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PET/CT Patient Dosage Assay

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***Abstract*—**A Positron Emission Tomography (PET) is a radioisotope imaging technique that illustrates the organs and the metabolisms of the human body. This technique is based on the simultaneous detection of 511 keV annihilation photons, annihilated as a result of electrons annihilating positrons that radiate from positron-emitting radioisotopes that enter biological active molecules in the body. This study was conducted on ten patients in an effort to conduct patient-related experimental studies. Dosage monitoring for the bladder, which was the organ that received the highest dose during PET applications, was conducted for 24 hours. Assessment based on measuring urination activities after injecting patients was also a part of this study. The MIRD method was used to conduct dosage calculations for results obtained from experimental studies. Results obtained experimentally and theoretically were assessed comparatively.

***Keywords*—**PET/CT, TLD, MIRD, Dose measurement, Patient doses.

I. Introduction

POSITRON Emission Tomography (PET) is a radioisotope imaging technique that has started to be used more commonly in recent years. Its imaging principle is using the simultaneous detection of two 511 keV annihilation photons that arise in conclusion of positron-electron annihilation [1]. In practice, the glucose molecules of positron-emitting radioisotopes such as ^{11}C, ^{13}N, ^{15}O, and ^{18}F, together with the radiopharmaceuticals obtained as a result of combining are given to the patients through their blood. The PET device detects the 511 keV photons emitted from the radiopharmaceutical cumulating in the abnormal structures of the body, and produces three-dimensional body images on the computer [2].

Fluorine-18 Fluorodeoxyglucose (F-18 FDG) is the most frequently used radiopharmaceutical in PET imaging. After injecting, due to its high radioactive content, the F-18 that accumulated in the bladder causes the radiation dose to increase by irradiating the bladder and its membrane. The Fluorine-18 excreted from the body through urination causes external irradiation where it is passed [3].

As PET becomes a more commonly used method, it is inevitable that the radiation dose the patients are exposed to and the compliance of this dose with standards should be determined [4], [5].

The purpose of this study was to designate and assess the dosage in patients during PET applications, a state of the art nuclear medicine diagnosis technique. Important was placed on monitoring the bladder dosage in particular, as it was the organ that received the highest dose during PET applications [6]-[8].

II. Materials and Methods

All PET-related studies were conducted at the PET/CT centre at the Department of Nuclear Medicine at Istanbul University Cerrahpaşa Faculty of Medicine. Experimental studies were conducted on patients even though conducting experimental studies on patients is extremely difficult [9]. The bladder dose of 10 patients was monitored for 24 hours by placing TLD dosimeters in patients undergoing PET applications.

In addition, the urination activities of these ten patients were also determined. Activity monitoring was conducted for a near six hours after the FDG injection. As well as being the most important time frame during dose intake, it also expresses a period that exceeds 3 half-lives of the F-18 radioisotope.

T-100 powder TLDs were used to measure the absorbed dose. The TLDs used were prepared using Cs-137 calibrated at the Turkish Atomic Energy Authority (TAEA) - Çekmece Nuclear Research and Training Centre (CNRTC) SSDL (Secondary Standard Dosimetry Laboratory).

Patients that applied to the PET unit at the Department of Nuclear Medicine at Istanbul University Cerrahpaşa Faculty of Medicine for patient dose determination (with an Ethic Report) were injected with 14.1 mCi (522 MBq) F-18 FDG intravenously in accordance with the PET imaging protocol.

The TLD's placed on the patients were not removed during CT applications in order to calculate the PET/CT dosages. Therefore, the doses received from PET and CT will be taken into consideration together. Conducted experiments carry grave importance in terms of the radiation dose patients are exposed to as the majority of PET devices produced nowadays, are produced combined with CT devices.

Two methods were used in this study. In Group 1, the bladder dosage of 10 patients was monitored. TLDs were placed on the bladders of patients, and removed at the end of 24 hours for assessment in order to achieve this purpose.

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In Group 2, the urine activity of 10 patients was monitored. Patients were left to rest in a special waiting room after being injected, and asked to empty their bladders before their first tomography. 6 urine samples were taken 6 hours after PET/CT in order to monitor their urine.

The volume of the urine samples were measured, 10mL samples were taken and placed in test tubes, and the F-18 FDG radioactivity they created in the dose calibrator was identified.

