



Contents lists available at ScienceDirect

Saudi Journal of Biological Sciences

journal homepage: [www.sciencedirect.com](http://www.sciencedirect.com)

Original article

# Radiobiological risks in terms of effective dose and organ dose from $^{18}\text{F}$ -FDG whole-body PET/CT procedures

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## ARTICLE INFO

### Article history:

Received 20 April 2021

Revised 19 June 2021

Accepted 20 June 2021

Available online 24 June 2021

### Keywords:

Effective dose

 $^{18}\text{F}$ -FDG

PET/CT

Organ dose

## ABSTRACT

**Introduction:** Integrated Positron Emission Tomography (PET) with Computerized tomography (CT) (PET/CT) are widely used to diagnose, stage and track human diseases during whole body scanning. Multi-modality imaging is an interesting area of research that aims at acquiring united morphological-functional image information for accurate diagnosing and staging of the disease. However, PET/CT procedure accompanied with high radiation dose from CT and administered radioactivity. The aim of the present study was to estimate the patients' dose from  $^{18}\text{F}$ -fluorodeoxyglucose imaging ( $^{18}\text{F}$ -FDG) hybrid PET/CT whole body scan.

**Materials and methods:** RADAR (Radiation Dose Assessment Resource) software was used to estimate the effective dose for 156 patients (110 (70.5%) males and 46 (39.5%) female) examined using Discovery PET/CT 710, GE Medical Systems installed at Kuwait Cancer Control Center (KCCC).

**Results:** The effective dose results presented in this PET/CT study ranged from (1.56–9.94 mSv). The effective dose was calculated to be 3.88 mSv in females and 3.71 mSv in males. The overall breast (female), lung, liver, kidney and thyroid were 7.4, 7.2, 5.2, 4, 3 and 2.9, respectively.

For females, the body mass index (BMI) was 28.49 kg/m<sup>2</sup> and for males it was 26.50 kg/m<sup>2</sup> which showed overweight values for both genders. **Conclusions:** The findings indicate that the effective dose of  $^{18}\text{F}$ -FDG in both male and female patients was not substantially different. The study suggested that the risk-benefit proportions of any  $^{18}\text{F}$ -FDG whole body PET/CT scan should be clarified and carefully weighed. Patient's doses are lower compared with previous studies.

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## 1. Introduction

Multi-modality imaging (Hybrid or fusion imaging) can detect noninvasively the physiological and anatomical disorders. Currently, PET/CT is extensively used for malignant tumors character-

ization and evaluation of response to therapy (Alkhorayef, 2020). PET scans comprise physiological findings and CT provides the anatomical details. As a result, hybrid PET/CT images provides better diagnostic findings than single CT or PET scans. The glucose analogue 2-[ $^{18}\text{F}$ ] fluoro-2-deoxy-D-glucose ( $^{18}\text{F}$ -FDG) has increasingly been used to detect inflammation and infection with positron-emission tomography/computed tomography (PET/CT). Infection site  $^{18}\text{F}$ -FDG accumulation is dependent on high glucose absorption of inflammatory cells triggered. The potential role of  $^{18}\text{F}$ -FDG-PET/CT for infection lesion detection and tumor staging has been suggested by published findings (Salah et al., 2020, Alkhorayef, 2020, Salomäki et al., 2020, Liao et al., 2016). The highest standardized uptake value (SUV<sub>max</sub>), developed during an integrated  $^{18}\text{F}$ -FDG-PET/CT-scan, is an index used to differentiate

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Peer review under responsibility of King Saud University.



Production and hosting by Elsevier

<https://doi.org/10.1016/j.sjbs.2021.06.055>

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between malignant lesions and benign lesions. A high  $SUV_{max}$  typically suggests that malignancy is highly probable. The alternative approach is an 18F-FDG dual-phase PET/CT where there is no strong distinction between benign and malignant lesions from the other forms of pre-operative imagery. Early and delayed  $SUV_{max}$  values are therefore essential for malignancy diagnosis (Ishikawa et al., 2020).

