Radiation dosimetry of PET and CT scan incorporation exam for brain and thyroid organs

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Abstract

Background: Positron Emission Tomography (PET) and Computed Tomography (CT) are devices used for diagnosis purposes. One of their helpful uses is in oncology. This study compares the effective dose of PET and CT scans for the brain and thyroid. **Materials and Methods:** One hundred individuals participated in this study: 50 patients with brain tumors and 50 with thyroid tumors. The tumors of each patient type are separated into two equal groups. Each group had twenty-five patients. The first group was evaluated using a PET scan, whereas the second group was inspected with a CT scan. The patients were previously diagnosed by an oncologist and then sent for PET/CT and CT scans. Before administering the radiopharmaceutical for PET, the blood glucose content is measured in all PET and CT patients who have been fasting for at least six hours. **Results:** The CT scan shows that the brain shows higher current (mAs) than the thyroid. The effective dose of x-ray reached the brain was the highest, followed by the thyroid. The scanning time (minutes) was significantly the highest in the thyroid, followed by the brain. There was no significant difference among the organs in effective dose or current (mAs). For PET scan, the effective dose (mSv), scan time (minute), radiation activity (mCi), and SUV (MBq/ml) shows a highly significant difference between the two studied organs (brain and thyroid). The effective dose shows to be the highest in the brain, followed by the thyroid. The brain, followed by the thyroid, was taken for the minimum examination time. The activity of the x-ray radiation in mCi was found in the thyroid and brain. The brain's standard uptake value (SUV) was higher than the thyroid's. The effective dose for the CT scan was significantly higher than the PET scan for the brain and thyroid. **Conclusion:** The effective dose obtained from the CT scan is higher than the PET scan for the brain and thyroid.

Keywords: radiation treatment; health, nursing care; **CT scan**

1. Introduction

PET/CT scanning using the radioactive tracer fluor-18 fluorodeoxyglucose (FDG) plays a significant role in tumor imaging for cancer patients. There is a movement toward standardization and harmonization in FDG-PET scanning to enable comparisons of FDG uptake parameters among patients, scanners, and medical facilities (1).

Due to the combination of metabolic and morphological data, PET/CT is a powerful tool in cancer. The PET emission scan offers physiological data utilizing a separate set of detectors than CT transmission detection. Even though two separate PET and CT pictures may be coregistered to create a single image, the most precise coupling occurs when both scans are taken during the same session using a PET-CT scanner. The CT scan is a diagnostic instrument that employs kilovoltage x-rays (2).

The majority of new PET scanners are dual PET/CT machines for this reason and because a built-in CT offers additional benefits, such as attenuation correction. In PET/CT tests, regardless of acquisition conditions, the patient dose from PET and the patient dose from CT are assessed independently and then combined to calculate the total whole-body radiation exposure (3).

As a basic general principle of radiological protection, the referral for PET/CT tests must be justified in each patient (4). According to the International Committee on Radiological Protection (ICRP), the second basic concept of radiologic protection is optimization, or ensuring that diagnostic information is as high as is reasonably practicable while keeping radiation doses as low as is reasonably attainable (5).

PET and CT are commonly used for diagnosing tumors. A brain tumor is a mass or development of aberrant brain cells. There are several forms of brain tumors. Some brain tumors are noncancerous (benign), while others are malignant (malignant). Brain cancers may originate in the brain (primary brain tumors) or other regions of the body and spread to the brain (secondary brain tumors, also known as metastatic brain tumors) (6).

The thyroid gland is the site of origin for thyroid cancer. Cancer begins when cells begin to multiply uncontrollably. The thyroid gland produces hormones that assist in regulating the body's metabolism, heart rate, blood pressure, and temperature. The thyroid

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gland is positioned in the front of the neck under the thyroid cartilage (Adam's apple). In the majority of people, the thyroid cannot be seen or felt. It is formed like a butterfly and has two lobes. The right and left lobes are joined by the isthmus, a narrow gland segment (6).

In addition, heightened knowledge of the dangers of ionizing radiation has led to initiatives to reduce the radiation dosage encountered during x-ray and nuclear medical imaging procedures (7). Implementation of dose-saving methods relies on precise dose measurement/dosimetry in order to optimize the benefit-to-risk ratio of imaging tests. (8).

