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Determination of Optimum Imaging Numbers for ^{177}Lu-PSMA Radionuclide Treatment Dosimetric Calculation

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ABSTRACT

Introduction: Lutetium-177 (^{177}Lu) prostate-specific membrane antigen (PSMA) was first applied for treating castration-resistant prostate cancer (CRPC) in 2015, and PSA changes, low side effects, and good responses have been reported in the literature. Dosimetric calculations are required to determine the optimum number of treatments and prevent damage to critical organs. The aim of this study was to retrospectively investigate the feasibility of dosimetric calculations with fewer than four scans and to determine the most optimum imaging hours if dosimetric calculations can be performed with fewer than four scans.

Methods: Whole body and single-photon emission computed tomography/computed tomography scans (4th hour, 24th hour, 48th hour and 96th hour) were performed on the patients after ^{177}Lu-PSMA infusion. A comparison was made between doses calculated using four images, doses calculated using three images, and doses calculated using two images. The calculations were repeated with four images in nine configurations: 1st, 2nd, 3rd and 4th. Scan configurations were classified as C1-C9. C1 was accepted as the reference and evaluated statistically for significance research between other groups.

Results: For an amount of ^{177}Lu-PSMA activity of 3.7 GBq (100 mCi) per treatment, the mean kidney doses for C1, C2, C3, C4, C4, C5, C6, C7, C8, and C9 were calculated as 1.8±0.54 Gy, 1.83±0.57 Gy, 1.7±0.47 Gy, 1.91±0.57 Gy, 1.82±0.54 Gy, 1.59±0.47 Gy, 1.90±0.58 Gy, 1.82±0.57 Gy and 1.75±0.52 Gy, respectively. A significant difference was found in all groups among C2-C9 compared to C1.

Conclusion: Optimum dosimetric calculations for treating CRPC should be performed with C5 (three images taken at the 4th, 24th and 48th hours) after ^{177}Lu-PSMA injection. The error rate increases in calculations performed with a lower number of images.

Keywords: Castration-resistant prostate cancer, ^{177}Lu-PSMA, dosimetry, imaging time, imaging number

Introduction

Prostate cancer is one of the most common malignancies in the world and the third most common cause of cancer-related male death in the United States of America (USA) (1). Lutetium-177 (^{177}Lu) prostate-specific membrane antigen (PSMA) radioligand treatment has been applied in castration-resistant prostate cancer (CRPC) with high efficacy and low side effects (2-4). In line with these results, ^{177}Lu-PSMA treatment has been increasingly used. In radionuclide therapy, there are limiting organ radiation doses for treatment, depending on the retention and excretion mechanism of the radiopharmaceutical. The kidneys are among the most important radiation- limiting organs, especially in treatments performed through systemic circulation, called peptide receptor radionuclide therapy. The radiation-limiting organs for treating ^{177}Lu-PSMA are the kidneys, bone marrow, salivary glands, and lacrimal glands (5). Dosimetric calculation in radionuclide treatments is important to apply the therapeutic dose without damaging critical organs. Many dosimetry studies have suggested that dosimetric calculations should be performed for each patient individually after each treatment because the physiology of patients may differ (6,7). In addition, according to the European Atomic Energy Community guidelines, making dosimetric calculations for patients receiving radionuclide therapy have been required since February 2018 (8). The dosimetry formalism of Medical Internal Radiation Dose (MIRD), recommended in the dosimetry guidelines of the European Association of Nuclear Medicine, is used for dosimetric calculations in radionuclide treatments (5).

Accurate calculation of the activity in the organ is critical for the accuracy of the dosimetric calculation. For accurate dosimetric calculations in ^{177}Lu treatments, many scientific studies have been conducted and guidelines have been published (5,9-12). Factors affecting dosimetric accuracy include the calibration of the dose calibrator, determination of the calibration factor, imaging modality, attenuation correction, scatter correction, and imaging time (5,13). Current guidelines do not recommend specific time points but emphasize the need for imaging at different time points because of slow radiopharmaceutical excretion (5,9). Although dosimetric accuracy increases in direct proportion to the number of imaging scans after treatment, scientific studies have

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emphasized that dosimetric calculations should be performed by scanning at four different time points after treatment (14). Whole body (WB) and single photon emission tomography (SPECT)/computed tomography (CT) imaging for dosimetric calculation takes about 30 minutes. In clinics where treatment is frequent, this poses problems in terms of the number of patient views, patient comfort, and clinical density. Although obtaining the correct result of dosimetric calculations is the top priority for radionuclide treatments, applicability is also an important factor. Coming to the clinic for scanning emerges as a problem for both the patient and the clinic. Accordingly, dosimetric calculations for CRPC treatment dosimeters are usually performed with 4-5 images (15,16). In addition, recent scientific studies have declared that dosimetric calculations can be performed with one, two, and three images in CRPC treatments (17-19). However, it has been emphasized that as the number of scans decreases, the deviation also increases.

