بسم الله الرحمن الرحيم

Sudan University of Sciences and Technology

College of Graduates Studies

Assessment of External Radiation Dose Rate after ^{18} Fluorodeoxyglucose Positron Emission Tomography Computed Tomography Examination

تقييم معدل جرعة الإشعاع الخارجية بعد فحص التصوير المقطعي المحوسب بإنبعاث البوزيترون بالفلورودوكسي جلوكوز18

Research Submitted for Partial Fulfilment of M.Sc. Degree in Nuclear Medicine Technology

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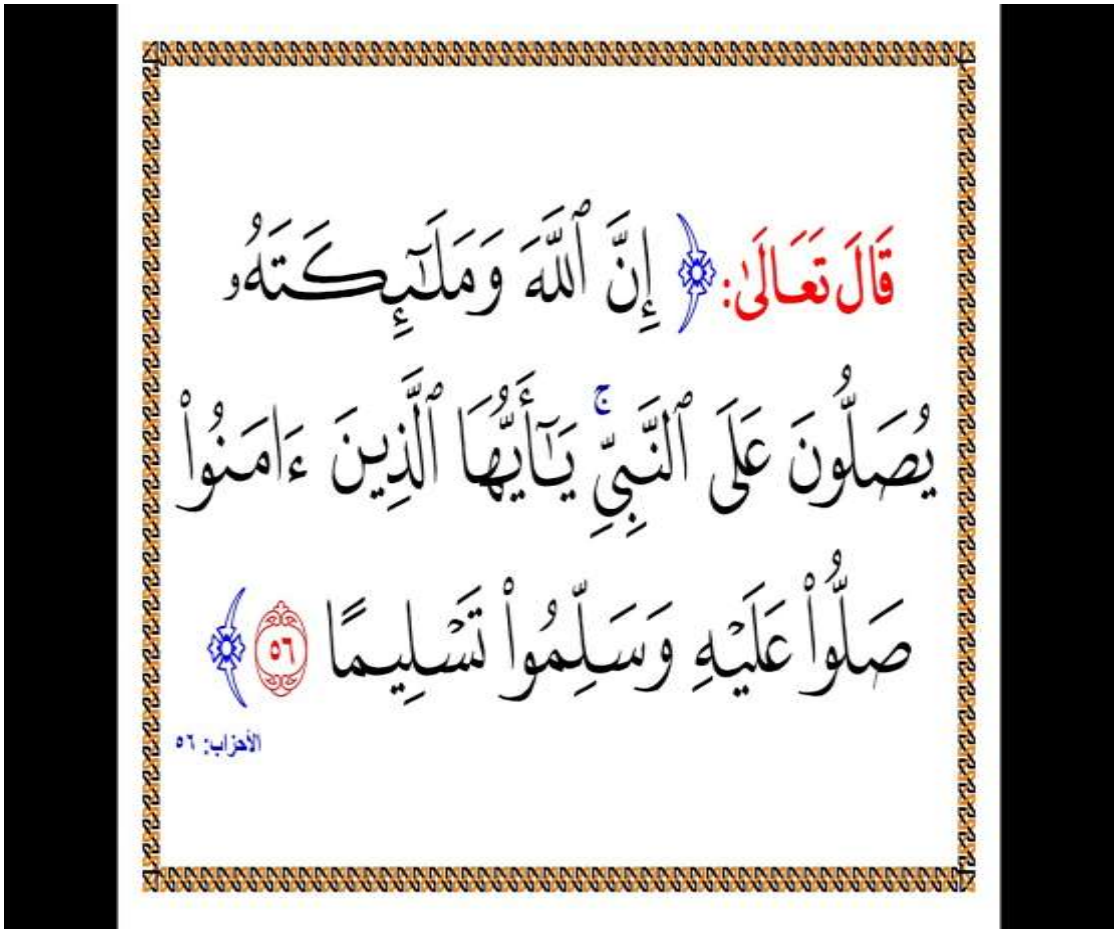
2022

الآية


قَالَ تَعَالَىٰ: ﴿ إِنَّ ٱللَّهَ وَمَلَٰٓئِكَتَهُۥ
يُصَلُّونَ عَلَى ٱلنَّبِيِّ ۚ يَٰٓأَيُّهَا ٱلَّذِينَ ءَامَنُواْ
صَلُّواْ عَلَيْهِ وَسَلِّمُواْ تَسْلِيمًا ﴿٥٦﴾
الأحزاب: ٥٦

Dedication

To my family who encourage and support me all the time

To my husband.....

To my son.....

To my teachers and colleagues.....

With love and respect.

Acknowledgment

All thanks and gratitude for Allah and my sincere gratitude also to Dr.Abdoalrahman Hassan Ali Bakry for his guidance, help and supervision until I accomplished this work.

deep thanks to Alsadeg Azrage for his help, support and encouragement.

I would like also to thanks all my friends and colleagues for their support.

And to my family I really can't thank them enough for their constant support and enormous care.

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Abstract

This study was conducted to assess the external radiation dose after 18FDG-PET/CT Examination. 117 patients were enrolled in the study. Radiation exposure was measured using a calibrated RadEye SPRD-ER personal radiation detector. The measurements were made at 0, 30, 100, 150, and 200cm distance from the patient. The time of measurement was; immediately post-injection, 30 min, 60 min after injection, and at the time of releasing the patient.

The result showed that the mean radiation equivalent dose rate at 0 min/0 cm was 414μSv/h, at 30 min/30 cm was 99.7μSv/h, and 60 min/100 cm was 18.3μSv/h. The radiation doses at different distances (0, 30, 100, 150, and 200cm) were 160.9μSv/h, 70.9μSv/h, 12.4μSv/h, 7μSv/h, and 3.7μSv/h respectively.

In conclusion, radiation protection will be sufficient within 2 h after (^{18}F-FDG) injection for PET/CT and the radiation dose can be limited by increasing distance from the radiation source.

المستخلص

أجريت هذه الدراسة لتقييم جرعة الإشعاع الخارجي بعد فحص FDG-PET / CT18. تم تسجيل 117 مريضا في الدراسة. تم قياس التعرض للإشعاع بإستخدام كاشف إشعاع شخصي معاير RadEye SPRD-ER. تم إجراء القياسات على مسافة 0 و 30 و 100 و 150 و 200 سم من المريض. كان وقت القياس ؛ بعد الحقن مباشرة ، 30 دقيقة ، 60 دقيقة بعد الحقن ، ووقت خروج المريض.

أظهرت النتيجة أن متوسط معدل جرعة الإشعاع المكافئ عند 0 دقيقة / 0 سم كان 414 سيفرت / ساعة ، عند 30 دقيقة / 30 سم كان 99.7 سيفرت / ساعة ، و 60 دقيقة / 100 سم كان 18.3 سيفرت / ساعة. كانت الجرعات الإشعاعية على مسافات مختلفة (0 ، 30 ، 100 ، 150 ، و 200 سم) هي 160.9 سيفرت / ساعة ، 70.9 سيفرت / ساعة ، 12.4 سيفرت / ساعة ، 7 سيفرت / ساعة ، و 3.7 سيفرت / ساعة على التوالي.

في الختام ، ستكون الحماية من الإشعاع كافية في خلال ساعتين بعد الحقن (F-FDG18) للـ PET / CT ويمكن تقييد جرعة الإشعاع عن طريق زيادة المسافة من مصدر الإشعاع.

List of abbreviations

PET: positron emission tomography

CT: computed tomography

FDG: Fluorodeoxyglucose

ALARA: As low as reasonably available

IAEA: International Atomic Energy Agency

TLD: Theromluminescent dosimeter

GTV: Gross Target Volume

SPECT: single-photon emission computerized tomography

^{99m}TC: Technetium-99m

ANSTO: Australian Nuclear Science and Technology Organization

ICRP: International Commission on Radiological Protection

NACL: Normal Saline

CT-AC: Computed Tomography for Attenuation Correction

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Chapter one

1.1. Introduction

Functional imaging with positron emission tomography (PET) is playing an increasingly important role in the diagnosis and staging of malignant disease, image-guided therapy planning, and treatment monitoring (Blodgett et al., 2007). PET with the labeled glucose analogue fluorine 18 fluorodeoxyglucose (FDG) is the most widely used radiopharmaceutical agent for clinical PET applications in general and oncology in particular. (Andersen et al., 2008)

It is a molecule similar to glucose labeled with a short physical half-life radionuclide (18F, 110 min). Unlike glucose, it is excreted mainly in the urine. On the other hand, positron-emitting florin generates 511 keV annihilation photons raising occupational as well as public safety concerns. To date, a number of studies have examined the occupational safety of this imaging modality (Benatar et al., 2000) however; information regarding environmental and public exposure following patient discharge is scarce. (Rohren et al., 2004)Such lack of information results in hesitations on the timing of safe patient discharge or safe referral to other hospital units. In nuclear medicine practice, as low as reasonably achievable exposure (ALARA) isawidelyacceptedprinciple.National and international regulatory bodies have set radioactivity levels at which patients can be discharged safely after radionuclide scan examinations. One of the most conservative guidelines recommends that the ambient dose equivalentrateat1mfromapatientwhounderwenttreatment with radioactive substance should not exceed 25 mSv/hour at the time of discharge. (Seierstad et al., 2007) The corresponding figure for the national guideline is 30 mSv/hour. (TAEA, 2000)

The radiation that is emitted from the radioactive tracer is more energetic than any other radiation used in medical diagnostic procedures and this requires special radiation protection routines. The CT image is based on the detection of radiation produced from an X-ray tube and transmitted through the patient. The total effective dose to the patient from a PET/CT procedure is ∼10 mSv. The major part comes from internal irradiation due to radiopharmaceuticals within the patients (18F-FDG: ∼6–7 mSv), and a minor part is due to the CT scan (low-dose CT scan: ∼2–4 mSv). The radiation dose to the personnel arises mainly due to handling of the radiopharmaceuticals (syringe withdrawal, injection, waste handling, etc.) and from close contact to the patient. This radiation dose can be limited by using the inverse-square law, i.e. by using the fact that the absorbed dose decreases substantially with increasing distance between the radiation source and the personnel (Leide, 2010).