Alternative to 18F FDG PET/CT for obtaining both anatomic and functional image and radiation free is whole body resonance imaging (WB-MRI), But  $^{18}F$ -FDG PET/CT has been proven to be highly sensitive especially in younger patients. (Wong et al., 2017)

Various PSMA types are available now: 68 Ga-PSMA-11, 68 Ga-PSMA-617, 18FDFCPL, and 18F-PSMA-1007. Various types are available in this group. They have different pharmacokinetic properties, but the same purpose (Evangelista et al., 2020).

As traditional gamma-ray source (for example germanium-68), the technology from CT depends on a corrective attenuation of the PET acquisition data. CT is a popular diagnostic method for radiological imaging that is a useful tool for cancer research, localization of infections, inflammatory lesions and treatment response assessment. The capacity of CT to reliably delineate anatomies allows to assess operatively and to stage accurately. In major PET/CT Practice, non-contrast enhanced and low-dose CT (NECT) were appropriate as this provides cost-efficient and lower exposure for patients to radiation. In the case of cancer staging, however, improved CT (CECT) contrast or so-called CT Diagnostics is preferred to NECT. In order to enhance the delineation and position of lesions, contrast administration is required and local invasions of lesions are removed. The characterization of lesions can also be obtained by multi-stage CT analysis in the diagnosis of cancer. When CT has been incorporated into PET, the intensity of the two modalities is combined, using the CT to mitigate PET data. There are in fact, different types of PET/CT image protocols conducted separately with the acquisition of PET, in various centers, for example in low dosage CT, PET, NECT/PET and CECT/PET (Mahmud et al., 2015). PET/CT plays a significant role in clinical applications and provides us more images to reliably diagnose and suggests the care most suitable for the patients received. The most important application of PET is oncology and provides an imagery of the fluorine 18 fluorodeoxyglucose distribution. Recent advances in radiomics have demonstrated the potential added benefit of discriminating and predicting cervical cancer evaluation, a tool that transforms the images into large-scale mineable data compared to certain typical semi-quantitative parameters from patient  $^{18}F$ FDG PET/CT scans, including maximum standard uptake value ( $SUV_{max}$ ), metabolic tumor volume or complete lesion glycolysis. However most recent PET/CT studies draw picture-derived characteristics separately from PET and CT pictures; or use semi-quantitative semi installed descriptors identified by the radiologist to classify PET and CT fusion pictures for the results, and most of the descriptors generally categorize tumors as a whole and rarely take into account the extraction of features from various subregion (Mu et al., 2020). Integrated in the oncology process,  $^{18}F$ -fluoro-2-deoxyglucose is primarily used for follow-up on the patient. Imaging changes in the metabolism of glucoses will lead to a more timely and precise evaluation of reaction than normal morphological imagery. Positron emission high-energy annihilation radiation may lead to a significant exposure to workforce radiation. In comparison, the internal distribution of beta (positron) emitting radiopharmaceutical products could give the patients relative low radiation exposure. Several research on the estimation of the effective dose have been reported with  $^{18}F$ FDG PET/CT for both sexes and various organs (Alkhorayef, 2020, Salah et al., 2020, Shiraishi et al., 2010, Marwa et al., 2019, Karakatsanis et al., 2015). In literature, patients reported to receive up to 40 mSv from

PET/CT procedures, and was calculated that 82% of the dose resulted from CT scanning (Salah et al., 2020). Therefore, assessment of patients effective and organ dose is recommended to ensure that proper imaging scan is used to provide diagnosable scan with minimal radiation risks. The goal of the present study is to estimate effective and organ doses from the  $^{18}F$ FDG PET/CT exams in both males and females for the whole body and the results achieved for the radiological safety of the facility for dose assessment and optimization.