The aim of this study was to retrospectively investigate the feasibility of dosimetric calculations with fewer than four scans and to determine the most optimum imaging hours if dosimetric calculations can be performed with fewer than four scans.

Methods

The collection of human samples in this study was approved by the Ethics Committee of İstanbul University, İstanbul Faculty of Medicine (approval number: 2023/558, date: 06.04.2023).

^{177}Lu Radioisotope

The most commonly used radionuclide in CRPC fractional radionuclide treatments is ^{177}Lu. ^{177}Lu has a half-life of 6.64 days. The decayed ^{177}Lu turns into stable halfium-177 (^{177}Hf). During the decay of ^{177}Lu, while emitting beta particles with energy, which have an abundance of 78% ($E_{\beta max}$=497 keV), 9.8% ($E_{\beta max}$=384 keV), 12% ($E_{\beta max}$=176 keV), and 0.053% ($E_{\beta max}$=248 keV), it decays to ^{177}Hf, emitting photons at 6 different energies as well as two gamma rays with an abundance of 11% (208.4 keV) and 6.4%, 112.9 keV. While beta particles cause cancer cells to die, gamma photonsprovide imaging for dosimetric calculations.

Treatment Application

Clinical evaluations, biochemistry, and gallium-68 (^{68}Ga)-PSMA positron emission tomography/CT examinations of patients diagnosed with CRPC were performed. Patients with high ^{68}Ga-PSMA accumulation in tumor areas were considered suitable for radionuclide treatment and were treated. Patients received 7.55±0.3 GBq (204±8.34 mCi) ^{177}Lu-PSMA per treatment by intravenous infusion for 30 min. WB and SPECT/CT scans (4th, 24th, 48th, and 96th hours) were performed on patients after the infusion.

MIRD Formalism

Dosimetric calculations were performed using the MIRD method. In MIRD Formalism, Formula 1 is used to calculate the dose absorbed by the organs (20).

$$D_{Target \leftarrow Source} = \frac{k \times \tilde{A}_{Source} \sum_i n_i E_i \varphi_i}{m_i} \quad (1)$$

D: Dose absorbed in the target organ-gray (Gy)

Ã: Cumulative activity in a source organ-mega becquerel/second (MBq-s)

n: Ratio of radiation released at energy E per nuclear decay

E: Energy per radiation-mega electron volt (MeV)

ϕ: Absorption rate of the radiation energy released from the source at the target

m: Mass of the target organ (kg)

k: Proportion constant (Gy-kg/MBq-s-MeV)

For the isotopes of all radionuclides, the energy transferred from the source organ to the target organ was calculated using human-like phantoms, and nearby values called the S-factor were determined to calculate the dose absorbed by the target organ. After detecting the cumulative activity in the source organ, the dosage absorbed by the target organ is calculated using Formula 2 (20).

$$D_{Target \leftarrow Source} = S \times \tilde{A} \quad (2)$$

To determine the cumulative activity in the source organ, imaging is performed at different time points depending on the physical and biological half-life of the radionuclide. Based on the images acquired from the patient, the activity in the source organ was calculated. The cumulative activity in the source organ is calculated using Formula 3 for the activities in the source organs calculated at different time points.