Estimation of equivalent dose for members of the staff is monitored with the use of TLDs badges and electronic dosimeters (Dalianis et al., 2015).

The radiation dose to the patient from a PET/CT scan depends on the PET/CT protocol, the patient's size and physiology, amount of injected activity and the make and model of the PET/CT scanner (IAEA, 2008). The combined PET/CT examination results in an increased radiation dose to patients as compared to stand alone components of PET/CT scan and also other conventional diagnostic radiology examination (Huang et al., 2009) The effective doses from PET/CT investigations are reported to be 25 mSv(Brix et. Al., 2005), and 13.45 - 31.91 mSv for female patients and 13.65 – 32.18 mSv for male patients from three different PET/CT protocols (Huang et al., 2009).

The setup of a PET scanner in a nuclear medicine department (PET/CT scanner) for ^{18}F-FDG oncology imaging raised the issue of radiation dose exposure of technologists undertaking the preparation and administration

of this radiopharmaceutical. Indeed, the higher γ-radiation energy of positron-emitting isotopes (511 keV) means that staff members could receive a higher whole-body dose than those working only with conventional nuclear medicine tracers. To date, however, few data have been published on technologist radiation doses received during work in dedicated PET departments. (Saif et al., 2010)

This study aimed to measure the rate of radiation emitted from patients that underwent ^{18}FDG PET/CT examination in order to evaluate the radiation hazards to technologist and population.

1.2. Problem of the study:

The clinical applications of PET/CT have been expanding, given this rise, PET/CT technologists have become increasingly exposed to radiation, which increases their overall occupational radiation exposure however, there has been a lack of research exploring the level received by technologists.

1.3. Objective of the study:

1.3.1. General objective:

This study aimed to assess the rate of radiation emitted from patients that underwent ^{18}FDG PET/CT examination.

1.3.2. Specific objective:

- To measure the mean dose for patient and other at different distance and time.
- To find the significance of the measured radiation dose with stander level of absorbed dose to the others.
- To identify the safe dose, time and distance for discharging the patient.
- To measure the dose to others who transporting the PET-CT injected patient.

1.4. Significant of the study:

PET\CT is playing an increasingly important role in the diagnosis and staging of malignant disease, image-guided therapy planning, and treatment monitoring. This study introduced to measure and assess the dose reduction and exposure status at different distance and time to safely release the patient after successful exam. Therefore, protect the patient, co-patient and general populations.

1.5. Overview of the Study:

The following thesis was laid out into five chapters. Chapter one deals with introduction, problem of the study, objectives and Significant of the study. Chapter two highlights the literature review and theoretical background. Chapter three cares about methodology, Chapter four about results and discussion and Chapter Five show the conclusion, recommendation, references and appendices.

Chapter Two

Literature Review

2.1. Positron Emission Tomography–Computed Tomography (PET/CT):

Combining two established modalities such as CT and PET, is an evolution in imaging technology, integrating two existing technologies that have historically progressed along separate but parallel paths. The two modalities are complementary, with CT images lacking the functional specificity of PET and PET images lacking the anatomic detail seen on CT. Since its inception in the early 1970s, CT has developed into a high-throughput, rapid, reliable, and widely used modality yielding good-quality, high-resolution images of x-ray attenuation. Despite the introduction of MRI into the clinic in the early 1980s, CT has remained a major imaging modality with steadily improving performance. In many applications, such as radiation therapy planning, CT is still the anatomic imaging modality of choice. PET, on the other hand, was primarily a neuroscience research tool until 1999 when reimbursement was approved for whole-body ^{18}F-FDG scanning for certain cancers. Compared with CT, ^{18}F-FDG PET scans have lower spatial resolution and higher levels of noise and require significantly longer imaging times, resulting in low patient throughput. (Townsend et al., 2004)

Fig: 2.1. Show the PET/CT scanner

2.2. Principle:

Positron emission tomography (PET) is a tomographic technique that computes the three-dimensional distribution of radioactivity based on the annihilation photons that are emitted by positron emitter labelled radiotracers. PET allows non-invasive quantitative assessment of biochemical and functional processes. The most commonly used tracer at present is the glucose analogue FDG. FDG accumulation in tissue is proportional to the amount of glucose utilisation. Increased consumption of glucose is a characteristic of most cancers and is in part related to over-expression of the GLUT-1 glucose transporters and increased hexokinase activity. Given the kinetics of FDG adequate static images are most frequently acquired approximately 60 min after administration. It is recognized, however, that the uptake period is highly variable, FDG concentration not reaching a plateau for up to 4–6 h in some tumours. Moreover, not all cancers are FDG avid. Variable uptake is likely related to biological features of individual cancers, as is observed in broncho-alveolar carcinomas, renal, thyroid cancers, several subtypes of malignant

lymphoma, carcinoids but also most prostate carcinomas. The reason and prognostic relevance of this biological heterogeneity is not always clear. However, in the majority of cases, FDG PET is a sensitive imaging modality for the detection, staging, re-staging as well as for assessment of therapy response in oncology. In contrast to PET, computed tomography (CT) uses an x-ray beam to generate tomographic images. CT allows the visualisation of morphological and anatomic structures with a high anatomical resolution. Anatomical and morphological information derived from CT can be used to increase the precision of localisation, extent, and characterisation of lesions detected by FDG PET. FDG PET and CT are established imaging modalities that have been extensively validated in routine clinical practice. Integrated PET/CT combines PET and CT in a single imaging device and allows morphological and functional imaging to be carried out in a single imaging procedure. Integrated PET/CT has been shown to be more accurate for lesion localisation and characterisation than PET and CT alone or the results obtained from PET and CT separately and interpreted side by side or following software-based fusion of the PET and CT datasets. PET/CT gains more and more importance in oncology imaging. At the same time, there is greater awareness that the quantitative features of PET may have a major impact in oncology trials and clinical practice. Therefore this guideline focuses on the use of FDG PET/CT in oncology. (Boellaard et al., 2010)

2.3. Indications:

Currently, PET/CT has mostly found its application in the clinical practices of oncology (97 percent) and much less in infection (2 percent) and cardiology (1 percent).

2.3.1. Diagnosis

In diagnosis, the PET/CT is not frequently used. It is mostly indicated in the evaluation of single pulmonary nodules especially those that are not amenable to percutaneous biopsy and the assessment of lymph adenopathy. It also may be helpful in cases of abnormalities that are "intermediate," according to imaging criteria and the patient, if the clinician is hesitant to proceed with an invasive procedure or in cases of suspicious lesions examined pathoanatomically but with no definite diagnosis. Furthermore, PET/CT may be used in cases of pyrexia of unknown origin and suspected paraneoplastic syndromes. (Saif et al., (2010)

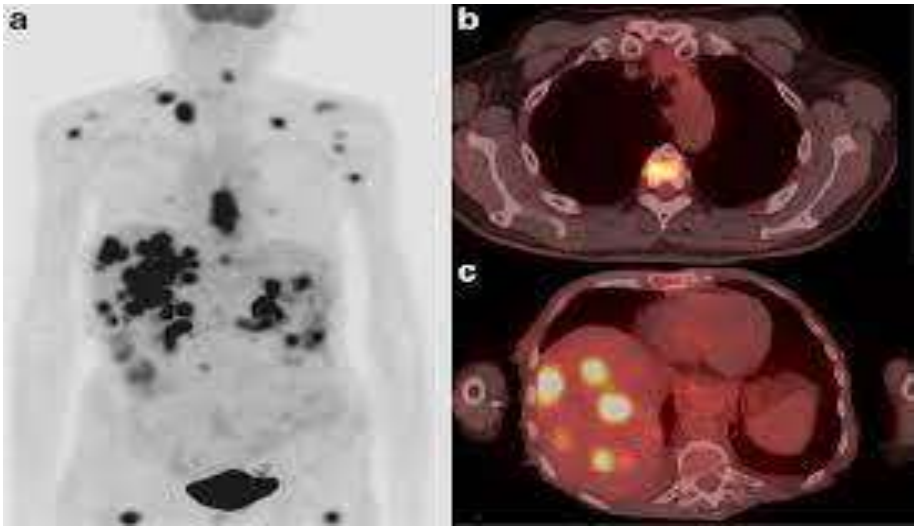


Fig: 2.2. Illustrate oesophageal cancer.