The activity amount (urine activity concentration) per ml and the activity amounts involved in the total urine volume were measured. The below stated equation was used to calculate these amounts.

$$A_{id} = (A_n / V_n) V_{id} \quad (1)$$

where; A_{id} is the Total Urine Activity, A_n is the sample urine activity, V_n is the sample urine volume, and V_{id} is the total urine volume.

In order to determine remaining amount of F-18 FDG, injected to the patient, in the body after urine collection, physical radioactive decay correction was calculated. Physical decay correction was conducted in accordance with the equation stated below, where N_t is the radioactive nuclear number at a certain moment, N_0 is the initial radioactive nuclear number, λ is a decay constant ($\lambda = 0.693/ T_f$), t is time, and T_f is the physical half life.

$$N_t = N_0 e^{-\lambda t} \quad (2)$$

Stated below is the equation used to determine the activity amount left in the body.

$$A_{k,i} = A_{m,i} - A_{r,i} \quad (3)$$

where; $A_{k,i}$ is the remaining activity amount in the body at the i^{th} time, $A_{m,i}$ is the activity amount to which physical decay correction will be applied at the i^{th} time, and $A_{r,i}$ is the activity amount excreting from the body with urine at the i^{th} time. The urine activity excreted through the body via the bladder after injecting was also analysed against time.

The below equation was used to expressed the activity amount excreted with urine as a excretion percentage (η).

$$\eta = A_{r,i} / A_{k,i} \quad (4)$$

This helped to identify the remaining amount in the body and excretion percentages.

III. MIRD Method Application

Apart from experimental studies, the MIRD method, a frequently used dosimetric method, was used for theoretical calculations. With this method it is possible to calculate the amount of radiation emitted from one or more source organ and target organs [10]-[13].

The mathematic functions used to calculate the interior radiation dose involve complexity. Absorbed dose (S) tables per cumulative activity have been set by MIRD to simplify these calculations [14].

These tables provide certain coefficients to identify the effect the source organ has on the target organ. The equations stated below illustrate the arranged average dose absorbed by the target organ.

$$\bar{D}(r_k \leftarrow r_h) = \frac{1}{m_k} \sum_h \tilde{A}_h \sum_i \phi_i (r_k \leftarrow r_h) \Delta_i \quad (5)$$

$$\bar{D}(r_k \leftarrow r_h) = \frac{\tilde{A}_h}{m_k} \sum_i \phi_i (r_k \leftarrow r_h) \Delta_i = \tilde{A}_h \sum_i \Phi_i (r_k \leftarrow r_h) \Delta_i \quad (6)$$

where; m_k mass of target organ (g),

$\tilde{A}_h$: Cumulated source organ activity (μCi-sa),

r_k is the target organ, r_h is the source organ, and Δ_i represents the total radiation energy (g-rad/μCi-sa) emitted by the i^{th} radioisotope [7], [13], [14]. The definition of the S-Value is;

$$S(r_k \leftarrow r_h) = \sum_i \Phi_i (r_k \leftarrow r_h) \Delta_i \quad (7)$$

The dose absorbed at the target organ is;

$$\bar{D}(r_k \leftarrow r_h) = \tilde{A}_h . S(r_k \leftarrow r_h) \quad (8)$$

$$\bar{D}(r_k \leftarrow r_h) = \sum_h \bar{D}(r_k \leftarrow r_h) \quad (9)$$

$$\bar{D}(r_k \leftarrow r_h) = \sum_i \tilde{A}_h S(r_k \leftarrow r_h) \quad (10)$$

where; S is the absorbed dose per activity (rad/μCi-sa), $\bar{D}$ is the absorbed dose (rad). For calculations, the activity accumulated in the bladder $\tilde{A}_m$ is calculated as:

$$\tilde{A}_m = 1,44 . T_e . A_0 \quad (11)$$

In order to calculate the bladder dose; $\bar{D}_m$:

$$\bar{D}_m = D_{(m \leftarrow m)} + D_{(m \leftarrow ak)} + D_{(m \leftarrow ov)} + D_{(m \leftarrow troid)} \quad (12)$$

$$\bar{D}_m = \tilde{A}_m . S_{(m \leftarrow m)} + \tilde{A}_{ak} . S_{(m \leftarrow ak)} + \tilde{A}_{ov} . S_{(m \leftarrow ov)} + \tilde{A}_{tr} . S_{(m \leftarrow tr)} \quad (13)$$

Lung, ovary, and thyroid doses were calculated in a similar way.