$$\tilde{A} = \int_0^\infty A(t)dt \quad (3)$$

Imaging

The study included a total of 30 treatments of 30 patients (62±8 years) diagnosed with CRPC who received ^{177}Lu-PSMA treatment in our clinic. After each treatment, 4 images were analyzed (1st scanning: at 4th hour, 2nd scanning: at 24th hour, 3rd scanning: at 48th hour, and 4th scanning: at 96th hour), and a total of 120 images were analyzed. Imagines were performed using the General Electric brand Discovery NM/CT 670 model SPECT/CT (General Electric, Milwaukee, WI, USA) machine in our clinic. A Medium Energy General Purpose collimator was used for imaging. SPECT imaging was performed in the position in which the patient's abdomen and thorax region would enter the image field. SPECT imaging was performed with 360° imaging using a 128x128 matrix, 60 projections, and 20 s per projection parameter. In addition to the primary peak in the window range of 208 keV (±10%), the scattering peak in the window range of 178 keV (±5%) was used in the scatter correction process. An ordered-subset expectation maximization algorithm with 12 iterations, 5 subsets, and no postprocessing filter was used for image reconstruction. WB images were obtained at a scanning speed of 15 cm/min and with an energy window of 208 keV (±10%). From the acquired raw data, 3D scattering and reduction-corrected images were created.

Image Analysis

The software OXIRIX (Geneva, Switzerland) was used for image analysis. 3D volume of interest of organs holding activity were drawn from SPECT images, and organ counts were determined. For the rest of the body, counts were determined by drawing regions of interest from the

geometric means of the WB anterior and posterior images. The acquired counts were divided by the count/activity factor to determine the ^{177}Lu activities in the relevant organs and regions. These procedures were performed separately for the four post-treatment images of the patient.

Calculation of Organ Doses

Cumulative activities were calculated by entering the post-treatment organ activities and scan times using Formula 3. Radiation doses absorbed by the kidneys, liver, and WB were estimated using the calculated cumulative activities and Olinda/EXM 1.1 software. Calculations were repeated with four images in nine configurations as follows: 1., 2., 3., and 4. scans configuration 1 (C1); 2., 3., and 4. scans configuration 2 (C2); 1., 3., and 4. scans configuration 3 (C3); 1., 2., and 4. scans configuration 4 (C4); 1., 2., and 3. scan configuration 5 (C5); 1. and 4. scan configuration 6 (C6); 2. and 3. scan configuration 7 (C7); 2. and 4. scan configuration 8 (C8); and 3. and 4. scan configuration 9 (C9). The organ doses obtained were compared with the results of four imaging studies. A correlation test was performed between the values.

Statistical Analysis

IBM SPSS Statistics for Windows, Version 24.0 (IBM Corp., Armonk, NY, USA) was used for statistical analysis. The pearson correlation test was used to analyze the relationship between C1 and C2-C9. The p-value was considered statistically significant when less than 0.05.

Results

For an amount of ^{177}Lu-PSMA activity of 3.7 GBq (100 mCi) per treatment, the mean kidney doses for C1, C2, C3, C4, C4, C5, C6, C7, C8, and C9 were calculated as 1.8±0.54 Gy, 1.83±0.57 Gy, 1.7±0.47 Gy, 1.91±0.57 Gy, 1.82±0.54 Gy, 1.59±0.47 Gy, 1.90±0.58 Gy, 1.82±0.57 Gy and 1.75±0.52 Gy, respectively. A significant difference was found in all groups among C2-C9 compared to C1. The kidney dose per 3.7 GBq (100 mCi) ^{177}Lu-PSMA calculated in different configurations for the kidneys is given in Table 1.

Table 1. Results of kidney doses per 3.7 GBq (100 mCi) ^{177}Lu-PSMA in different configurations (Gy)