Liu et al., 2017 (9) aims to characterize radiation dosimetry for whole-body dual-tracer PET/CT techniques. They discovered that equivalence organ doses could be better estimated with the patient-specific parameters. Every recommendation for a full body dual-tracer PET/CT must have a medically sound basis. This information is of importance and useful for justifying, assessing risk/benefit, and optimizing protocols, even though the population with cancer may be less affected by radiation dangers because to their shorter life expectancy.

Quinn et al., 2020 (10) medical imaging techniques, other imaging methods, and guided dose optimization initiatives were evaluated for their relative organ-absorbed and effective radiation exposure. According to their findings, commercial software may be used to predict organ and effective CT and PET components using data from a real patient and scans. Dosage estimates based on software were usually consistent with those based on dose conversion factors, while there were notable discrepancies for specific organ doses. Dosage factors may be customized for everyone using software-based techniques of dose computation. Patient-adjusted dosimetry is valuable, thus it's worth the time and effort to collect the necessary data.

The present study uses patient-specific data dose estimation techniques to characterize and compare the radiation dosimetry types of specific organs (brain, thyroid) of body PET and CT scan devices.

2. Materials and Methods

This is a retrospective study performed in PET/CT department, Baghdad Center for Radiation Therapy and Nuclear Medicine, Medical City, Baghdad, Iraq. The period of data acquisition was from January 2022 to June 2022. The Institution Review Board (IRB) of the College of Medicine at Al- Nahrain University approved this study. This study involved one hundred patients: 50 with a brain tumor and 50 with a thyroid tumor. Each type of patient's tumor is divided into two equal groups. Each group contained 25 patients. The first group underwent a PET Scan, and the other group was examined with a CT scan. The patients were diagnosed previously by an oncologist and forwarded to a PET/CT and CT scanning examination. Before the PET administration, the radiopharmaceutical, the blood glucose concentration is assessed for PET patients, all patients for PET and CT who have fasted for at least six hours.

After an uptake period of around 60 minutes, General Electric (GE) scanners were used to do PET/CT imaging. Information for this study was gathered from CT scans performed on patients using the GE Lightspeed 16 CT scanner used in the Discovery 690 DSTE PET/CT (GE Healthcare, Milwaukee, Wis). Emission data was accounted for scattering, random events, and dead time losses using the manufacturer's software. A 128 x 128 grid of 4.25 mm squared picture pixels was used. These data were rebuilt using two rounds of the iterative reconstruction with 28 subsets, which is the default. After that, a PET scan was performed, which took two minutes each bed position and spanned from the head to the thighs in a three-dimensional representation. To account for attenuation, PET data were rebuilt iteratively using the low-dose CT datasets and an ordered subset expectation maximization technique.

The parameters of the PET sets are as follows: the image type is a Static emission image obtained after 45 minutes as an average time from the injection of FDG-18. The voxel dimensions (mm^3) were 6.3 mm X 6.3 mm X 30 mm. The reconstruction algorithms are used to generate consistent and repeatable image data under different scanning conditions. The Standardized uptake values SUV units are used for image intensity values conversion.

The model of the CT scan device used in this research is 64 slices from Toshiba model AQUILIONE CGGT-021A. The CT Gantry rotation is set to 0.8 s, with a table speed of 30 mm per gantry rotation. The 5-mm-thick trans axial CT images were reconstructed at 4.25-mm intervals (trans axial). The setting of the CT parameters are as follows: the type of image is Helical–Axial for low-dose CT scans. The voxel dimensions in mm^3 are 3.27 mm X 1.37 mm X 1.37 mm. The tube voltage and current sets at 240 KVp and 440 mA, respectively. The innovative CT reconstruction algorithms used for Hyperplane and Crossbeam for providing artifact-free images and optimized slice profiles at any pitch solve the technical challenges of cone-beam and high-pitch helical scanning. Image intensity conversion values were obtained in the Hounsfield unit (HU).

Data analysis was carried out using the available statistical package of SPSS-25 (Statistical Package for Social Science-version 25). The significance of the difference in dependent mean (quantitative data) was tested using paired t-test. Statistical significance was considered whenever the p-value was equal to or less than 0.05.

