генератора являются технические характеристики генератора, количество и периодичность поставки генератора, обеспеченность гамма-камерами.
Таким образом, описанная нами методика планирования проведения диагностических процедур может быть полезной для эффективного использования генераторной системы, что обеспечивает получение максимального количества качественных РФП из элюата генератора и способствует объективизации онкологического процесса с целью выбора тактики лечения.

Ключевые слова:
радионуклидные исследования, остеосцинтиграфия, генератор ^{99m}Tc, радиофармпрепарат, планирование ОСГ, пирфотех, пропускная способность.

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RELEVANCE

The examination of cancer patients is extremely complex, including radiation, endoscopic and various laboratory methods of investigation [1]. Modern diagnostics of metastatic lesions of the skeletal bones is of great importance for the choice of treatment and prognosis for many malignancies, such as: breast, prostate, thyroid, lung, kidney, stomach, esophagus, intestine [2–5]. Among the existing methods of radiological diagnosis of bone metastases, osteoscintigraphy (OSG) occupies a priority position [6].

OSG is a method of radionuclide diagnostics based on the introduction of a radiopharmaceutical (RPD) drug to the patient's body and subsequent registration of its distribution and accumulation in the skeleton using gamma-cameras. OSG is not only highly sensitive, but also allows scanning the entire skeleton, which is not possible with other more specific methods of examination (fig. 1).

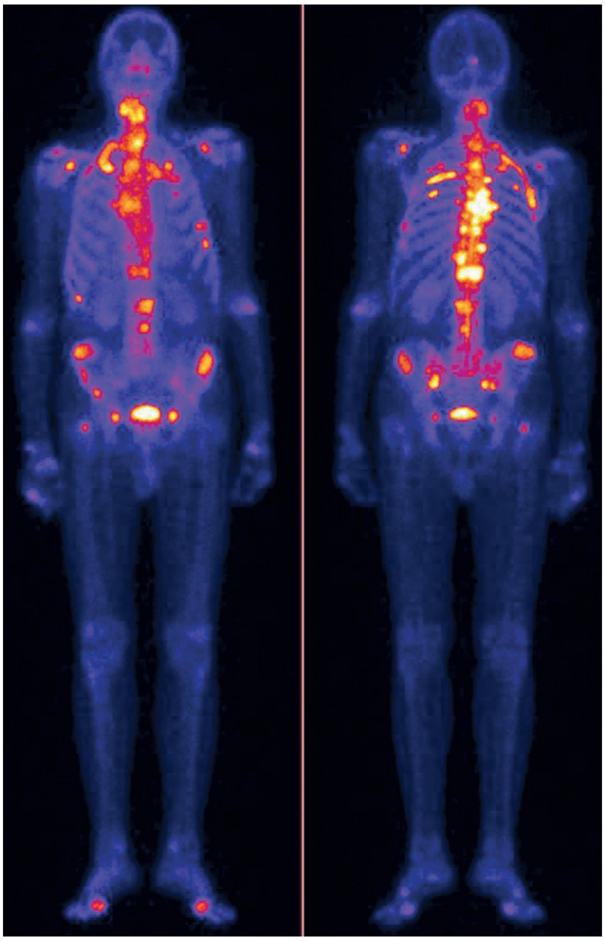

Fig. 1. Multiple foci of pathological hyperfixation of RF are detected on the osteoscintigram (osteoblastic metastatic lesion of skeletal bones in prostate cancer).

Spiral computed tomography is also used to diagnose bone metastases. Although highly specific, it does not provide early diagnosis of the lesion [7].