Treatment no	C1	C2	C3	C4	C5	C6	C7	C8	C9
1	1.59	2.13	1.42	2.09	1.83	1.27	2.12	2.14	1.52
2	1.95	1.97	1.92	2.15	1.78	1.97	2.14	1.69	0.80
3	1.70	1.19	2.08	1.62	1.70	1.04	1.22	1.19	2.73
4	1.33	1.39	1.13	1.39	1.24	0.85	1.39	1.43	1.34
5	1.83	1.86	1.67	1.86	1.93	1.84	1.86	1.86	1.52
6	2.63	2.63	2.47	2.71	2.74	2.49	2.71	2.59	2.41
7	2.59	2.72	2.28	2.73	2.64	1.74	2.75	2.73	2.35
8	2.12	2.13	1.98	2.26	2.16	1.92	2.26	2.06	1.92
9	1.46	1.46	1.38	1.57	1.44	1.31	1.57	1.40	1.49
10	1.49	1.48	1.43	1.48	1.59	1.46	1.50	1.48	1.38
11	1.94	1.94	1.99	1.95	1.91	1.92	1.98	1.94	2.04
12	1.55	1.55	1.45	1.65	1.52	1.36	1.65	1.50	1.75
13	1.65	1.67	1.59	1.76	1.65	1.50	1.77	1.65	1.71
14	3.10	3.09	2.70	3.23	3.00	2.57	3.22	3.01	2.82
15	3.11	3.11	2.67	3.36	3.03	2.50	3.29	3.16	2.84
16	1.99	2.13	1.95	2.26	2.11	1.84	2.26	2.13	2.08
17	1.40	1.40	1.36	1.51	1.35	1.27	1.51	1.34	1.50
18	1.31	1.30	1.21	1.34	1.44	1.25	1.34	1.27	1.15
19	1.70	1.71	1.57	1.82	1.74	1.52	1.82	1.67	1.61
20	1.38	1.38	1.38	1.45	1.35	1.29	1.45	1.34	1.51
21	1.75	1.75	1.76	1.58	1.95	2.09	1.49	2.21	1.48
22	1.39	1.39	1.33	1.50	1.37	1.21	1.50	1.38	1.47
23	1.07	1.08	0.99	1.16	1.06	1.00	1.15	1.07	1.07
24	0.93	0.94	0.90	1.02	0.91	0.76	1.04	0.94	1.09
25	1.84	1.87	1.67	1.87	1.94	1.85	1.87	1.87	1.53
26	1.45	1.47	1.39	1.58	1.45	1.32	1.58	1.42	1.50
27	1.53	1.53	1.43	1.63	1.50	1.34	1.63	1.48	1.73
28	2.01	2.15	1.97	2.28	2.13	1.86	2.28	2.15	2.10
29	2.58	2.71	2.27	2.72	2.64	1.73	2.74	2.72	2.34
30	1.66	1.68	1.60	1.77	1.66	1.51	1.78	1.66	1.72
Average ± SD	1.80±0.54	1.83±0.57	1.70±0.47	1.91±0.57	1.82±0.54	1.59±0.47	1.90±0.58	1.82±0.57	1.75±0.52

^{177}Lu: Lutetium, PSMA: Prostate-specific membrane antigen, Gy: Gray, SD: Standard deviation

In addition to Table 1, the mean and standard deviations (SD) of the patients' liver and WB doses were calculated as follows:

For an amount of ^{177}Lu-PSMA activity of 3.7 GBq (100 mCi) per treatment, the mean liver doses for C1, C2, C3, C4, C4, C5, C6, C7, C8 and C9 were calculated as 0.3±0.13 Gy, 0.31±0.14 Gy, 0.35±0.23 Gy, 0.32±0.16 Gy, 0.3±0.13 Gy, 0.23±0.12 Gy, 0.32±0.15 Gy, 0.31±0.14 Gy and 0.36±0.12 Gy respectively.

For an amount of ^{177}Lu-PSMA activity of 3.7 GBq (100 mCi) per treatment, the mean WB doses for C1, C2, C3, C4, C4, C5, C6, C7, C8 and C9 were calculated as 0.1±0.04 Gy, 0.1±0.04 Gy, 0.11±0.06 Gy, 0.09±0.04 Gy, 0.09±0.05 Gy, 0.1±0.04 Gy, 0.1±0.05 Gy, 0.1±0.05 Gy and 0.12±0.04 Gy respectively.

According to the pearson correlation test between C1 and other configurations, the averages of kidneys, liver, and WB were calculated as 0.936±0.06, 0.895±0.20, 0.909±0.21, respectively.

Discussion

Kidney doses were one of the main limiting factors for the cumulative treatment of ^{177}Lu-PSMA radioligands. Thus, we aimed to determine optimum imaging times with minimum scans for accurate kidney doses and compared different time points. Briefly, we found that three time points could give accurate dosimetric results, but dosimetric calculation with two time points may result in inaccurate results. We observed significant differences in patient kidney doses, and these differences were at a level that would affect the number of patient treatments. Because there are differences that will affect patient treatment, it is important to perform patient-specific dosimetric calculations in treatments. There are some difficulties in performing dosimetric calculations. Considering the burden that patient screening brings to the clinic, as well as the general condition of the patient population, transferring the patient to the clinic also poses a significant problem. Although these reasons are problematic aspects of dosimetric calculations, it is important to perform dosimetric calculations in terms of patient treatment effectiveness and patient safety. Although having less data to be used in dosimetric calculations is beneficial in terms of patient comfort and clinical intensity, it is more important to make the correct calculation. Although it is every clinic's dream to make accurate dosimetric calculations with low scanning, decreasing data may cause problems in calculations. When determining cumulative activity, the more measurement points considered in creating thetime activity curve, the closer the result is to reality. Therefore, the values obtained from the four images (4th, 24th, 48th, and 96th hour after treatment) were evaluated and compared with the results of the dosimetric calculation using different time configurations.