2.3.2. Staging and Restaging

When PET/CT was first introduced, the oncological indications approved by Medicare included staging and restaging of non-small cell lung cancer, esophageal cancer, colorectal cancer, pancreatic cancer, ovarian cancer, head and neck cancer, breast cancer, melanoma, and lymphoma. In 2003,

the additional indications of monitoring breast and thyroid cancer were approved, and it is expected that more indications will be approved in the future. (Saif et al., (2010)

2.3.3. Treatment monitoring

The assessment of residual tumor after a course of therapy (surgery, chemotherapy, or irradiation) is usually made by conventional anatomical imaging procedures, although FDG-PET is sometimes used in clinical practice during restaging. However, metabolic changes within the tumor have been documented very early after treatment. For example, FDG uptake reduction in patients with lymphoma can be monitored within a few hours after treatment. Evidently, a metabolic response, reflecting the malignant cells' viability, may precede an alteration in the size of a tumor lesion. As a result, reduced FDG uptake may demonstrate treatment effectiveness much earlier than a CT image, even after only one chemotherapy infusion. Studies demonstrated that the decrease of FDG uptake after a single infusion of chemotherapy was a predictor of eventual response to this regimen. Similarly, no decrease of tumor FDG uptake after the first infusion was a predictor of non-response. Morphological changes in the tumor usually occur after a certain interval following therapy. (Saif et al., (2010)

2.3.4. Radiotherapy planning:

PET/CT will have an important role in radiotherapy planning in the future. Successful radiation planning requires accurate evaluation of the extent of the disease. Traditionally, this is performed with a CT scan prior to radiotherapy simulation. The anatomical information is used in order to determine the radiation boundaries. However, the microscopic extension

of the tumor around the gross tumor volume (GVT) cannot be determined by CT. In order to overcome this problem, the volume treated is much greater than the gross tumor volume. On the other hand, precise and accurate localization of RT targeted to GTV is critical for optimizing the therapeutic ratio. By measuring the metabolically active tumor volume, PET on its own provides functional data that can be used in order to improve tumor coverage, including the involved lymph nodes, and thus reduce normal tissue exposure. (Saif et al., (2010)

2.3.5. Infectious diseases:

Imaging infections with molecular imaging technologies can improve diagnosis and treatment follow-up. Clinically, PET has been widely used to image bacterial infections using fluorodeoxyglucose (FDG) to identify the infection-associated inflammatory response. (Rudd et al., 2002)

2.3.6. Cardiology:

Cardiology, atherosclerosis and vascular disease study: [^{18}F] FDG PET can help in identifying hibernating myocardium. However, the cost-effectiveness of PET for this role versus SPECT is unclear. [^{18}F]FDG PET imaging of atherosclerosis to detect patients at risk of stroke is also feasible. Also, it can help test the efficacy of novel anti-atherosclerosis therapies. (Rudd et al., 2002)

2.4. Radionuclide production:

Radionuclides are required in both diagnostic and therapeutic nuclear medicine procedures. Naturally occurring radionuclides are generally not suitable for diagnostic and therapeutic procedures due to their typically long half-lives or less than ideal physical or chemical characteristics;

therefore appropriate radionuclides need to be produced. The common methods of radionuclide production for nuclear medicine include: fission, neutron activation, cyclotron and generator.

Fission occurs in a nuclear reactor where neutrons are used to bombard fission nuclides such as uranium-235 (^{235}U) or plutonium-239 (^{239}Pu). Fission results in the splitting of the large nucleus into smaller fission fragments along with the release of gamma radiation and high energy neutrons. Neutron activation also takes place in a nuclear reactor. The neutrons are used to bombard stable nuclides to form other radionuclides. There are disadvantages with this process so other production means are often preferred.

Cyclotrons are used to accelerate charged particles such as protons (p), deuterons (d), triton (t) and alpha (α) particles to high velocities to penetrate the orbital electrons of the target atom and interact with the nucleus. Generators produce the most commonly used radionuclide in nuclear medicine, technetium-99m (^{99m}Tc). The radionuclide generator sees the decay of a long half-life parent radionuclide to a short half-life daughter radionuclide. The daughter is the radionuclide used in nuclear medicine.

An understanding of radionuclide production will assist in the understanding of both diagnostic and therapeutic nuclear medicine procedures. (Currie et al., 2013)

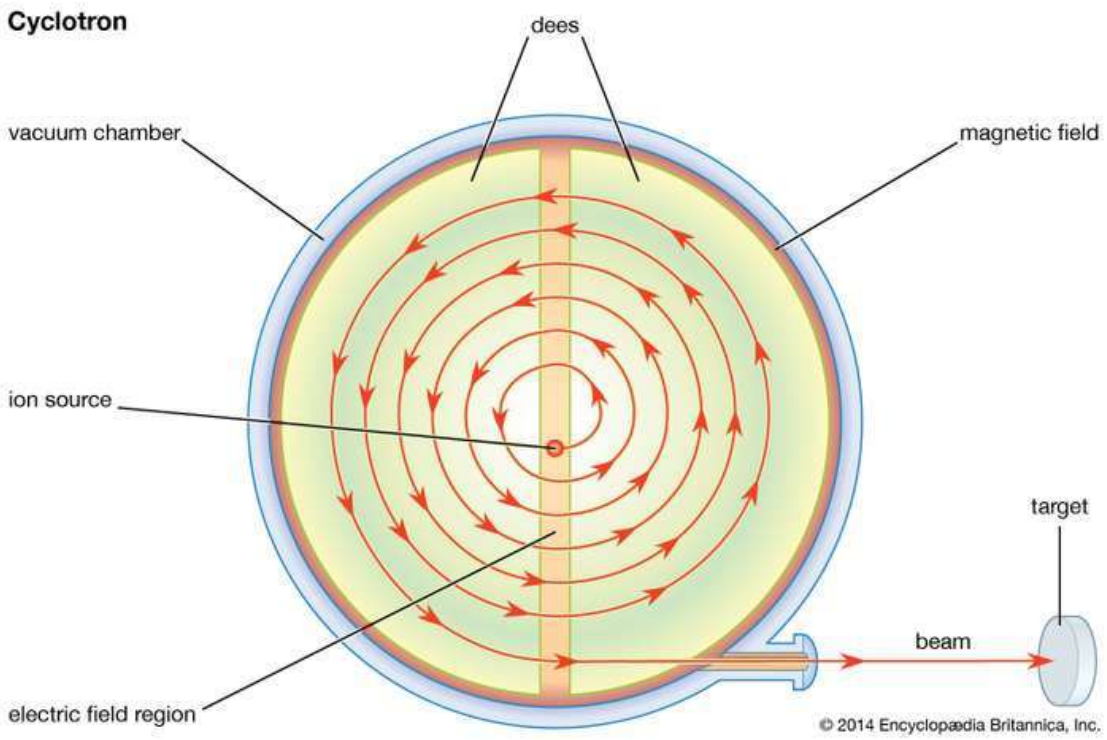


Fig: 2.3.a. demonstrate structure of cyclotron.

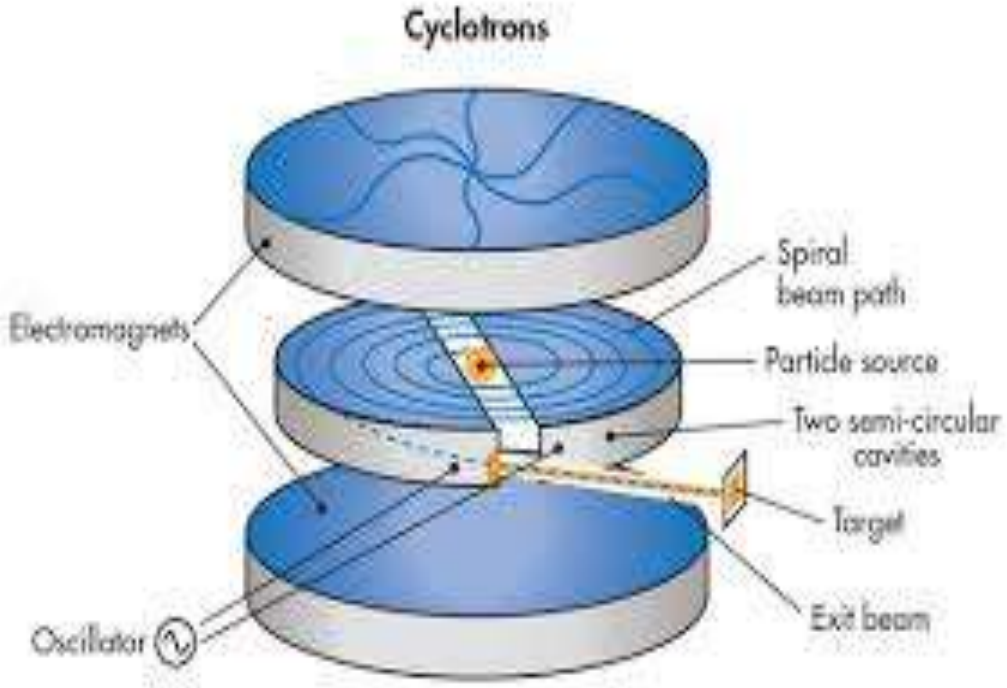


Fig: 2.3.b. demonstrate structure of cyclotron.

2.4.1. Cyclotrons and the Production of Unconventional Radionuclides:

A cyclotron can be thought of as a linear accelerator but using a spiral to overcome the long linear distance that would be required to reach the energies required. The cyclotron bombards a stable nuclei with high energy charged particles; protons (p), deuterons (d), triton (t) and even alpha (α) particles. To penetrate the nucleus of the target, the particles must be accelerated to very high energies. A charged particle gains speed and energy when it is attracted to an opposite charge. The cyclotron is comprised of a vacuum contained within semi-circular electrodes ('D's) within a magnetic field. Each 'D' is separated from the other by a narrow gap. Within seconds, a single neutron could produce tens of thousands of fission reactions. A single fission reaction can result in a further 9840 fission reactions in just nine generations. The charged particle will be attracted across the 'gap' toward the 'D' with the opposite charge. The magnetic field ensures the charged particle travel in a circular path through the 'D' with the radius dependent on the speed. When the charged particle traverses the first 'D', the charge on the 'D' has been switched so the particle is now repelled from the first 'D' and attracted to the second 'D'; picking up speed as it accelerates across the 'gap'. The charged particle then traverses the second 'D' in a circular arc with a larger radius because the speed is higher. This process continues until the charged particle reaches the target speed or energy. For example, when a proton is required for the target, a hydrogen ion is introduced at the centre of the cyclotron, accelerated and after reaching peak velocity or energy, the electrons are stripped using a carbon foil. The change in charge alters the orbit of the proton which is directed out of the 'D' and toward the target. The particle bombardment causes nuclear transformation. Some of

the more common cyclotron reactions include:1-4,6 • 68Zn [zinc] (p,2n) 67Ga • 122Te [tellurium] (d,n) 123I • 201Hg [mercury] (d,2n) 201Tl • 109Ag [silver] (α,n) 111In • 14N (p,α) 11C • 18O (p,n) 18F • 20Ne [neon] (d,α) 18F Cyclotrons are rated based on the energy of the accelerated charged particle. Small cyclotrons (9-11 MeV) are typically limited to producing fl uorine-18 (18F) for positron emission tomography (PET). Medium sized cyclotrons (in the order of 15 MeV) can produce a larger array of PET radionuclides (13N, 11C, 15O). Larger cyclotrons (30 MeV) are capable of producing other nuclear medicine radionuclides like 67Ga, 201Tl, 123I. In Australia, a 30 MeV cyclotron (Australian National Medical Cyclotron) was commissioned at Royal Prince Alfred Hospital in Sydney, Australia in 1990 to be operated as part of the Australian Nuclear Science and Technology Organisation (ANSTO) in tandem with the Lucas Heights reactor. The cyclotron was meant to provide both nuclear medicine and PET radionuclides. Prior to this, Australia imported nuclear medicine radionuclides at high cost and had no PET services. The facility largely failed to meet the dual needs and multiple smaller (9-15 MeV) cyclotrons. The National Medical Cyclotron was decommissioned commercially in 2010. It now only operates as a research facility and cyclotron radionuclides for non-PET nuclear medicine are again being imported; ironically more cheaply than local production. (Currie et al., 2013).