IV. Results and Discussion

A. Results for Group 1

For the Group 1 which, the bladder dosage of 10 patients was monitored as TLDs were placed on the bladders. Table I illustrates the experiment results for 24-hour F-18 FDG bladder dose monitoring of the patients that had PET/CT at the Positron Emission Tomography (PET) Unit at the Department of Nuclear Medicine at Istanbul University Cerrahpaşa Faculty of Medicine.

TABLE I
Patiens Bladder Pet/Ct Dose Experiments Results

Patient No	Average TLD Dose (mGray)
1	68.50
2	64.39
3	67.39
4	66.25
5	68.12
6	65.23
7	67.65
8	67.42
9	66.78
10	64.25
Average Dose	**66,598 mGy (0.127582) mGy/MBq)**

TABLE II
Average Patients Bladder PET/CT Doses and Dose Calculated Using the MIRD Method

Average Patient's Bladder Doses (mGy/MBq)	Calculated MIRD Dose (mGy/MBq)	der Doses (mGy/MBq)
0,127582	0,128326	0,127582

Apart from experimental studies, dose calculations were also conducted for the positron emission tomography using the MIRD method, frequently preferred for patient dose calculations nowadays. Dose calculation using the MIRD method can be carried out as excreted and not excreted for organs for which MIRD tables are available.

Here the biologically excreted bladder dose was calculated using the MIRD method. Table II illustrates the comparison between obtained results and the average bladder dose of patients. Fig. 1 illustrates the comparison as a graph. Fig. 1 illustrates the results as a graph. Doses are could be acceptable [15] (ICRP, 1991).

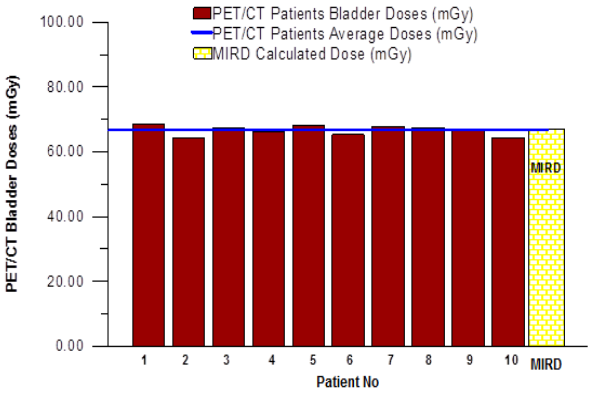

Fig. 1 PET/CT bladder doses and MIRD calculation results for PET patients

B. Results for Group 2

Results reached with results obtained regarding urine activity measuring experiments after FDG injecting 10 PET/BT patients were comparatively analyzed. Figs. 2 and 3 illustrate the comparative graphs of urine activity and the rate of total activity excreted with urine.

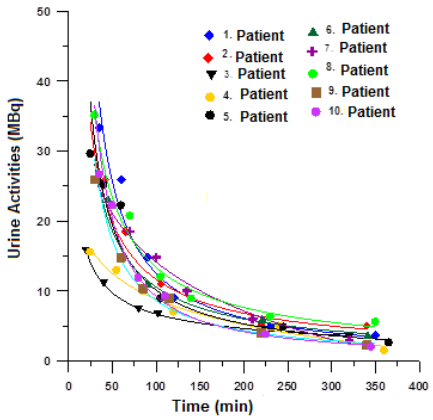

Fig. 2 Comparative graph of the urine activity of ten patients

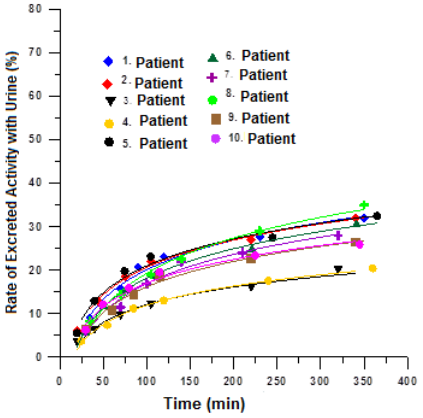

Fig. 3 Rate of total activity excreted with urine of ten patients

Figs. 4 and 5 illustrate the comparative graphs of urine activity concentration and the change in remaining activity in the body.