When it comes to kidney doses, which stand out as the critical organ in radioligand treatment due to the excretion mechanism; it was observed that there was a correlation between C1 configuration dose values and all configurations ($p<0.05$). Considering these results, it is seen that accurate dosimetric calculations can be made with three images taken from the patients. In the calculations made using three images, the highest correlation was calculated using the C5 (4th, 24th and 48th hour images). In this group, a difference of >10% was calculated in 2 patients, a difference between 5% and 10% in 8 patients, and the remaining values were calculated as <5%, also when looking at the SD values, the lowest deviation value was observed in the C5 configuration (Table 2). After C5, the highest correlation was found to be with C4. The reason for this is that both configurations have early post-injection images. When looking at other configurations, it was observed that the SD values increased. When looking at the two-image configurations, C8 was seen to have the highest correlation (0.961) and lowest SD (0.027). The reason why the highest correlation was with C5 was interpreted as the change in activity in the kidneys within 24 h after treatment was applied (21). Because the excretion rate was considered infinite in the period following the peak of activity retention, it was thought that measurements taken at a later time did not significantly affect our results.

The excretions of pharmaceuticals used in neuroendocrine tumor and CRPC treatments are different. Although many studies have investigated the dosimetric accuracy in neuroendocrine tumor treatments with ^{177}Lu compounds, there are few studies with low patient data in CRPC treatments (17-19). Although there are articles stating that two images are sufficient for kidney dosimetry, there are studies showing that two images have a high deviation rate and are not sufficient for other organ and tumor dosimetry. In their study of 20 treatments of 10 patients, Peters et al. (17) investigated the optimum imaging number for kidney and tumor dosimetry. They suggested that dosimetric calculations could be performed with two images in the first 24 h and the 168th hour. In the study conducted by Resch et al. (18) with the treatment of five patients, they suggested that lesion dosimetry should be performed on the 1st, 3rd, and 7th days, and that the most optimum imaging for kidney dosimetry should be performed on the 1st, 2nd, and 3rd days.

In their study with 13 patient treatments and the virtual patient lesion they created, Rinscheid et al. (19) suggested that three images were required for optimal tumor dosimetry. It has been emphasized in all studies that error rates increase as the number of images decreases. In the study conducted by Gleisner et al. (22) with 7 patients, they made calculations using images taken 1, 24, 96 and 168 hours after radionuclide application in ^{177}Lu/^{177m}Lu-DOTATATE treatment and taken between 33-70 days (5 images in total). They reported that there were 5-6% differences in the tumor dose and WB dose calculations made

Table 2. Pearson correlation test results for kidney dose calculation configurations

Kidneys correlations									
		C2	**C3**	**C4**	**C5**	**C6**	**C7**	**C8**	**C9**
C1	Pearson correlation	0.967**	0.967**	0.980**	0.986**	0.806**	0.949**	0.961**	0.874**
	Sig. (2-tailed)	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
	n	30	30	30	30	30	30	30	30

**: Correlation is significant at the 0.01 level (2-tailed)

with and without the late image (33-70 day image), but there was no difference in the kidney dose (22). In this study, it was emphasized that late imaging was unnecessary for kidney dose calculation, but dose calculations with fewer images were not considered. As stated in the study, the limited number of patients may pose a statistical problem.