Today, more than 2700 radionuclides have been produced artificially with particle accelerators. In addition, a few examples are also being obtained *in loco* using radionuclide generators through radioactive decay.

PET radionuclides, in particular, can be produced in cyclotrons, especially using inducing *(p,n)* nuclear reactions in the targets of stable isotopes. Routine cyclotron production processes are made possible by

the actual dissemination of these devices. As a matter of fact, by the end of 2005, there were 262 cyclotrons operating in the 39 member states of International Atomic Energy Agency (IAEA); however, it was believed that around 350 cyclotrons were operating in the whole world, according to a database of the agency. Unfortunately, there is no official update of this report, because it is not easy to correctly estimate the number of cyclotrons operating nowadays all over the world.

The commercially available cyclotrons can be classified with respect to the particle type and maximum energy reached, the method of ion production, the technique of beam extraction from the cyclotron (or absence of extraction), the intensity of the accelerated ion beams, and other specific properties or features. There are different classifications based on the type and energy of the accelerated particles. Independently from the classification used, an important aspect to mention is that near 70% of the cyclotrons disseminated over the world are low-energy cyclotrons (≤20 MeV).

According to empirical and practical evidence, the cyclotrons that typically have been applied worldwide in radionuclide production comprise properties such as: (i) the capability of accelerating negative ions (H^-); (ii) beam extraction using stripper foils; (iii) fixed beam energy between 10–18 MeV, or 10–24 MeV mainly if the installation is intended for the production of many radionuclides, large-scale production and/or research purposes; (iv) fixed frequency of the RF generator; (v) two or four *dees* placed in valleys; (vi) internal ion source(s); (vii) the possibility of adjusting the beam position on the target; (viii) possibility of multi-target irradiations; (ix) compact radiation shielding around the device ("self-shielded" cyclotron); and (x) a high level of automation and simplicity in maintenance.

Despite the existence of the formal classifications, cyclotrons that respect the criteria stated in the last paragraph are normally classified by professionals of the field as “small cyclotrons”, “low-energy cyclotrons” or even as “medical cyclotrons”, and are applied to induce *(p,n)* reactions, which are typically low-energy processes with a constant onset below 9 MeV. (Costa et al., 2018)

2.5. Radiopharmaceuticals:

Table 2.1. Shows the radiopharmaceutical**:**

Product	: [^{18}F]-fluorodeoxyglucose (FDG)
Nuclide	: Fluorine-18
Dosage	: Dependent on the system and the patient’s weight.
Administration	: Intravenous
Synthesis and Quality Control	: Conform the European Pharmacopeia

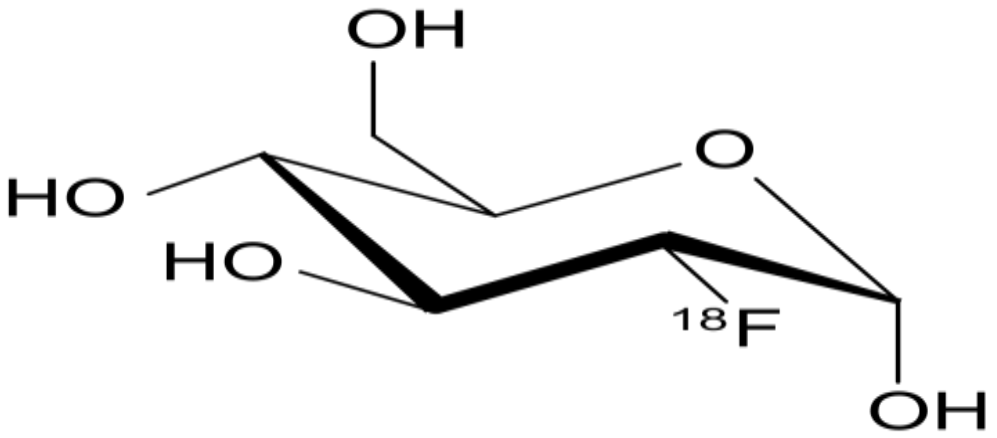


Fig: 2.4. Chemical structure of 18 FDG.

2.6. Patient preparation:

The main purpose of the patient preparation is the reduction of tracer uptake in normal tissue (kidneys, bladder, skeletal muscle, myocardium, brown fat) while maintaining and optimizing tracer uptake in the target structures (tumour tissue). Generally applicable protocol that Patients are not allowed to consume any food or sugar for at least 6 h prior to the start of the PET study (i.e. with respect to time of injection of FDG). In practice, this means that patients scheduled to undergo the PET study in the morning should not eat after midnight and preferably have a light meal (no alcohol) during the evening prior to the PET study. Those scheduled for an afternoon PET study may have a light breakfast before 8.00 a.m. (i.e. up to two sandwiches, no sugars or sugar containing sandwich filling). Medication can be taken as prescribed. Farther more adequate pre-hydration is important to ensure a sufficiently low FDG concentration of FDG in urine (less artefacts) and for radiation safety reasons (for example, 1 l of water in the 2 h prior to injection; where

necessary, account for volume of water in oral contrast medium for a diagnostic CT scan). Also Parental nutrition and intravenous fluids containing glucose should be discontinued at least 4 h before the PET/CT examination. In addition, the infusion used to administer intravenous pre-hydration must not contain any glucose. Additionally During the injection of FDG and the subsequent uptake phase the patient should remain seated or recumbent and silent to minimise FDG uptake in muscles. For a brain examination with FDG, injection should take place in a darkened and quiet room and the patient should stay there for the subsequent uptake phase to avoid areas of enhanced uptake due to brain activation. The patient should be kept warm starting at 30–60 min before the injection of FDG and throughout the following uptake period and PET examination to minimise FDG accumulation in the brown fat (especially relevant if the room is air conditioned). Moreover, all patients must avoid (extreme) exercise for at least 6 h before the PET study (for example, they must not cycle to the hospital). (Boellaard et al., 2010)

2.7. Radiation exposure:

The radiation dose with PET/CT or PET is the combination of the radiation exposure caused by the radiopharmaceutical and the CT study (or the external transmission sources). Radiation dose of diagnostic CT has been a matter of debate over the last years, particularly for paediatric examinations. It is difficult to state a mean dose for a CT scan because of the variety of applications, protocols, and CT systems. Especially for children but also for adults it is of importance to optimise the radiation exposure with respect to the diagnostic question. In recent years there has been much effort to minimise the radiation dose related to a conventional CT-or PET-examination. The radiation dose of FDG is approximately

2×10^{-2} mSv/MBq according to ICRP publication 106, i.e. about 3–4 mSv for an administered activity of 185 MBq. The radiation exposure related to a CT performing a PET/CT examination depends on the intention of the CT carried out and may differ from case to case: the CT can be performed as a low-dose CT (with lower voltage and current) to be used for attenuation correction and localisation of PET lesions. Alternatively (or additionally) a diagnostic CT can be indicated (in most cases with intravenous contrast agent application and deep inspiration in case of a chest CT) for a full diagnostic CT examination. The effective CT-dose could range from 1–20 mSv and may be even higher for a high resolution diagnostic CT scan. Given the variety of CT systems and protocols the radiation exposure for a PET/CT examination should be estimated specific to the system and protocol being used and an expert from radiology or guidelines provided by the European radiological societies should be consulted regarding effective dose from the CT examination. The choice of the imaging protocol used strongly depends on the clinical question and must be discussed for every single case. In this respect, special attention is required in case of paediatric applications. For the optimisation of PET/CT examinations, dose reduction techniques should be considered. (Boellaard et al., 2010)

2.8. Performing the PET/CT study:

In case of manual administration an indwelling intravenous device is used to administer the FDG intravenously once the patient’s blood glucose has been determined and blood samples for laboratory testing have been taken if necessary. Make sure that if there is a needle on the syringe it is

free from FDG.Flush and rinse out the administration syringe with at least 10 ml of normal saline (NaCl 0.9%) using the three-way valve.

In case of automated administration make sure that the automated system and procedures assures a net administered FDG activity within 3% accuracy (this must be ensured by manufacturer and verified by the user), i.e. the actual administered activity may not deviate more than 3% from that indicated by the reading of that device or used dose calibrator. Follow instructions given by the manufacturer. The administration system can be removed after intravenous administration (unless CT contrast agent is to be administered subsequently by intravenous injection).The ambient conditions in the waiting room must be relaxing and warm. Give the patient extra blankets if necessary. Tell the patients to lie or sit as calmly as they can, and not to talk. Provide comfortable beds or chairs. They may go to the toilet while waiting, preferably after the first 30 min. ask the patient to use the bathroom 5 min before the start of the PET study.An intense bladder or ureter activity concentration can impair the interpretation of lesions in the pelvis and retroperitonium. Hydration and loop diuretics (e.g. furosemide i.v.) may be used to reduce bladder activity and radiation exposure to the bladder. Therefore, during the waiting period, patients will be asked to drink another half a litre of water, or this amount can be given in the form of physiological saline intravenously, if such fluid load is not medically contra-indicated. This is of course dependent on the patients other clinical conditions, e.g. impaired renal function or poor cardiac function, where this amount of fluid may be contraindicated. The recommended interval between FDG administration and the start of acquisition is 60 min. However, for certain clinical trials this may change depending on the disease and aims of the study. This should then be clearly stated in the study protocol. The actual

interval should be recorded, i.e. the time of FDG injection (administration) should be reported. Please be aware that this is usually not equal to the FDG activity assay or calibration time. Note that consistency of SUV measurements (in-house and compared with literature) depends on strict application of the interval schedule and therefore a 60-min interval is recommended. When repeating a scan on the same patient, especially in the context of therapy response assessment, it is essential to apply the same interval (tolerance ±5 min). In addition, use of the same PET or PET/CT system and identical acquisition and reconstruction settings must be applied when making multiple scans of the same patient.