Emission tomography (osteoscintigraphy) of the whole body remains one of the most popular methods of radionuclide diagnostics. According to our data, OSG consistently accounts for more than 80% of the total number of radioisotope studies. So, in 2017, 2057 radionuclide studies were performed in the radioisotope laboratory with the ultrasound diagnostics group based on the National Medical Research Centre for Oncology of the Ministry of Health of Russia, of which 89% (1837) is skeletal emission tomography, in 2018, 2255 were performed, of which 86% (1928) is skeletal emission tomography, in 2019. 2394 were conducted, of which 88% (2110) were OSG. The quality of the received information and the throughput is affected by the activity of the RFP: increasing the activity, in order to reduce the scanning time to increase the throughput, increases the patient's dose load [6]. Reducing the activity, in order to increase the number of OSH (RFP is distributed to a larger number of patients), reduces the image quality, affects the reliability of the conclusion. The scan time indicator affects the quality of the information received, the throughput, and also depends on the patient's condition. The radioactivity factor of the RFP inevitably affects the planning of the OSG. In the presence of low RFP activity, it is impossible to plan a large number of OSG, because in such cases, technological capabilities will not be observed and the information obtained during scanning will be of poor quality; increasing the scan time reduces throughput.

The high demand for OSG requires optimization of research planning with the maximum use of the generator resource on the days of operation, taking into account the RFP activity indicator, the scan time.

The purpose of the study. To determine the most possible number of high-quality radionuclide studies by the days of the generator's service life.

MATERIALS AND METHODS

For conducting events an OSG was applied RFP "Pirfotech, ^{99m}Tc", cooking which one provided by using the generator ^{99m}Tc GT-4K type.

Generator set technetium-99m the GT-4K type represents is a device containing the sorbent is molybdenum-99 with a period half-life 66.02 hours in the form molybdenum ammonium $(NH_4)^-$ $(MoO_4)^+$ and destined for multiple use obtain sterile solution pertechnetate sodium with technetium-99m (eluate) [9].

Calculation General activity eluate (resource of the generator) as of the date of the event conducted by using the formula radioactive material maternal breakdown the isotope ^{99}Mo:

$A = A^0 * 2^{\wedge}(^{t/T}{}_{1/2})$,

where A – total activity eluate for the day t, GBk;

A_0 – activity starting point on delivery date by passport to the generator and the start time (8:00 h) operating conditions of the generator, GBk;

t – elapsed time after the start operating conditions of the generator for the day and time shift starts, one o'clock.;

$T_{1/2}$ – half-life molybdenum-99, equal to 66.02 hours.

Scheme radioactive materials transformations described by next one with the scheme:

^{99}Mo ($T_{1/2}$=66.02 h) → β-(86.3%) → ^{99m}Tc ($T_{1/2}$=6.01 h) → γ (140keV, 89.6%) → …

As a result beta-minus the decay is formed by new isotope – ^{99m}Tc with a period half-life 6.01 hours Maximum value activity ^{99m}Tc achieved byafter 23 hours, which provides possibility every day obtain the isotope ^{99m}Tc.

Activity radionuclide (radioactive substances) ^{99m}Tc evaluated derived form using the SI unit – Becquerel. In the calculations for amenities enjoyed a multiple of one gigabecquerel – GBk (1 GBk = 10^9 BC) [11].

Processing indicators OSG process was carried out using mathematical methods methods with using the program Excel.

OSG conducted by on gamma-cameras systems e.cam Signature Series, Symbia T16 "Siemens, syngo M1 Applications VB10 "Siemens" several timesstages.

Initial stage to patient intravenous enter the RFP, then, through 3 hours after introduction of the RFP, conducted by planar scanning full body study on average, it takes 20 minutes.

The final one this stage is used for archiving and a computer program processing received data results [10].

In calculations and in the future process analysis OSG we were systematized the following factors affecting on efficiency planning process, time of the event OSG and access card the ability of the process:

1) generator resource (volume activity received eluate 5–10 ml) the first one day of operation it is 11.59 GBk. Calculated by at the start time opening hours 8:00 from passport number values equal to 11.00 GBk as of date and delivery time 13:00;

2) total time for conducting a survey all OSG per shift compose 180 min. It turns out by subtracting out of time duration shifts (420 min) preparation time to be held OSG 30 min, time savings entered