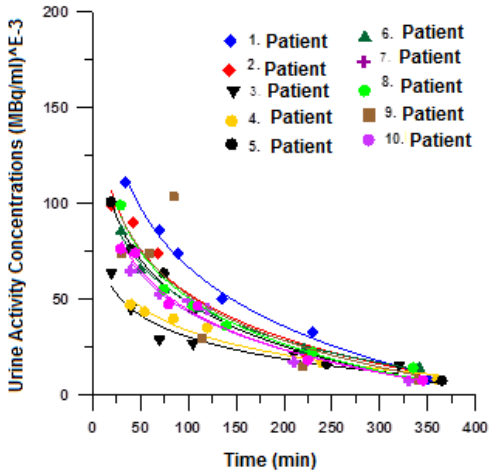

Fig. 4 Comparative graph of the urine activity concentration of ten patients

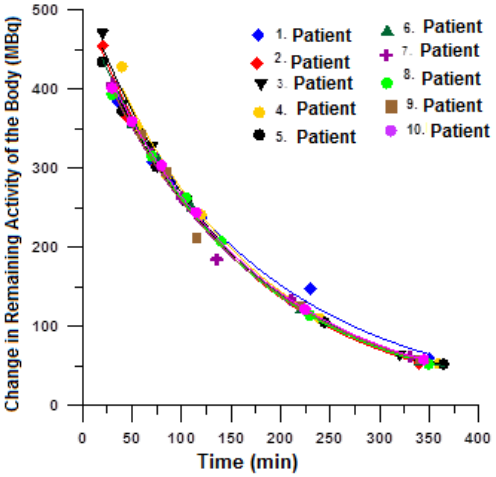

Fig. 5 Comparative graph of the change in remaining activity of ten patients

Figs. 6 and 7 illustrate the comparative graphs of cumulative activity excreted into the environment and the change in corrected cumulative excreted activity.

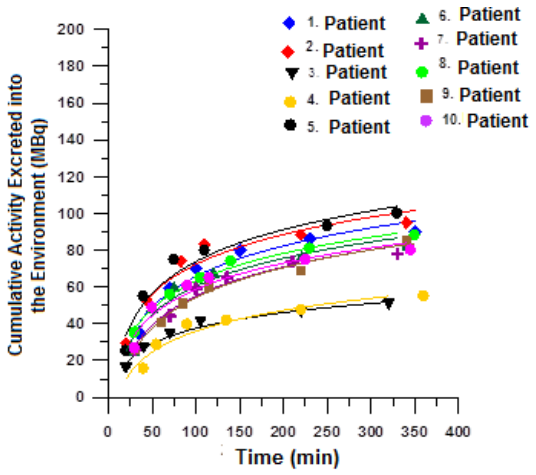

Fig. 6 Comparative graph of cumulative activities excreted into the environment of ten patients

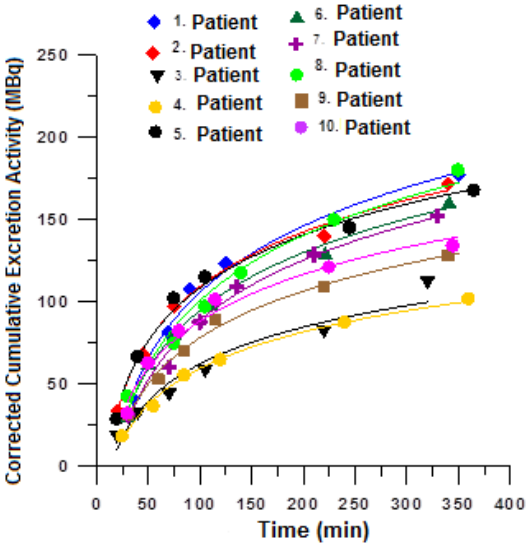

Fig. 7 A comparison of corrected Cumulative excretion activity of ten patients

V. Conclusion

The experimental studies conducted proved that the bladder dose received by ten patients participating in the study were significantly close to each other (Fig. 1). The differences between them were explained as being due to their own nature (and the rate of their urinary system and the amount of water they drank).

The MIRD method was used to calculate the bladder dose of patients and the results obtained were significantly were close to experimental results. In other words, calculations conducted using the MIRD method was in compliance with patients' experimental results. Consequently, the PET/CT doses which were observed in the study are in the permissible levels according to ICRP.

In addition, in conclusion of experiments conducted on monitoring the urine activities of ten patients comparative assessment illustrated that the change in excreted urine

activities with time, the rate of excreted total activity, the urine activity concentration, the activity amount remaining in the body, the cumulative activity excreted into the environment, and the changes in corrected cumulative excretion activity values according to the initial activity were all compatible with each other. Differences were again related to the personal nature of patients (and the rate of their urinary system and the amount of water they drink). It was also observed that the remaining activity values in the body were very similar to each other.

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