Scan trajectory for most oncology indications, a whole-body scan is sufficient. A ‘whole-body’ uptake normally covers the part of the body from the mid-femora to the external auditory meatus (in that direction, as bladder activity increases during the scan). A longer scanning trajectory may be used if appropriate. Whole-body PET/CT offers the opportunity for whole-body staging/re-staging. For most oncology indications, skull base-to-mid thigh tumour imaging is sufficient. Extended whole-body examinations are performed in tumours that show a high probability of metastases in the head, skull, brain, cranium, and in the lower extremity. Limited-area tumour imaging can be considered for follow-up examinations, if the disease is restricted to a defined region (i.e. solitary pulmonary nodule, suspicion of lung cancer, examination of hilar lymph nodes, head and neck tumours, assessment of therapy response).

The patient should be positioned with the arm elevated over the head to avoid beam hardening artefacts as well as artefacts caused by truncation of the field of view. For the examination of head and neck tumours, a

two-step protocol is recommended (head and neck portion and from the apex of the lung through mid-thigh) with the appropriate acquisition and reconstruction parameters adapted for the protocol. Alternatively, the arms can be positioned along the side for head and neck imaging. If the FDG PET/CT data are used for radiation planning, the examination should be carried out in the radiation position using the same dedicated radio-opaque positioning devices as used in the radiotherapy department (e.g. same table tops, laser alignment, immobilisation measures, etc.).

Scan acquisition depends on various factors, including the system type and acquisition mode (2D, 3D). For CT settings in case of PET/CT, CT whole-body or low-dose CT. Transmission scanning time for each bed position depends on whether the scan is a CT scan or a transmission scan with Ge-68/Ga-68 source.

In general, PET/CT is carried out using a protocol comprising a scanogram/scout scan/topogram and a low-dose CT for attenuation correction (CT-AC) and anatomical correlation. IV contrast agent must not be administered during the low-dose CT, used for attenuation correction purposes, because of its potential influence on SUV calculation.

In the case of single slice or dual-slice CT, artefacts are created in the diaphragm area when the patient breathes. The patient must therefore hold his/her breath for a few seconds on the technician’s instructions during CT-AC acquisitions. No such instructions need be given in the case of PET/CT systems with more than two slices. The CT-AC scan can then be carried out while the patient continues to breathe shallowly. A standard diagnostic CT scan with (i.v.) contrast agent may, if appropriate, be carried out according to standard radiological methods after the low-

dose CT and PET acquisition in case quantification of the PET study will be performed or is required.

Recommendations for FDG activities are based on assuming a fixed scan duration of 5 min per bed position and a bed overlap of less than 25%. In the case of 2D scans: ca. 5 MBq/kg body weight (±10%). In the case of 3D scans: ca. 2.5 MBq/kg body weight (±10%). (Boellaard et al., 2010)

2.9. Safety:

PET scanning is non-invasive, but it does involve exposure to ionizing radiation. 18FDG, which is now the standard radiotracer used for PET neuroimaging and cancer patient management (Kelloff et al., 2005) has an effective radiation dose of 14 mSv. For comparison, radiation dosage for other medical procedures range from 0.02 mSv for a chest x-ray and 6.5–8 mSv for a CT scan of the chest. (Jong et al., 2008) Average civil aircrews are exposed to 3 mSv/year (IAEA, 2008) and the whole body occupational dose limit for nuclear energy workers in the USA is 50mSv/year. (NRC, 2020)

For PET-CT scanning, the radiation exposure may be substantial around 23–26 mSv (for a 70 kg person dose is likely to be higher for higher body weights). (Brix et al., 2005)

2.10. Limitations:

The minimization of radiation dose to the subject is an attractive feature of the use of short-lived radionuclides. Besides its established role as a diagnostic technique, PET has an expanding role as a method to assess the response to therapy, in particular, cancer therapy, where the risk to the patient from lack of knowledge about disease progress is much greater

than the risk from the test radiation. Since the tracers are radioactive, the elderly and pregnant are unable to use it due to risks posed by radiation. (Young et al., 1999)

Limitations to the widespread use of PET arise from the high costs of cyclotrons needed to produce the short-lived radionuclides for PET scanning and the need for specially adapted on-site chemical synthesis apparatus to produce the radiopharmaceuticals after radioisotope preparation. Organic radiotracer molecules that will contain a positron-emitting radioisotope cannot be synthesized first and then the radioisotope prepared within them, because bombardment with a cyclotron to prepare the radioisotope destroys any organic carrier for it. Instead, the isotope must be prepared first, then afterward, the chemistry to prepare any organic radiotracer (such as FDG) accomplished very quickly, in the short time before the isotope decays. Few hospitals and universities are capable of maintaining such systems, and most clinical PET is supported by third-party suppliers of radiotracers that can supply many sites simultaneously. This limitation restricts clinical PET primarily to the use of tracers labelled with fluorine-18, which has a half-life of 110 minutes and can be transported a reasonable distance before use, or to rubidium-82 (used as rubidium-82 chloride) with a half-life of 1.27 minutes, which is created in a portable generator and is used for myocardial perfusion studies. Nevertheless, in recent years a few on-site cyclotrons with integrated shielding and "hot labs" (automated chemistry labs that are able to work with radioisotopes) have begun to accompany PET units to remote hospitals. The presence of the small on-site cyclotron promises to expand in the future as the cyclotrons shrink in response to the high cost of isotope transportation to remote PET machines.(Fratt, 2008) In recent years the shortage of PET scans has been alleviated in the

US, as rollout of radio pharmacies to supply radioisotopes has grown 30%/year.(Phelps, 2015)

Because the half-life of fluorine-18 is about two hours, the prepared dose of a radiopharmaceutical bearing this radionuclide will undergo multiple half-lives of decay during the working day. This necessitates frequent recalibration of the remaining dose (determination of activity per unit volume) and careful planning with respect to patient scheduling.

2.11. Quality control:

The overall performance of PET systems can be evaluated by quality control tools such as the Jaszczak phantom. (Prekeges and Jennifer, 2012).

2.2. Previous Study:

Talab et al, (2013) estimated the radiation exposure to the physicians & technologists working in PET/CT facility based on the dose rate measurement with regularly calibrated pocket dosimeter and thermo-luminescent detector (TLD); for cumulative dose confirmation. The mean dose measured at the chest level per PET/CT procedure was4 μSv and 4.75μSv for the physicians and technologists respectively. The mean dose to the physicians per MBq of 18F-FDG injected was10nSv/MBqand35nSv/MBq at the chest and wrist levels respectively; whereas it was 12 and 25 nSv/MBq for technicians respectively.

Damir et al., (2011) they purposed to measure the total radiation doses for the radiation workers and for the accompanying person to the patients in positron emission tomography (PET)/computed tomography (CT) imaging. Urines samples from the patients were collected at 43, 62, 87, 117, 238, 362 min after the 555-MBq ^{18}flour-fluorodeoxyglucose (^{18}F-FDG) injection and activities were measured. Dose rates were recorded using a Geiger–Muller counter and the total radiation doses were measured with using an electronic personnel dosemeter. According to the results here, 18.4 % of ^{18}F-FDG was excreted in the urine in 117 min after injection. At 117th min after injection, dose rates were determined as 345, 220, 140, 50 and 15 μSv h^{-1}, at proposed distances. The radiation doses after 117 min were measured as 3.92 mSv at 0.1 m, 2.11 mSv at 0.25 m and 1.08 mSv at 0.5 m. In conclusion, radiation protection will be sufficient within 2 h after ^{18}F-FDG injection for PET/CT imaging in daily practice.

Berberoglu et al., (2019) aimed to measure the rate of radiation emitted from patients that underwent ^{18}FDG PET/CT examination for oncological conditions, approximately 2 hours after the procedure,before and after urination. A total of 100patients who underwent^{18}F-FDGPET/CTexaminationwere included in this study. Following imaging, external radiation exposure rate was measured using proportional counter probe at 1-m distance, approximately 2 hours after the completion of imaging procedure, before and after urination. Factors effecting resulting exposure from patients were examined. The mean post-urination activity ranged between 0.2 and 6.3 mSv/h (median, 1.8 mSv/h). Presence of metastasis, tumor type and gender did not have any effect on mean post-urination activity (P>0.05 for all comparisons). Older age, greater BMI and higher administered dose were associated with higher post-urination activity (P<0.05for all comparisons). Findings of this study showed that 2hours after radionuclide injection, activity rate from patients is far below the recommended limits for general population and further decreases after urination.

Emad et al, (2018) aimed to assess the radiation exposure resulting from radioactive patients injected with different activities of 2-[^{18}F] fluoro-2-deoxy-D-glucose (^{18}F-FDG) in PET/CT units. This objective is fulfilled by measuring the dose rates practically inside and outside PET/CT rooms around radioactive patients using a calibrated survey meter. Afterwards, the dose rates are estimated mathematically using Monte Carlo simulation model. The results show that the dose rates on patient's body surface decrease greatly with distance and it is recommended for PET/CT staff to stand at distances more than 1.5 m from radioactive patients if possible during direct contact. Also, it is found that the shielding thickness in the

selected room dimensions is adequate and effective for the γ-radiation arising from radioactive patients. The practically measured dose rates around radioactive patients are quite similar to mathematically predicted results and slight differences may be attributed to the difference between the estimated ^{18}F biological half life time and real biological half life time due different biological uptake or excretion time from one patient toanother.