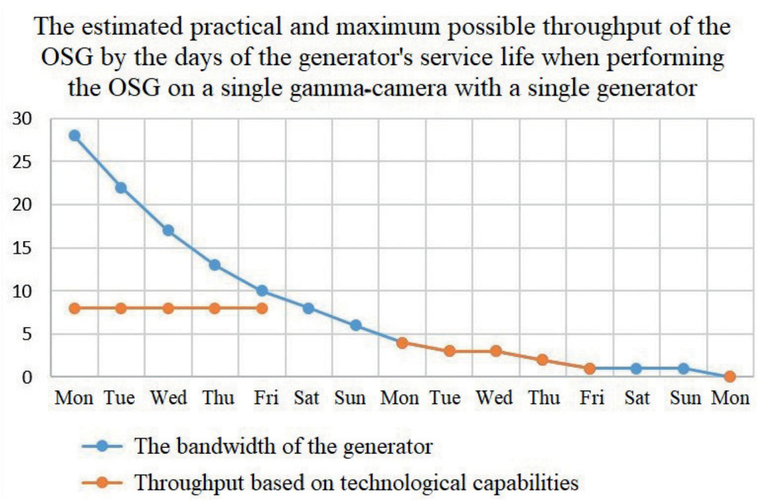

Fig. 2. Maximum throughput when conducting OSG on one gamma-camera and having one generator.

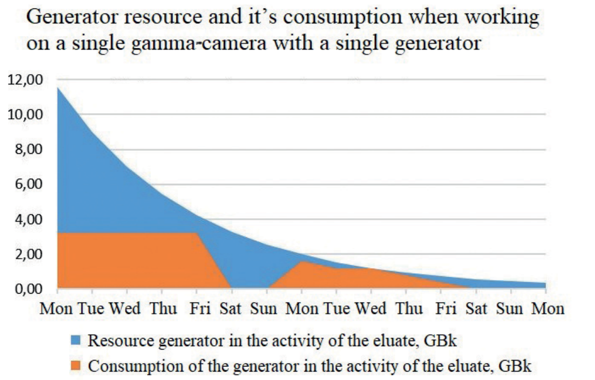

Fig. 3. The generator resource, in the activity (GBk) of the resulting eluate, by the days of its service life and its consumption, taking into account the technological capabilities when working on a single gamma-camera.

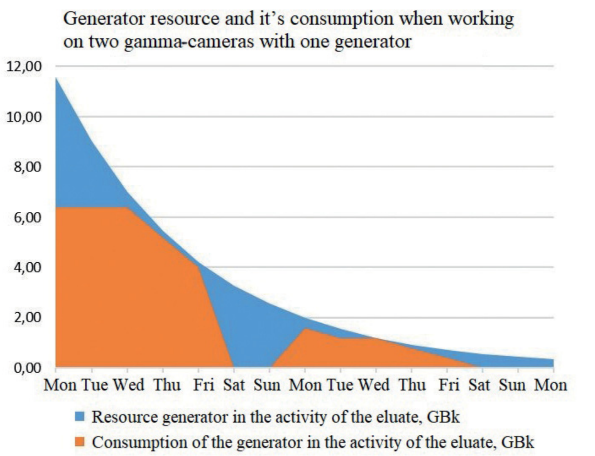

Fig. 4. The generator resource, in the activity of the resulting eluate, by the days of its service life and its consumption, taking into account the technological capabilities when working on two gamma-cameras with one generator.

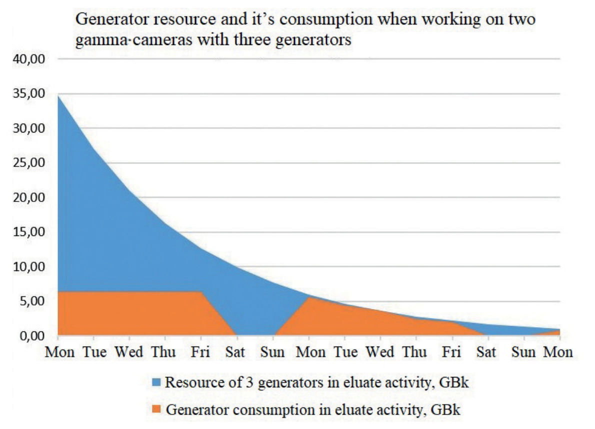

Fig. 5. Generator resource and its consumption when performing OSG on two gamma-cameras and simultaneously delivering three generators.