3. Results

This study compares the effects of PET and CT scans on patients. The characteristics of patients included in this study are shown in table (1). The characteristics include age, gender, and body mass index (BMI) in (kg/m^2). The analysis shows no significant difference between the age of patients who underwent PET and CT scans. For gender classification, female (54%) shows more prevalence than male patients who underwent a CT scan (44%). In comparison, those who underwent a PET scan showed more prevalence than males (65%) than females (35). There was a significant difference between the gender of patients exposed to CT and PET scans. The patients scanned with CT scan were significantly obese with high BMI than those scanned with PET scan.

Table (1): Characteristics of patients included in this study.			
Characteristics	CT scan	PET Scan	*p*-value
Age	48.99 ± 18.39	50.15 ± 16.94	0.6691 NS
Gender	Female: 56 % Male: 44 %	Female: 35 % Male: 65 %	0.002864*
BMI	30.52 ± 15.21	26.83 ± 6.26	0.036931*
* Significant difference at ≤0.05 level			

The parameters of patients forwarded to CT scan are analyzed, such as the dose of X-ray (mSv), the current used to heat the filament of x-ray tube (mAs), the scanning time for the overall sites, and each anatomical organ included in this study. The organs are the brain, thyroid, lung, and stomach. The results of CT parameters are shown in table (2). The brain shows higher current (mAs) than the thyroid, as shown in figure (1). The effective dose of x-ray reached the brain was the highest, followed by the thyroid, respectively, as shown in figure (2). The scanning time (minutes) was significantly the highest in the thyroid, followed by the brain, as shown in figure (3). There was no significant difference among the organs in effective dose or current (mAs)

Table (2): The Parameters of CT Scan.			
Anatomical Site	Effective Dose (mSv)	mAs	Scan Time (Minute)
Brain	1.75 ± 0.27	134.4 ± 47.54	1.071 ± 0.051
Thyroid	0.855 ± 0.2017	115.83 ± 11.59	4.48 ± 0.679
p-value	0.741121	0.646442	< 0.00001*
* Significant Difference at p-value level ≤ 0.05.			

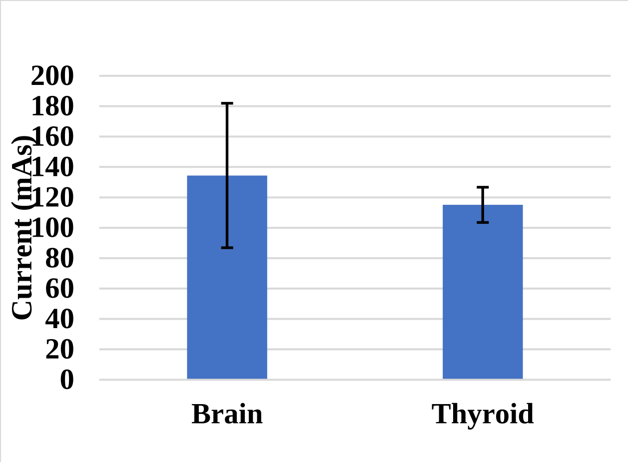

Figure (1): Comparison of CT Scan Current between the Brain and Thyroid

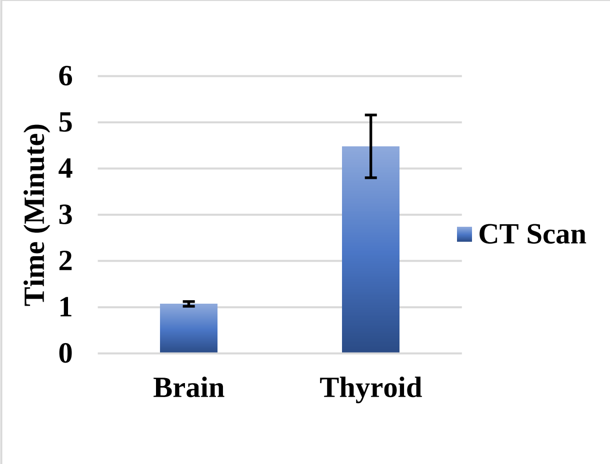

Figure (3): Comparison of the Time (Minute) by CT Scan between the Brain and Thyroid