## 2. Materials and methods

This study was performed at nuclear medicine department, at Kuwait Cancer Control Center (KCCC). All procedures were carried out using Discovery PET/CT 710, GE Medical Systems (3000 N. Grandview Blvd. Waukesha, WI 53188, USA). A total of 156 patients (110 (70.5%) males and 46 (29.5%) females) (mean age  $\pm$  SD,  $61 \pm 11.44$  years; age range, 31–85 years) with suspected cancer underwent  $^{18}F$ -FDG PET/CT in the KCCC. General characteristics of the demographic data of the patient (age, gender, weight and height) were reported. The dose parameters and the dose administered for both the left and the right lungs were calculated using the RADAR Medical Procedure Radiation Dose Calculator.

### 2.1. Measurements

The measurement of the effective PET-CT dose consists of both internal and external exposure as shown in ICRP publications 102, 103 and 106. External exposure to radiation due to exposure from radiopharmaceuticals  $^{18}F$ -FDG were calculated from the reported DLP using the below equation and the effective dose per unit dose-length product conversion factors. The  $^{18}F$ -FDG is a 240 keV and 511 keV beta-energy positron emitter. Internal exposure to patients was determined on the basis of the equation as follows (Hussin et al. (2017)

$$DT = AxTTFDG \quad (1)$$

where DT is the absorbed doses to a tissue or organ, T, A is the activity (MBq) of  $^{18}F$ -FDG administered to the patient and TTFDG is dose coefficient provided by ICRP 106 for a variety of organs and tissues.

The effective dose, E received by patients were evaluated based on equation (2).

$$E = \sum TWT \times DT = AX \sum TWT \times TTFDG = AxTTFDG \quad (2)$$

Where TTFDG =  $19 \mu Sv/MBq$  is the dose coefficient for the effective dose F18-FDG (adults >15y).

### 2.2. Imaging procedure

The patient received 4.4 mCi intravenous injection of 18F-FDG. After an initial uptake period of approximately 65 min, a CT-Scan without oral contrast without Intravenous (IV) contrast, without breathing at low mA level was acquired for attenuation correction and localization purposes only (low CT dose non-enhanced images). The arms were held up. Subsequently, PET images were taken from the vertex to the mid-thigh. CT, PET and fused images were reconstructed in *trans*-axial, coronal and sagittal projections and interpreted from the workstation. Plasma glucose in the patient was 5.2 mmol/l (Kazimierczyk et al., 2021).

## 3. Results

In the present study, the absorbed dose was calculated based on the biokinetic data obtained from a group of 156 patients, after a

bolus intravenous injection. For the whole-body review <sup>18</sup>F-FDG PET/CT an overview of patient details such as age, BMI and dosage parameters such as administration and efficacy dose. For all patients according to their sex, the average demographic results presented as mean ± standard deviation are shown in Table 1.

Radiation doses parameters, for example, tube potential, tube current, weighted CT dose index CTDI<sub>w</sub>, volume CTDI<sub>vol</sub> and the dose length product (DLP, mGy.cm), and table motion parameters for scan length, feeding table and pitch, and table movement parameters. The details of the scan models are presented in Table 2. It showed CT image acquisition protocol and the movement parameters with the data viewed as medium ± default.

The average effective dose was 3.17 mSv for both male and female patients with: 2.89 ± 1.13 and 3.93 ± 1.71 mSv for computed tomography examinations and 3.75 and 3.78 ± 1.79 and 3.71 ± 1.63 for internally administered <sup>18</sup>F-FDG for males and females respectively. During the whole-body PET/CT procedure, 6.66 ± 2.38 and 7.64 ± 2.42 mSv <sup>18</sup>F-FDG was internally administered for male and female patients. Table 3 reported all the data.