RFP for the patient 180 min and time complete run works on gamma-cameras in a shift of 30 minutes. 30-minute session preparation and completion works based on on technical sites and organizational issues events isotope analysis works ad blocks;

3) max. number of OSG in the change is equal to eight. It turns out by dividing the total OSG time per shift 180 min on average collection time data for one research – 22 min (adds up out of time installation/removal the patient and scan time (scan time with a height of 170 cm and speed scanning system that provides the optimal one the exhibition consists of about 17.5 min);

4) required information need the eluate for security features maximum value access point abilities for a change to 3.2 GBk. It turns out by multiplying-max. the number of OSG in change (8) to activity eluate for one research – 0.4 GBk (in accordance with The with instructions for medical purposes to use "of the drug Pirfotech, ^{99m}Tc",– 3–6 MBq per 1 kg weight, for an adult a patient with weighing 75 kg was accepted equal to 0.4 GBk);

Calculation max. the number of OSG in the shift was made for the following to the algorithm:

defined possible max. number of OSG on the site planned day 2 dividing values generator resource for this day and the start time works on the valueactivities the eluate for conducting events one of OSG (0,4 GBk). Then, we compared this value is with the maximum the number of OSG in a shift. Ifestimated value the meaning of OSG more than or if it is equal to 8, then for planned the value accepted – 8 if less 8, then the calculated value the value was rounded up down and received the value was accepted for what is planned the number of OSG. Calculation performed by all days of the deadlineoperating conditions the generator. Figure 2 shows results calculating the actual cost of access point abilities OSG taking into account technological solutions features in the comparison with the maximum access point ability to when using total resource generator, by expiration date operating conditions of the generator when you run OSG on the one gamma-camera with one generator.

The results of the calculations were tabulated, and graphs of the OSG process indicators were plotted. Numerical values and graphical construction were analyzed. The throughput of the possible

OSG for all days of the guaranteed life of the generator was determined as the sum of all calculated values for the specified period.

The dependence of the total throughput on the day of the week of generator delivery for the operational period was calculated similarly to the algorithm described above.

We considered the following options for the OSG process under the specified conditions:

1. One gamma-camera and one generator;
2. Two gamma-cameras and one generator;
3. Two gamma-cameras and three generators set at the same time.

All patients signed an informed consent to conduct the study before the study.

THE RESULTS OF THE RESEARCH AND THEIR DISCUSSION

Fig 3–5 shows the results of calculating the generator resource and the required eluate demand to ensure maximum throughput per shift, depending on the number of generators and gamma chambers used.

We see that in the first week of operation of the generator, the generator resource significantly exceeds the necessary eluate requirement to ensure maximum throughput during the OSG, the number of which is limited by the technological capabilities of the research process.

In the second week of the generator's life, the maximum possible throughput is limited only by the

Table 1. Indicators of the efficiency of the use of the generator during the OSG

Indicator	Unit of measurement	1 gamma-camera 1 generator	2 gamma-cameras 1 generator	2 gamma-cameras 3 generator
The resource of the generator in the activity of the resulting eluate				
Generator resource for all days of the service life	GBk	50.86	50.86	152.58
Generator resource in the first five working days of the service life	GBk	37.28	37.28	111.85
Generator resource from 8 to 15 days of operation (only for working days)	GBk	6.73	6.73	20.19
The needs of the eluate to ensure the highest possible bandwidth when performing OSG				
The need for eluate for conducting OSG for all days of the service life	GBk	21.20	33.60	50.80
Maximum eluate requirement for OSG in the first five working days	GBk	16.00	28.40	32.00
Eluate requirement for OSG from the 8th to the 15th day of operation (only on working days)	GBk	5.2	5.20	18.80
Throughput during OSG, taking into account technological capabilities				
The maximum possible number of OSG for all working days of the generator's service life	Unit	53	84	127
The maximum possible number of OSGS for the first five working days	Unit	40	71	80
The maximum possible number of OSG from 8 to 15 days of operation (only on working days)	Unit	13	13	47
The indicators of efficiency of the eluate				
The proportion of eluate to ensure maximum throughput over all days of the life of the generator over the same period	%	41.68	66.07	33.27
The proportion of the eluate to ensure maximum throughput for the first five days of the life of the generator over the same period	%	42.92	76.18	28.61
The proportion of eluate to ensure maximum throughput from 8 to 15 days of the service life of the generator resource for the same period	%	77.26	77.26	93.11