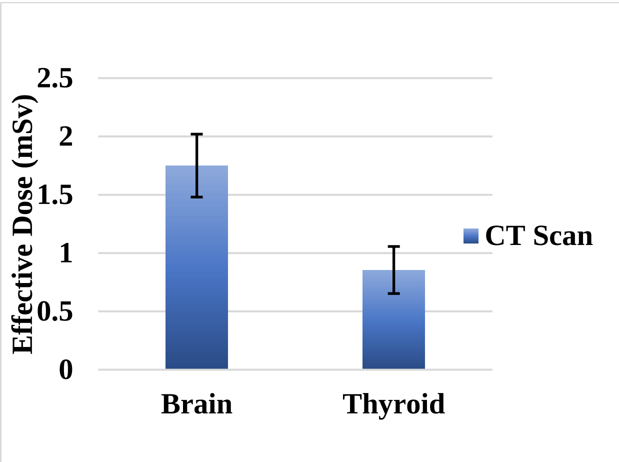

Figure (2): Comparison of the Patient's Effective Dose (mSv) by CT Scan between the Brain and Thyroid

The statistical results of the effective dose (mSv), scan time (minute), radiation activity (mCi), and SUV (MBq/ml) acquired by the PET scan are illustrated in table (3). All these parameters are shown a highly significant difference between the two studied organs (brain and thyroid). The effective dose shows to be the highest in the brain, followed by the thyroid, as shown in figure (4). The brain, followed by the thyroid, was taken for the minimum examination time, as shown in figure (5). The activity of the x-ray radiation in mCi was found in the thyroid and brain, respectively, as shown in figure (6). The brain's standard uptake value (SUV) was higher than the thyroid, as presented in figure (7).

Table (3): The Parameters of PET Scan.				
Anatomical Site	Effective Dose (mSv)	Scan Time (Minute)	Radiation Activity (mCi)	SUV (g/ml)
Brain	1.071 ± 0.051	16.72 ± 0.17	7.57 ± 1.72	0.37 ± 0.03
Thyroid	0.63028 ± 0.0907	15.083 ± 1.59	7.99 ± 1.785	0.107 ± 0.0607
p-value	< 0.00001*	0.04321*	< 0.00001*	< 0.00001*

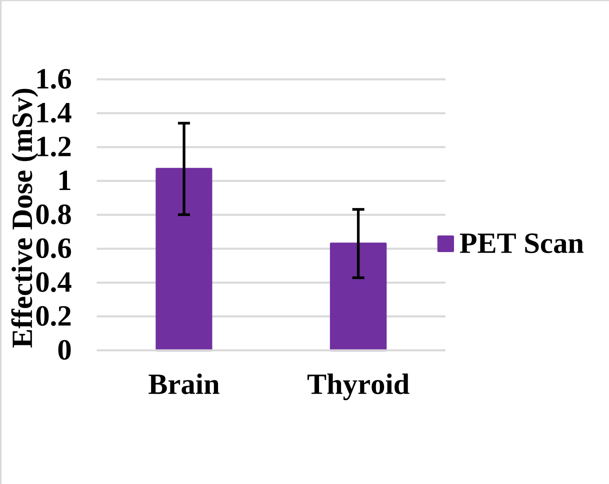

Figure (4): Comparison of the Effective Dose (mSv) by PET Scan between the Brain and Thyroid.

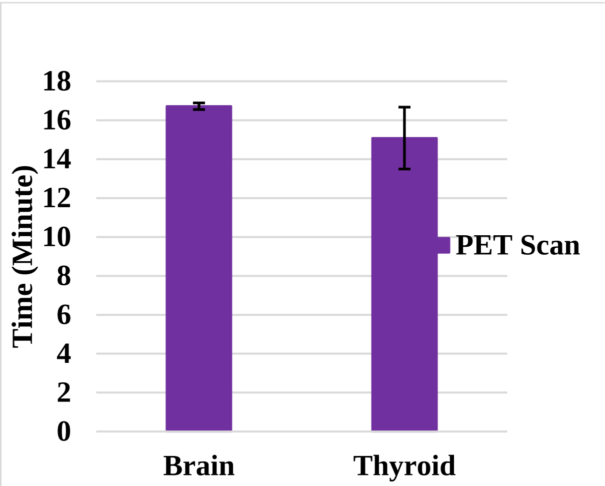

Figure (5): Comparison of the Time (Minute) by PET Scan between the Brain and Thyroid,