In Table 4, the complete list of human organs in both the male and female subjects were categorized separately. Patients undergoing an <sup>18</sup>F-FDG PET/CT Whole body examination As the range is from the top of the lungs to the top of the stomach, a large dose was received by the different organs. Table 4 provides a thorough

**Table 1**  
Anthropometric and demographic information for enrolled patients.

Variables	Male	Female	Overall
Age (Years)	61.29 ± 10.40	57.28 ± 13.52	59.3 ± 12
BMI (Kg/m <sup>2</sup> )	26.69 ± 4.89	27.98 ± 6.81	27.3 ± 5.9

**Table 2**  
List of parameters of scan and the activity doses.

Scan parameters	Mean ± SD	Variables Scan parameters	Mean ± SD
Tube Potential	120 or 140	Collimation	16 or 32
Tube current	93.72 ± 35.81	Turn	4.9 ± 0.9
Table feed	16.43 ± 1.5	CTDI <sub>w</sub>	4.43 ± 1.94
Pitch	1.02 ± 0.09	CTDI <sub>vol</sub>	4.17 ± 1.83
Slice thickness	2.5 or 5	DLP	177 ± 71.62
Scan length	80.57 ± 14	Activity	5.35 ± 2.48

**Table 3**  
Comparison of CT scan and PET in both the male and female subjects.

CT			PET			Total		
Male	Female	Total	Male	Female	Total	Male	Female	Total
2.9 ± 1	3.9 ± 1.7	3.2 ± 1.4	3.8 ± 1.8	3.7 ± 1.6	3.8 ± 1.7	6.66 ± 2.4	7.64 ± 2.42	6.93 ± 2.42

**Table 4**  
List of dose received by the different organs in male and female patients.

Organs	Male		Female		Total	
	Mean	SD	Mean	SD	Mean	SD
Thyroid	6.7	2.9	3.4	1.7	5.8	2.9
Breasts	0.04	0.47	7.4	3.5	2.0	3.7
Esophagus	6.3	2.7	6.9	3.2	6.4	2.8
Lungs	6.7	2.8	7.2	3.4	6.8	2.9
Liver	5.0	1.9	5.9	2.6	5.3	2.1
Stomach	4.7	1.6	5.6	2.4	4.9	1.9
Kidneys	4.1	1.2	5.1	2.0	4.3	1.5
Gall bladder	4.5	1.8	5.3	2.4	4.7	1.9
Heart	5.8	2.5	6.2	2.9	5.9	2.6

assessment of the distribution of organ dose within the human body within the entire body presented as mean ± standard deviation. The mean dose was found to be high in females when compared to males in breasts, esophagus, lungs, liver, stomach, kidney, gall bladder and Heart.

#### 4. Discussion

The aim of the present study was to estimate the patients' effective and organ doses from <sup>18</sup>F-FDG in whole body scan for both male and female patients during PET/CT imaging. The effective dose from PET/CT calculated in this study: 1.56–9.94 mSv was found to be lower than the international commission on radiological protection (ICRP) values (Cantone, 2009). It has been calculated that the effective dose is 3.88 mSv in females and 3.71 mSv in males. However, several studies have been published on absorbed dose of various internal organ <sup>18</sup>F-FDG administered based on the kinetics of the human <sup>18</sup>F-FDG distribution. The overall effective dose of the entire PET/CT procedures is close to previously reported results (15.7 ± 3.1 mSv for the baseline protocol and 11.2 ± 2.4 in the final protocol). The average successful total FDG full-body PET/CT in recent publications has been calculated to be 14 ± 1.3 mSv (Quinn et al., 2016), 14.2 mSv and 17.2 mSv in the male population (Kaushik et al., 2015), 13.6 and 12.7 in both systems (Avramova-Cholakova et al., 2015) and 14.5 mSv using the ICRP calculation (Willowson et al., 2012). However, we did not agree with previous studies in our current research results (Prieto et al., 2018, Quinn et al., 2016, Kaushik et al., 2015, Avramova-Cholakova et al., 2015, Willowson et al., 2012) Table 5. Conversely, very few studies have been carried out that provide the kind of kinetics data of <sup>18</sup>F-FDG distribution in people required for internal dosimetry calculations for both genders (Niven et al., 2001).