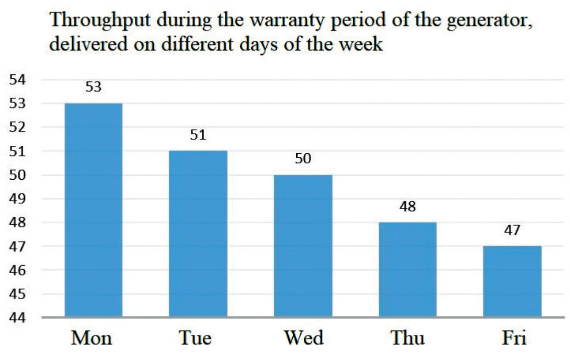

Fig. 6. The total throughput during OSG on one gamma-camera, depending on the day of the week of delivery of one generator for a five-day working week.

generator's activity on the day of the study, which decreases non-linearly with each subsequent day.

The table 1 shows the quantitative indicators of the generator resource by the days of the service life, the capacity of the OSG, taking into account the technological capabilities and the need for eluate to ensure the maximum possible capacity during the OSG with various combinations of generator supplies.

Thus, the entire life of the generator has two periods:

a) the period with the maximum possible throughput;

b) the period of limited possibility of conducting the OSG.

We found that the maximum number of possible OSG (127) is performed in the presence of two gamma chambers and three generators, and according to the scheme 1 gamma-cameras – 1 generator is the minimum possible (53), but at the same time the efficiency of using the capabilities of the generator (s) is different:

1. The maximum efficiency of using the eluate (generator resource) is shown when working according to the scheme 2 gamma-cameras – 1 generator (66.07%); the minimum – according to the scheme 2 gamma-cameras – 3 generators (33.27%);

2. The maximum throughput can be provided when working according to the scheme 2 gamma-cameras – 3 generators (127); the minimum – according to the scheme 1 gamma-cameras – 1 generator (53);

The total estimated capacity of one generator for the period of operation (including weekends) was 119 OSG; the total number of OSG, taking into account technological capabilities, was 53 OSG. The resource of a single generator is sufficient to provide 2.2 times more OSG research than the actual throughput capabilities of a single gamma-camera.

The analysis shows that in the first week, the generator's resource in eluate activity significantly exceeds the needs of one gamma-camera when working with one generator: the total resource of the generator for the entire period of operation (including weekends) is 50.58 GBk, and the need for eluate is 21.20 GBk, which is 41.68% of the total resource of the generator.

All the figures show that in the second working week, the generator resource is used most efficiently.

The throughput dependence during the OSG depends on the day of the delivery week. The optimal day for the generator delivery and the start date of the OSG is Monday. Figure 6 shows the analysis of the capacity for the warranty period of the generator (15 days), when delivered on different days of the week.

CONCLUSION

The most significant factors of optimal OSG planning for the days of the generator's service life are the technical characteristics of the generator, the number and frequency of generator delivery, and the availability of gamma-cameras.

Thus, the method of planning diagnostic procedures described by us can be useful for the effective use of the generator system, which ensures the maximum amount of high-quality RFP from the generator eluate and contributes to the objectification of the oncological process in order to choose treatment tactics.

Authors contribution:

Maksimova N.A. – scientific editing, general guidance, research concept.
Karpun V.G. – collection, analysis and interpretation of data, article preparation.
Arzamastseva M.A. – collecting material during OSG, preparation of illustrations.
Ilchenko M.G. – collection of material for OSG, technical editing, article preparation.
Shlyk O.S. – collection of material for OSG, bibliography writing.

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