The main purpose of our study was to determine whether we can obtain the most accurate radiation dose with the least amount of imaging. In the statistical analysis, it was determined that the post-treatment C1 configuration for kidney doses was highly correlated with the values of C7 and C8 configurations calculated from two images. The difference between the C1 and C8 configurations was >10% in 6 patients, 5-10% difference in 15 patients, and the remaining values were <5%. The difference between the C1 and C7 configurations was calculated as >10% in 4 patients, and the difference between 5% and 10% in 6 patients, and the remaining values were <5%. The average percentage difference between the C1 and C7 configurations was calculated to be 5.86% (8.82). Similar to our study, Maaß et al. (23), based on the results of their study with 15 patients, reported that kidney doses could be calculated with scans performed at the 4th and 48th h. Although it has been seen in both studies that dosimetric calculations can be made using two images, there are differences between the scanning times of the studies. While their patient group comprised patients who received ^{111}In-labeled-diethylenetriaminopentaacetic acid-octreotide for the treatment of neuroendocrine tumors, our patient group comprised patients diagnosed with CRPC who received ^{177}Lu-PSMA. The different retention and excretion mechanisms of both radiopharmaceuticals may affect the pharmacokinetics in organs and therefore the scanning times. In a study conducted by Guerriero et al. (24) with a method similar to ours, with 28 patients receiving ^{177}Lu/90 Y-DOTATATE treatment, early post-treatment imaging significantly affected the dose results. They stated that the first four days of data for ^{177}Lu are important for the accuracy of the results. They calculated that late image data changes the results by 5%. Although different pharmaceuticals are used, renal retention appears to be similar (24).

When looking at WB values; it was determined that there were differences between the C1 configuration dose values and the C4 configuration dose values (p=0.267). There was a high correlation between C1 configuration and C2 (0.999), C5 (0.997), C7 (0.997), and C8 (0.991) had the value respectively (Table 3).

When looking at liver values; it was determined that there was a difference between the C1 configuration dose values and the C4 configuration dose values (p=0.232). There was a high correlation between C1 configuration and C2 (0.999), C3 (0.994), C5 (0.991), and C7 (0.996) had the value, respectively (Table 4). Although the liver is not a critical organ in terms of radiation toxicity, it affects the results when the liver is considered as the source organ.

In dosimetric calculations, the dose absorbed by an organ, the activity within the organ itself, and the dose absorption due to activity in other organs are considered. Maaß et al. (23) In his study, only the activity change in the kidney was examined, and the contribution of the activity change in other organs to the kidney was not considered. In the present study, we determined the scanning time, and the effect of activity in other organs, as well as activity in the kidney, was also included in the calculation. Therefore, in our study, the total dose absorbed by the kidney was calculated. The main purpose in determining effective scanning hours for dosimetric calculation is the total dose absorbed by the kidney.

Considering these values, results closest to the values obtained with four scans can be obtained for kidney doses with scans performed at the 4th, 24th, and 48th h after treatment. Although current guidance for ^{177}Lu-PSMA treatment recommends that the late time point should be performed at least 4-7 days later, in our study, we found the 4th, 24th, and 48th scan times to be the optimum scan times.

Study Limitations

Conducting this study with more frequent patient data and imaging at the 240th hour after treatment for clearer detection of excretion may enable error rates to be determined more clearly. Since the study was retrospective, it was conducted with four images up to the 96th hour.

Table 3. Pearson correlation test statistical analysis results of whole body dose calculation configurations

Whole body correlations

		C2	C3	C4	C5	C6	C7	C8	C9
C1	Pearson correlation	0.999**	0.909**	0.389	0.997**	0.996**	0.997**	0.991**	0.972**
	Sig. (2-tailed)	<0.001	<0.001	0.267	<0.001	<0.001	<0.001	<0.001	<0.001
	n	30	30	30	30	30	30	30	30

**: Correlation is significant at the 0.01 level (2-tailed)

Table 4. Pearson correlation test statistical analysis results of liver dose calculation configurations

Liver correlations

		C2	C3	C4	C5	C6	C7	C8	C9
C1	Pearson correlation	0.993**	0.994**	0.416	0.991**	0.944**	0.996**	0.922**	0.906**
	Sig. (2-tailed)	<0.001	<0.001	0.232	<0.001	<0.001	<0.001	<0.001	<0.001
	n	30	30	30	30	30	30	30	30

**: Correlation is significant at the 0.01 level (2-tailed)

Conclusion

It was observed that three imaging sessions after CRPC treatment would be sufficient for optimal dosimetric calculation. Taking the images at the 4th, 24th, and 48th hours or 4th, 24th, and 96th hours after the injection showed that the deviation would be at the lowest rate compared to four scans.

Ethics Committee Approval: The collection of human samples in this study was approved by the Ethics Committee of İstanbul University, İstanbul Faculty of Medicine (approval number: 2023/558, date: 06.04.2023).

Informed Consent: Retrospective study.

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