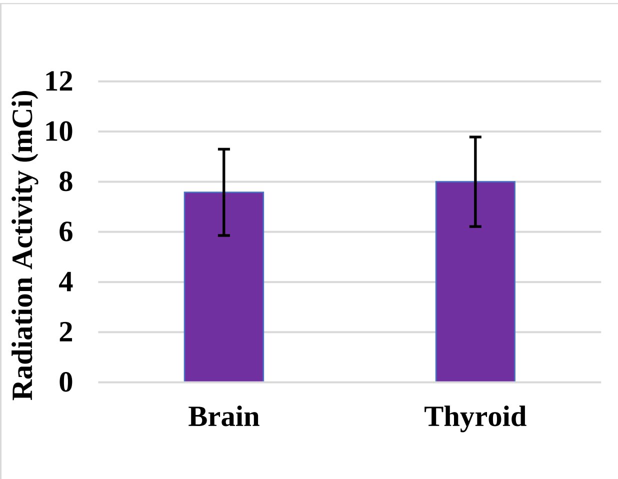

Figure (6): Comparison of the Radiation Activity (mCi) by PET Scan between the Brain and Thyroid

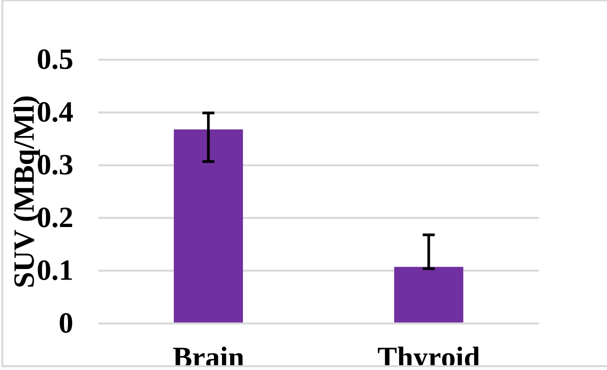

Figure (7): Comparison of the SUV (MBq/ml) by PET Scan between the Brain and thyroid

The results of the CT scan's effective dose compared with the PET scan's effective dose for the brain and thyroid are presented in table (4). The effective dose for the CT scan was significantly higher than the PET scan for all the anatomical sites (brain and thyroid), as shown in figure (8).

Table (4): Comparison of the Effective Dose (mSv) Between the CT Scan and PET scan			
	CT scan	PET Scan	*p*-value
Brain (mSv)	1.75 ± 0.27	1.071 ± 0.051	< 0.00001*
Thyroid	0.855 ± 0.2017	0.63028 ± 0.0907	< 0.00001*

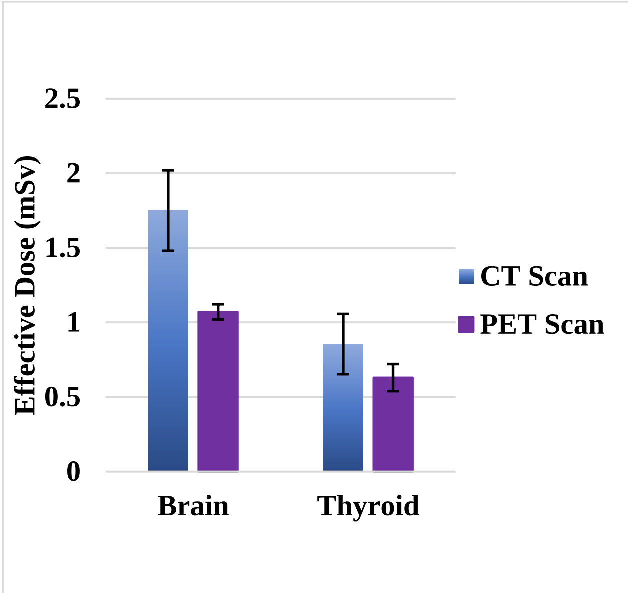

Figure (8): The Comparison of the Effective Dose (mSv) Between the CT Scan and PET Scan

The scanning time of the PET scan compared with the CT scan is shown in table (5). The examination time of a PET scan is highly significant than the time required for the CT scan. In the PET scan, the scanning time of the brain was higher than the thyroid, as shown in figure (9). At the same time, the thyroid requires more time than the brain in a CT scan.