Briks et al, (2005) investigated radiation exposure of patients undergoing whole-body ^{18}F-FDG PET/CT examinations at 4 hospitals equipped with different tomography. Patient doses were estimated by using established dose coefficients for ^{18}F-FDG and from thermoluminescent measurements performed on an anthropomorphic whole-body phantom. And the Results show that The most relevant difference between the protocols examined was the incorporation of CT as part of the combined PET/CT examination: Separate low-dose CT scans were acquired at 2 hospitals for attenuation correction of emission data in addition to a contrast-enhanced CT scan for diagnostic evaluation, whereas, at the other sites, contrast-enhanced CT scans were used for both purposes. Nevertheless, the effective dose per PET/CT examination was similar, about 25 mSv. And they conclude that the dosimetric concepts presented in this study provide a valuable tool for the optimization of whole-body ^{18}F-FDG PET/CT protocols. Further reduction of patient exposure can be achieved by modifications to the existing hardware and software of PET/CT systems.

Seierstad et al., (2006) studied the doses to nuclear technicians in a dedicated PET/CT centre utilising 18F fluorodeoxyglucose (FDG) this study was carried out in order to map the doses to staff members during different working operations and to see if any dose reducing measures

were needed. The results of the study are in good agreement with other studies, and a technician dose of 20–25 nSv per injected MBq of ^{18}F seems to be representative for such centres. For an average injected activity of 350 MBq per patient, the dose limit is reached after handling around 3000 patients annually. For an annual number of less than 500 patients at the centre and rotation of the staff, an annual individual dose for the technicians would realistically be less than 2–3 mSv. Even a major increase in the number of patients will not result in individual doses near the ICRP dose limit.

Roberts et al., (2005) they conducted a prospective study of the radiation exposure of technologists working in PET and evaluated the occupational radiation dose after implementation of strategies to lower exposure. Radiation doses measured by thermoluminescent dosimeters over a 2-y period were reviewed both for technologists working in PET and for technologists working in general nuclear medicine in a busy academic nuclear medicine department. The separate components of the procedures for dose administration and patient monitoring were assessed to identify the areas contributing the most to the dose received. The impact on dose of implementing portable 511-keV syringe shields (primary shields) and larger trolley-mounted shields (secondary shields) was also compared with initial results using no shield and they found that the radiation exposure of PET technologists was higher than that of technologists performing general nuclear medicine studies, with doses averaging 771 +/- 147 and 524 +/- 123 microSv per quarter, respectively (P = 0.01). The estimated dose per PET procedure was 4.1 microSv (11 nSv/MBq). Injection of 18F-FDG contributed the most to radiation exposure. The 511-keV syringe shield reduced the average dose per injection from 2.5 to 1.4 microSv (P < 0.001). For the longer period of dose transportation and

injection, the additional use of the secondary shield resulted in a significantly lower dose of radiation than did use of the primary shield alone or no shield (1.9 vs. 3.6 microSv [P = 0.01] and 3.4 microSv [P = 0.03], respectively). They conclude that the radiation doses currently received by technologists working in PET are within accepted occupational health guidelines, but improved shielding can further reduce the dose.

Guillet et al, (2005) the use of 18F-FDG for clinical PET studies increases technologist radiation dose exposure because of the higher gamma-radiation energy of this isotope than of other conventional medical gamma-radiation-emitting isotopes. Therefore, 18F-FDG imaging necessitates stronger radiation protection requirements. The aims of this study were to assess technologist whole-body and extremity exposure in our PET department and to evaluate the efficiency of our radiation protection devices (homemade syringe drawing device, semiautomated injector, and video tracking of patients). Radiation dose assessment was performed for monodose as well as for multidose 18F-FDG packaging with both LiF thermoluminescence dosimeters (TLD) and electronic personal dosimeters (ED) during 5 successive 18F-FDG PET steps (from syringe filling to patient departure). The result show that the mean +/- SD total effective doses received by technologists (n = 50) during all of the working steps were 3.24 +/- 2.1 and 3.01 +/- 1.4 microSv, respectively, as measured with ED and TLD (345 +/- 84 MBq injected). These values were confirmed by daily TLD technologist whole-body dose measurements (2.98 +/- 1.8 microSv; 294 +/- 78 MBq injected; n = 48). Finger irradiation doses during preparation of single 18F-FDG syringes were 204.9 +/- 24 and 198.4 +/- 23 microSv with multidose vials (345 +/- 93 MBq injected) and 127.3 +/- 76 and 55.9 +/- 47 microSv with

monodose vials (302 +/- 43 MBq injected) for the right hand and the left hand, respectively. The protection afforded by the semiautomated injector, estimated as the ratio of the doses received by TLD placed on the syringe shield and on the external face of the injector, was near 2,000. These results showed that technologist radiation doses in our PET department were lower than those reported in the literature. This finding may be explained by the use of a homemade syringe drawing device, a semiautomated injector, and patient video tracking, allowing a shorter duration of contact between the technologist and the patient. Extrapolation of these results to an annual dose (4 patients per day per technologist) revealed that the annual extrapolated exposure values remained under the authorized limits for workers classified to work in a radioactivity-controlled area.

Weiguo et al., (2020) The aim of this study was to measure occupational exposure doses of technologists who dispense and inject radiopharmaceuticals in 7 positron emission tomography/computed tomography (PET/CT) departments. This was done with the goal to help improving protective designs in PET departments and/or establishing national protection standards. Common LiF thermoluminescence dosimeters (TLDs) were placed on the chest and necklace of the technologists to monitor whole-body and thyroid doses, respectively. Ring TLDs were also worn on both index fingers to measure individual hand doses. All TLDs were assembled and measured once every 3 months for a total of 12 months. Additionally, we measured and compared the dose of TLDs attached to both the inside and the outside of the technologist's lead coat. The results show that technologists received relatively high exposures, which accounted for 64% to 94% of the collective dose in their respective departments. Their thyroid doses

ranged from 1.2 to 1.7 mSv/a; some technologists' hand doses exceeded 500 mSv/a. Use of a lead coat reduced the average dose by 8%. They conclude that technologists working in PET/CT departments were the main population exposed to radiation. This work underscores the need for enhanced protective measures for these workers to better reduce their exposure, particularly for their hands.

Chapter Three

Methodology

3.1. Materials:

^{18}F-FDG studies were performed using a PET/CT scanner (GE Healthcare scanner with an absolute sensitivity of 10 cps/Kbq) (GE optima 520 16 slice solarix (3.5 MHU) tube. European Association of Nuclear Medicine (EANM) procedure guidelines for tumour imaging (version2) was followed for patient preparation and imaging. Each patient received ^{18}F- FDG (18flour-fluorodeoxyglucose) intravenously through an intravenous catheter and imaging was done after an hour of rest. The mean administered dose was 260.3 ± 55.5 MBq(range,136.9–421.8).

3.2. Methods:

External radiation rate form the patient was the main focus of this study; where the problem originating from the machine breakdown at the department and the patient already injected the FDG dose, so patients were safely transported to the other department to perform the imaging procedure of the patient, then the study was conducted to measure and assess the external radiation rate in term radiation equivalent dose rate, when the readings converted from mR/h to µSr/h.

Measurement was done using calibrated survey meter immediately after the injection, 30 mints, and 60mints and at time of patient release; each measurement was repeated at 0cm, 30cm, 100cm, 150cm and 200cm distances for each time to assess the differences in time and distance effect in radiation exposure reduction.

Then the data transferred to the Excels Microsoft office program and SPSS (21.0 version) to calculate the mean and STD of each measurement in mSr/h and the Paired sample t-test has measured the difference in dose reduction level at release time for different distances (at $p<0.05$, and CL=95%).

3.2.1. Study design:

This was analytical nuclear medicine study aimed to measure and assess the rate of radiation emitted from patients that underwent ^{18}FDG PET/CT examination.

3.2.2. Area of the study:

This study was conducted at Universal Hospital, Khartoum State.

3.2.3. Duration of the study:

This study conducted in period from February -July 2020.

3.2.4. Sample of the study:

This study consist of 117 patients underwent ^{18}FDG PET\CT examination.

3.2.5. Inclusion criteria:

The study was carried out in all patients injected by 18Ffluorodeoxyglucose (FDG).

3.2.6. Exclusion criteria:

Patient injected by other radiopharmaceuticals was clearly excluded from this study.

3.2.7. Method of data collection:

The data were collected using standard master data sheet contain the necessary study variables.

3.2.8. Data collection variables:

Patient age, weight, dose and exposure rate

3.2.9. Example of master data sheet used for data analysis:

Time	D=0	D=0.3 m	D=1m	D=1.5m	D=2m
Post Injection					
At 30mint					
At 60mint					
At Release time					

3.2.10. Method of data analysis:

All data were presented as mean± SD values. Data were analyzed by pair sample two-tailed t-test and by correlation analysis with the use of the SPSS (Inc., Chicago, Illinois version 21.0). A value of $P< 0.05$ was considered significant.

3.2.11. Ethical issues:

- There was official written permission to Universal Hospital to take the data.
- No patient data were published also the data was kept in personal computer with personal password.