The patient's doses from the administered radiopharmaceutical for males and females is only made with one study reported by Kaushik et al group, in which a substantial difference in sex was recorded in the residency times and a dose absorbed by the brain in <sup>18</sup>F-FDG. No important difference in the time of residence and absorbed dose to male and female organ except for spleen have been shown in the previous study (Kaushik et al., 2013). In this current study, the mean and standard deviations were found to be strongly associated in females when compared to males as describe the human organs in Table 4.

**Table 5**  
Summarized comparison with previous studies for whole body diagnostic CT effective dose.

Effective dose (mSv)	14 ± 1.3	17.2	13.6	1.56–9.94
Pet/CT study	Quinn et al	Kaushik et al	Avramova-Cholakova et al	This study

Over recent decades, there has been a significant increase in the number of imaging procedures for PET/CT. Estimates of the patient's exposure are more important because of the late effects of radiation. The use of  $^{18}\text{F}$ -FDG will however in certain respects reduce the exposure to radiation taking into account the key radiation safety principles. Early cancer cells which break off the original tumor can be identified by the  $^{18}\text{F}$ -FDG.

CT dose reduction is of great significance for the patient as CT is the main contributor to the final efficient PET/CT dosage procedures, but PET dose reduction may have an effect on the patient as well as on the exposure of nuclear medicine personnel and PET/CT facilities. Final dose reduction protocol will be especially useful for patients undergoing recurring PET/CT scans (i.e. treatment monitoring). The final protocol has been in effect since May 2016, and physicians in nuclear medicine are secure in interpreting the PET/CT images. Although the minimum dose for PET or CT could not be reached in this analysis, consolidating the protocol was a priority before reducing more FDG dose (Prieto et al., 2018). Over the past 10 years the number of imaging procedures for PET/CT has greatly increased. Owing to the late results of radiation effects, the estimates of dose absorbed by patients become higher. The use of  $^{18}\text{F}$ -FDG will somehow reduce radiation exposure with due regard to the key radiation safety standards. Early cancer cells that break out of the original tumor are identified with the  $^{18}\text{F}$ -FDG.

There have been never been studies of the effects of a dual-time images scan on the CT effective dose due to the location of the arms in a PET/CT sample and the impact of the second PET/CT. We have shown in this analysis, in connection with the Torso- $^{18}\text{F}$  protocol, that ED increases by about two when the arms are next to the body relative to the location of the arms above the head. In addition, the overall effective dose of 18% of patients with body protocols in double-time imaging was increased by 3.8 mSv. In brain research there are very few references to patient dosimetry, other than those that include radiopharmaceutical and organ dosimetry records. Possibly because of the lower dose of these protocols relative to oncology trials in 18FDG. Only Ireland had 18FDG brain trials for DRL in 2014 (290 MBq) (Martí-Climent et al., 2017).

## 5. Conclusion

In conclusion, imaging using the  $^{18}\text{F}$ -FDG PET/CT whole-body scan significantly decreased the patient extremity dose while preserving the image quality. The average dose reported in this study which was conducted in Kuwait Cancer Control Center for 156 patients who were subjected to an  $^{18}\text{F}$ -FDG PET-CT whole-body test was 3.76 mSv. The effective dose calculated in this study, 1.56–9.94 mSv was less than the values recorded in ICRP 106, 2009. Our results indicate that the  $^{18}\text{F}$ -FDG dose in male and female patients does not vary from the previous findings. Yet, the authors strongly recommended that all the clinical practices should be justified and the risk–benefit proportions should be carefully weighted prior to any 18F-FDG whole-body PET/CT scan. Patient's doses are lower compared with previous studies, nonetheless optimization of CT dose is necessary since highest portion of patients' doses is from external exposure, especially from the CT component. Protection of sensitive organ from unjustified

exposure is necessary to reduce the risk and maximize the benefit of the procedure.

## Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Acknowledgment

This research was funded by the Deanship of Scientific Research at Princess Nourah bint Abdulrahman University through the Fast-track Research Funding Program to support publication in the top journal (Grant no. 42-FTJ-45).

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#### Further Reading

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