Table (5): Comparison of the Time (minute) Between the CT scan and PET scan			
Anatomical Sites	CT scan	PET Scan	*p*-value
Brain (minute)	1.071 ± 0.051	16.72 ± 0.17	0.00052*
Thyroid (minute)	4.48 ± 0.679	15.083 ± 1.59	< 0.00001*

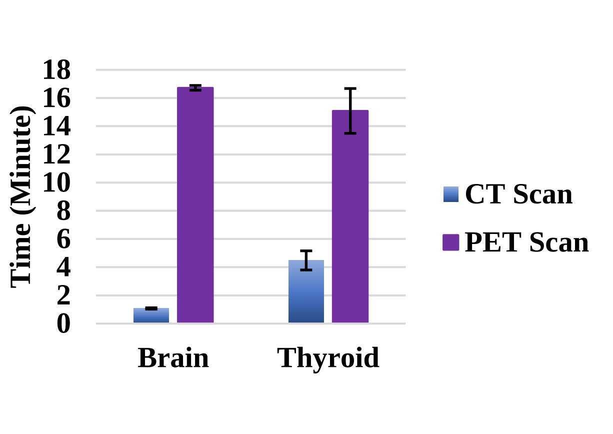

Figure (9): The Comparison of Scanning Time (minute) Between the CT scan and PET Scan

Khursheed et al. surveyed CT scans in multiple centers for adult patients. They found that the effective dose (mSv) for adults was one mSv (11). The total effective dose of this study (PET and CT) is subtracted from the recommended effective dose to calculate the difference, as shown in table (7). The results show that this study's effective dose is below the threshold, which means it is safe for patients. The PET and CT results were within limits for the thyroid but not for the brain, which exceeds the one mSv.

Table (7): The difference between the Total Effective Dose in this Study with the Khursheed et al.,

Anatomical Site	CT scan	PET Scan
Brain (mSv)	0.75 ± 0.27	0.071 ± 0.051
Thyroid (mSv)	Within limits (Less than 1)	Within limits (Less than 1)

4. Discussion

Patient dose used in risk estimation is dependent on the dose estimation method used, with reference value-based dose estimation being subject to the characteristics of the patient population in comparison to the reference population, and specific information-based dose estimation being subject to the degree to which specific information is utilized (5).

It is not appropriate to use Monte Carlo-based organ dose coefficients to establish an effective dosage for people, since effective dose is normally employed for evaluating relative biological risk. Variables unique to each patient and exam are required for a precise dosage estimate technique. The current study compared the radiation dosimetry of PET and CT for two organs (brain and thyroid) (12,13). There are risks of extrapolating biological risk estimations for radiation doses below 100 mSv. Still, the results of our studies were within the average International Organization for Medical Physics, ICRP, Health Physics Society, and American Association of Physicists in Medicine policy statements (12,14,15).

For gender, female patients with PET scans have significantly more prevalence than male patients with CT scans for reasons of age and gender. The patients' data in this research, as in table 2 and figures 1, 2, and 3 are evaluated. The brain current (mAs) is greater than that of the thyroid. The effective dosage (mSv) and scanning time for the brain and thyroid were determined.

The thyroid required the longest scanning time (in minutes), followed by the brain, the stomach, and the lungs. There were no significant differences in effective dosage or current across organs (mAs). The stomach had the largest effective dosage of x-rays, with the brain closest to the front of the queue.

The brain seems to have the largest effective dose (mSv) of x-ray radiation, followed by the thyroid and the lung. The lung has more scanning time (minutes) than the stomach or thyroid, while the brain and thyroid examination time is the least possible.

Multiple studies have presented findings about the kinetics of FDG-18 distribution in humans, which may be used to calculate the absorbed dose to different organs after intravenous administration of 18FDG (16–20). These investigations were based on the kinetics of FDG-18 dispersion in people. For internal dosimetry estimates for both sexes, data on the kinetics of 18FDG distribution in humans are necessary from a very limited number of investigations. Since these computations are required for medical imaging, this is an issue. There is only one study completed by Niven et al. (16) that compares the residence time and the dose received in male and female brains, 18, which concludes that there is a significant gender difference in the residence durations and the dose absorbed by the brain from FDG-18.