Chapter Four

Results

Table 4.1. Showed the mean difference in equivalent dose rate (µSv/h) measured at a different time (minute) and distance D (cm) for FDG/PET-CT radiopharmaceuticals

Time	D=0	D=30cm	D=100cm	D=150cm	D=200cm
Post Injection	414	136.5	38.4	19.3	10.3
At 30 min	282	99.7	25.8	12.8	6.9
At 60 min	222	77.1	18.3	8.8	5.1
At Release time	161	70.9	12.4	7.00	3.7

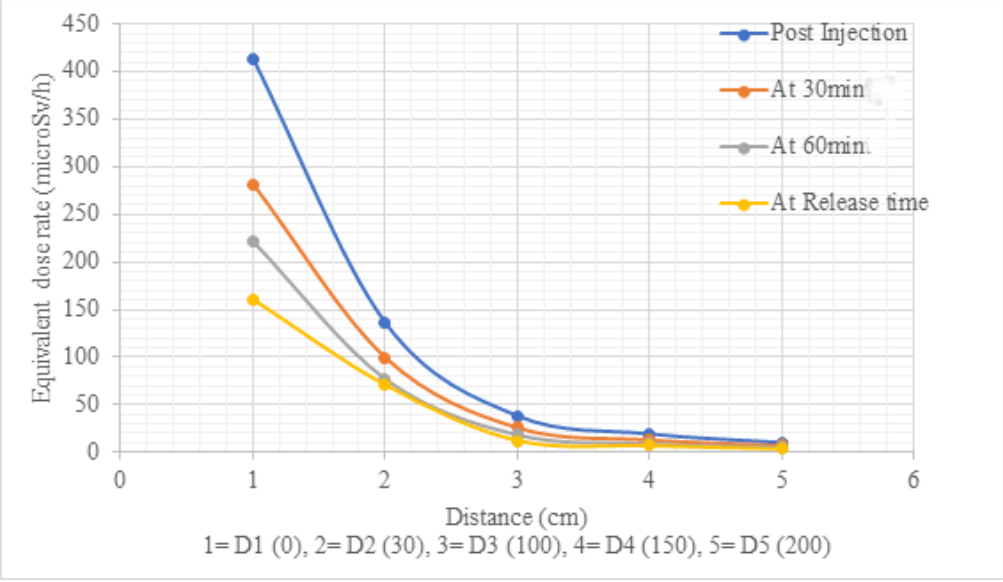


Figure 4. 1. A line graph demonstrates the external dose reduction rate (µSv/h) status for different time (T) and distance (cm).

Table 4. 2. Demonstrates the mean dose rate (µSv/h) for patient urinated and not urinated post-injection and at the time of patient release

Time	**D=0**	**D=30cm**	**D=100cm**	**D=150cm**	**D=200cm**
Urinated Post Injection	389	132.3	37.7	19.0	9.2
Non-Urinate Post Injection	423	138.0	40.1	19.8	10.7
Urinated At Release time	145.4	53.9	12.2	5.9	3.2
Non-Urinate At Release time	166.7	115.4	13.0	7.4	3.9

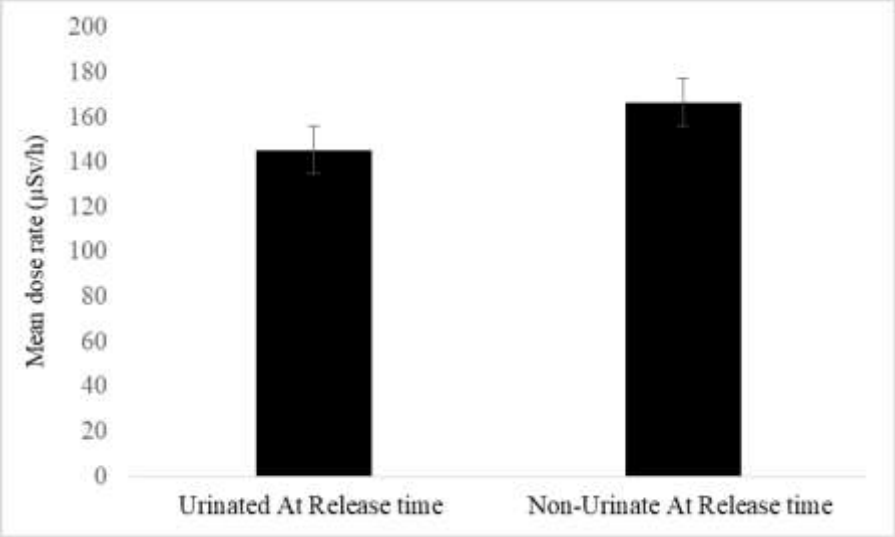


Figure 4.2. Bar chart demonstrates the difference in dose reduction for urinated and not urinated patients at release time.

Table 4.3. Showed Paired Samples Statistics for the difference in dose (µSv/h) measurement at patient release time at different distances compared to the distance (0)

Paired Samples Statistics		**Mean**	**Std. D**
Pair 1	Immediately post-injection at distance =0	414.0	131.5
	Immediately post-injection at distance =200cm	10.3	6.5
Pair 2	Immediately post-injection at distance =0	414.0	131.5
	30 min after injection at distance 0	282.8	78.5
Pair 3	Immediately post-injection at distance =0	414.0	131.5
	60 min after injection at distance =0	211.8	63.5
Pair 4	Immediately post-injection at distance =0	414.0	131.5
	Post-acquisition at distance equal 0	160.9	53.9

Table 4.4. Showed the Paired Samples t-Test (at p-value is significant below 0.05, and confidence level equal to 95%) which demonstrates the significant difference in measured external radiation dose at the Release time (T) of the patient at a different distance (D). PA: Post-acquisition

		Paired Differences				**T**	**Sig. (2-tailed)**
		Mean	Std. D	95% Confidence Interval of the Difference			
				Lower	Upper		
Pair 1	T0D0 - T0D2m	403.7	129.6	379.9	427.5	33.7	0.000
Pair 2	T0D0 - T30D0	131.2	86.8	115.3	147.1	16.4	0.000
Pair 3	T0D0 - T60D0	202.3	105.7	182.9	221.6	20.7	0.000
Pair 4	T0D0 - PAD0	253.1	122.5	230.7	275.6	22.4	0.000

Chapter five

Discussion, conclusion and Recommendations

5.1. Discussion:

This study was conducted to assess the external radiation exposure rate (converted to equivalent radiation dose per hour- µSv/h) to the external populations that originated from the intravenous injection of FDG-PET/CT dose.

Occupational exposure was the main focus; an earlier study identified higher radiation exposure to a nuclear medicine technician or the person who interacts with the patient (including all medical staff and general populations) during PET scanning. Radiation exposure at any area of radiation according to the ICRP classification (Clarke et, al., 1993) should be monitored and measured to protect the patient and the others especially in the NM department as well as any area of radiation exposure.

The patient in PET scan as we know become a source of exposure when is injected with radiopharmaceuticals (^{18}F), the measurement was done for every patient to ensure safe patient discharge which is depending on time and distance as shown in table (4.1) the highest radiation dose measured at this study at time zero (immediately post-injection of FDG was 414µSv/h which is lower than the previous studies (Berberoglu et al., (2019) and Seierstad et al., (2006)), also at 30min time-D0 was 282µSv/h, and at 60min-D0 was 221.8µSv/h, and at releasing time distance (0) was 160.9µSv/h. These results indicate that safe and optimum radiation protection to the staff and patient relatives when releasing or interacting with the patient taking into account the rules of radiation protection according to ICRP reports. See table (4.1) for the rest of the findings according to the time and distance factor.

When compared with the result of the other time interval (30 min) the gradient of the dose reduction was significant, the reduction is bigger in the first time interval between the 0 min to 30 min but the minimum difference is noted between 60 min and release time which indicates that the amplitude of dose reduction according to the time is happened between 0 min to 30min from 414 to 282µSv/h (see table 4.1) figure (4.1) as an example of reduction phenomena. This type of reduction phenomenon is noted in the exponential low of decay graphs (Maher., 2006) where the dose decreases as time and distance increased.

Both factors are very important in terms of patient discharge in addition to the number and time of micturition as demonstrated in figure (4.2) the reduction of radiation dose from the patient is reduced to the minimum after 30min of dose injection at 150cm distance and 200cm. The patient can be released safely at these times and distances starting from 30min (Emad et. al., 2018).

Another factor that play an important role in reducing the radiation dose to the public or the radiation worker in the medical field, the amount of radiation dose injected. The departments should considered the reduction of radiation dose and the image quality and diagnostic information, in our center the dose injected was 0.06mCi/kg, this technique of reducing the injected dose is adopted by(Marafi et a.,2017).

Also, this study tested the difference of the patient who empties the bladder or not where the mean difference reveals that there is no significant difference but the dose for those who empty the bladder at a mean time of 53 min was 145.4µSv/h compared to 166.7µSv/h for not urinated patient at time of releasing patient (table4.2, figure4.2). This result was in line with the previous study which stated that an active emptying of bladder in patients having PET/CT scans where 18F-FDG

radiopharmaceutical is involved is an effective method for the radiation safety of both health workers and patients (Berberoglu et al., 2019).

A significant difference was noted in the measured radiation dose rate (mSv/h) at the release time of the patient at a different distance. This difference noted for all release time external dose rate (p-value was 0.000) mean values of radiation dose at releasing time is significantly reduced from 160.9µSv/h at 0 distance to 3.7µSv/h at 200cm distance, this indicates the effect of distance is more effective in the reduction of exposure rate (dose rate) especially with increasing the time (table4.3 and 4.4).

5.2. Conclusion:

This study was conducted to assess the external radiation dose after 18FDG-PET/CT Examination. 117 patients were enrolled in the study. Radiation exposure was measured using a calibrated RadEye SPRD-ER personal radiation detector. The measurements were made at 0, 30, 100, 150, and 200cm distance from the patient. The time of measurement was; immediately post-injection, 30 min, 60 min after injection, and at the time of releasing the patient.The result showed that the mean radiation equivalent dose rate at 0 min/0 cm was 414µSv/h, at 30 min/30 cm was 99.7µSv/h, and 60 min/100 cm was 18.3µSv/h. The radiation doses at different distances (0, 30, 100, 150, and 200cm) were 160.9µSv/h, 70.9µSv/h, 12.4µSv/h, 7µSv/h, and 3.7µSv/h respectively. The study concluded that radiation protection will be sufficient within 2 h after (^{18}F-FDG) injection for PET/CT and the radiation dose can be limited by increasing distance from the radiation source; also instructing them to drink much more water to enhance the process of excretions. The short half-life of 18F limits the dose that members of the public are likely to receive. In addition, the safe external radiation dose rate at releasing time is significantly correlated to the time and distance according to previously discussed data.