When compared across all anatomical areas, the effective dosage for the CT scan was much greater than that of the PET scan (brain and Thyroid). Based on the findings of this study, it has been determined that the examination time necessary for a PET scan is much less than the time needed for a CT scan. Regarding CT scans, the amount of time spent scanning the thyroid is more than that spent scanning the thyroid

The effective dose generated by the CT and PET scan in this study combined to calculate the overall dose accumulated inside the patient's body when PET/CT scanned them in combination. The results were compared with Khursheed et al. (11), who found that the recommended and safe, effective dose for patients should be less than one mSv.

You can determine the difference between the total effective dosage of this study (PET and CT) and the recommended effective dose (PET, CT). This can be done by calculating the difference. It is possible to do this by subtracting from the required effective dose, as shown in table 6 (7). The outcomes of this study show that it is safe for patients to use since the effective dose required is far less than the threshold. The PET scan revealed that the thyroid was within acceptable limits. The only organ that exceeded normal limits was the brain, which was determined to contain more than one mSv. In contrast to the CT scan results concerning the brain, the thyroid was found to operate within the usual range of parameters.

In a study performed by Kaushik et al. (20), they found no significant difference in the residence time and absorbed dose to male and female organs, brain, and stomach. In addition, they discovered that the proportion of uptake in male brains was greater than that of female brains and that the amount of time spent in male brains was somewhat longer than that spent in female brains. Both differences were seen. On the other hand, for a given quantity of activity delivered, the overall dosage given to the female brain was somewhat larger than the dose given to the male brain. Furthermore, they declare that It was found that there was no significant variation in the biodistribution of FDG-18 between the brains of men and females because there was no significant difference in the residence periods of activity in the brains of males and females. This might be because the people or patients picked for the research were of a different kind, which in turn could influence how quickly the radiopharmaceutical worked in their bodies. Although Bacher et al. reported that the men and females have comparable biodistribution, females are given a larger dosage for the same activity, owing to a difference in the SUV values (21).

In the research by Kaushik et al., the relative weight of the brain to the whole body was determined to be 2.3%. The proportion of brain mass to total body mass was 2.6% among Japanese adults, 2% among European adults, and 2% among Americans (21,22). Due to this high background accumulation of FDG-18 in the normal brain, the uptake in lesions did not vary substantially from that in normal brains. Although no study has published female patient values,(12,17), The length of the drug's residency in the male and female livers was less than previously reported. In contrast, both male and female livers absorbed dosages comparable to those reported by the International Commission for Radiological Protection (ICRP), which were 0.02 mGy/MBq (23).

Estimation uncertainty must be taken into account in the development and use of risk coefficients for predicting public health determinants based on individual or community exposures.(15). Dosimetric uncertainties, epidemiological and methodological uncertainties, low statistical power and precision in epidemiology studies of radiation risk, modeling risk data uncertainties, extrapolating risk estimates to different populations and dose rates, and relying on epidemiological studies based on observational rather than experimental data all contribute to these limitations (24).

From the standpoint of the patient, it is more convenient to make just one trip to the imaging clinic rather than two. If both scans need the same amount of radiation, patients may find it more convenient to have a single, combined scan. Standard PET/CT with a separate diagnostic CT may provide a higher or lower radiation dosage than a diagnostic PET/CT, depending on the clinic's specific circumstances. Intuitively, a PET/CT with diagnostic approach may seem to be qualitatively identical to a normal PET/CT with separately obtained diagnostic CT, but the CT in the latter may also be utilized for attenuation correction, therefore the dosimetry is different. The CT dose from a routine PET/CT scan appears to be in addition to the CT dose from a standalone diagnostic scan. The dosage may be more or lesser depending on the PET/CT or CT scanner used. The number of slices is one such difference, and PET/CT devices may not have access to adaptive filtering. Patients may get a greater or lower dosage from a combined scan, depending on hardware and software considerations. The dosage in a specific clinic must be evaluated in comparison to reference or literature doses, and these factors must be taken into account. Estimated PET doses from a single source, as ICRP 106, tend to have less fluctuation in reported values. Dose may be affected by any number of factors, including the imaging clinic's own requirements for uptake time and acquisition time, which in turn affects injected activity (26).

To our knowledge, no previous study compared the effective dose to the patient-generated from the CT and PET scans. So this is the first study spoked on this subject.

5. Conclusion

The effective dose obtained from the CT scan is higher than the PET scan. The CT scan needs to be recalibrated to reduce the dose for the patient. The PET scan is more accurately diagnosed, especially in oncology, but it is more time and money-consuming

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