5.3. Recommendations:

- Functional imaging with positron emission tomography (PET) is playing an increasingly important role in the diagnosis and staging of malignant disease, image-guided therapy planning, and treatment monitoring, so it should be used in all cancer centre.
- All staff must be aware about radiation protection procedure and stand about 2m from patients.
- For public and workers safety release patients after 2 hrs after injection

References

1- Al-HajAN, LobriguitoAM, ArafahA, ParkerR.2011.Derivingstaff and public doses in a PET/CT facility from measured radiation levels using thermoluminescent dosimetry. Radiat. Prot.Dosime- try 144:487–491.

2- AndersenPA,ChakeraAH,KlausenTL,BinderupT,GrossjohannHS,Friis E, Palnaes Hansen C, Schmidt G, Kjaer A, Hesse B. 2008. RadiationexposuretosurgicalstaffduringF-18-FDG-guidedcancer surgery. Eur. J. Nucl. Med. Mol. Imaging 35:624–629.

3- ARPANSA Radiation protection series No. 4. 2002. Australian Radiation Protection and Nuclear Safety Agency. Discharge of patients undergoing treatment with radioactive substances. Retrieved January 7, 2019, Available from https://www.arpansa.gov.au/sites/g/files/net3086/f/legacy/pubs/rps/rps4.pdf.

4- Benatar NA, Cronin BF, O'Doherty MJ. 2000. Radiation dose rates from patients undergoing PET: implications for technologists and waiting areas. Eur. J. Nucl. Med. 27: 583–589.

5- ChiesaC,DeSanctisV,CrippaF,SchiaviniM,FraigolaCE,BogniA, Pascali C, Decise D, Marchesini R, Bombardieri E. 1997. Radiation dose to technicians per nuclear medicine procedure: comparisonbetweentechnetium-99m, gallium-67, andiodine-131 radiotracers and fluorine-18 fluorodeoxyglucose. Eur. J. Nucl. Med. 24:1380–1389.

6- Demir M, Demir B, Sayman H, Sager S, Sabbir Ahmed A, Uslu I. 2011.Radiationprotectionforaccompanyingpersonandradiation workersinPET/CT.Radiat.Prot.Dosimetry147:528–532.

7- Królicki L, Kunikowska J, Kobylecka M, Mączewska J, Fronczewska K. 2011. Significance of positron emission tomography (PET) in the diagnosis of cancer diseases. Prog. Med. Sci. 2: 104–108.

8- KumarS,PandeyAK,SharmaP,ShamimSA,MalhotraA,KumarR. 2012. Instantaneous exposure to nuclear medicine staff involved in PET-CT imaging in developing countries: experience from a tertiarycarecentreinIndia.Jpn.J.Radiol.30:291–295.

9- Mithun S, Jha AK, Puranik AD, Monteiro P, Shah S, Agarwal A, Purandare NC, Rangarajan V. 2018. Reduction of radiation exposure to patients and professionals by reducing the adminis- tered activity of 18F-fluorodeoxyglucose in a positron-emission tomography/computed yomography study. Indian J. Nucl. Med. 33: 6–9.

10- NakamuraF,KannoT,OkadaH,YoshikawaE,AndouI,Futatsubashi M,ShinkeT,OuchiY,TorizukaT.2006.Measurementofradiation exposure to a PET institution driver from patients injected with FDG.NihonHoshasenGijutsuGakkaiZasshi62:1105–1110.

11- Rohren EM, Turkington TG, Coleman RE. 2004. Clinical applications of PET in oncology. Radiology 231: 305–332.

12- Schleipman AR, Gerbaudo VH. 2012. Occupational radiation dosimetry assessment using an automated infusion device for positron-emitting radiotracers. J. Nucl. Med. Technol. 40: 244–248.

13- Seierstad T, Stranden E, Bjering K, Evensen M, Holt A, Michalsen HM, Wetteland O. 2007. Doses to nuclear technicians in a dedicated PET/CT centre utilising 18F fluorodeoxyglucose (FDG). Radiat. Prot. Dosimetry 123: 246–249.

14- TAEA. 2000. Turkish Atomic Energy Authority. Regulation on Radiation Safety. Retrieved January 7, 2019, Available from: http://www.taek.gov.tr/en/documents/documents/Regulations/radiation-safety/Regulation-on-Radiation-Safety/lang-en-gb/

15- Brix G, Lechel U, Glatting G, Ziegler SI, Munzing W, Muller SP, et al. Radiation exposure of patients undergoing whole-body dual-modality [18] F-FDG PET/CT examinations. J Nucl Med. 2005; 46:608–13. [PubMed] [Google Scholar]

16- Huang B, Law MW, Khong PL. Whole-body PET/CT scanning: estimation of radiation dose and cancer risk. Radiology. 2009; 251:166–74 [PubMed] [Google Scholar]

17- Towson JEC, Eberl S. Radiation protection and dosimetry in PET and PET/CT. In: Valk PE, Delbeke D, Bailey DL, Townsend DW, Maisey MN, editors. Positron emission tomography. London: Springer; 2006. pp. 41–62. [Google Scholar]

18- Radiation protection in newer medical imaging techniques: PET/CT. Safety Reports Series No. 58. Vienna, Austria: IAEA; 2008. International Atomic Energy Agency (IAEA) [Google Scholar].

19- Juweid ME, Cheson BD. Positron emission tomography and assessment of cancer therapy. New Engl J Med. 2006; 354 (2):496–507. - PubMed

20- Al-Aamria M, Al-Balushia N, Dale B. Estimation of radiation exposure to workers during [18F] FDG PET/CT procedures at molecular imaging center, Oman. J Med Imaging Radiat Sci. 2019; 50(4):565–570. - PubMed

21- Martinez NE, Kraft SL, Johnson TE. A proposed simple model for estimating occupational radiation dose to staff from veterinary F-18-FDG pet procedures. Health Phys. 2014; 106 (5):583–591. - PubMed

22- Younas S, Yar A, Qadir E. Radiation dose management of 18FDG for occupational workers and comforters. Pakistan J Nuclear Med. 2015; 5 (2):58–66.

23- Leide-Svegborn S. External radiation exposure of personnel in nuclear medicine from 18F, 99mTc and 131 I with special reference to fingers, eyes and throid. RadiatProt Dosimetry. 2012; 149 (2):196–206. - PubMed

24- Rudd JH; Warburton EA; Fryer TD; Jones HA; et al. (2002). "Imaging atherosclerotic plaque inflammation with [18F]-fluorodeoxyglucose positron emission tomography". Circulation.**105** (23): 2708–11. doi :10.1161/01.CIR.0000020548.60110.76. PMID 12057982

25- Kelloff GJ; Hoffman JM; Johnson B; Scher HI; et al. (Apr 2005). "Progress and promise of FDG-PET imaging for cancer patient management and oncologic drug development".Clin. Cancer Res. **11** (8): 2785–808. doi :10.1158/1078-0432.CCR-04-2626. PMID 15837727.

Managing Patient Does, ICRP, 30 October 2009.

26- de Jong PA; Tiddens HA; Lequin MH; Robinson TE; et al. (May 2008). "Estimation of the radiation dose from CT in cystic fibrosis".Chest.**133** (5): 1289–91, author6 reply 1290–1. doi :10.1378/chest.07-2840. PMID 18460535.

27- "Chapter 9 Occupational Exposure to Radiation]"(PDF). Radiation, People and the Environment.IAEA. pp. 39–42. Archived from the original (PDF) on July 5, 2008.

28- "NRC: Information for Radiation Workers", www.nrc.gov. Retrieved Jun 21, 2020.

29- Brix G; Lechel U; Glatting G; Ziegler SI; et al. (April 2005). "Radiation exposure of patients undergoing whole-body dual-modality 18F-FDG PET/CT examinations". J. Nucl. Med. **46** (4): 608–13. PMID 15809483.

30- Wootton, R; Dore, C (November 1986). "The single-passage extraction of 18 F in rabbit bone".Clinical Physics and Physiological Measurement.**7** (4): 333–343. Bibcode: 1986CPPM....7. 333W. doi :10.1088/0143-0815/7/4/003. ISSN 0143-0815. PMID 3791879.

31- Young H; Baum R; Cremerius U; Herholz K; et al. (1999). "Measurement of clinical and subclinical tumour response using [18F]-fluorodeoxyglucose and positron emission tomography: review and 1999 EORTC recommendations". European Journal of Cancer.**35** (13): 1773–1782. doi :10.1016/S0959-8049(99)00229-4. PMID 10673991.

32- Lisa Fratt (July 2003). "Technology".MedicalImaging.Archived from the original on November 20, 2008.

33- Michael Phelps (January 16, 2013). "PET History and Overview"(PDF).Crump Institute for Molecular Imaging. Archived from the original (PDF) on May 18, 2015.

34- Prekeges, Jennifer (2012). Nuclear Medicine Instrumentation. Jones & Bartlett Publisher

35- Muhammad Wasif Saif, IfigeniaTzannou, NektariaMakrilia et al; (Jun, 2010).). "Role and Cost Effectiveness of PET/CT in Management of Patients with Cancer":PMCID: PMC2892773 /PMID: 20589185.

36- Benjamin Guillet, Pierre Quentin, Serge Waultier, Marc Bourrelly, Pascale Pisano and Olivier Mundler. "Technologist Radiation Exposure in Routine Clinical Practice with ^{18}F-FDG PET"Journal of Nuclear Medicine Technology September 2005, 33 (3) 175-179;

37- David W. Townsend, Jonathan P.J. Carney, Jeffrey T. Yap and Nathan C. Hall). " PET/CT Today and Tomorrow"Journal of Nuclear Medicine January 2004, 45 (1 suppl) 4S-14S;

38- S. Zargan, P. Ghafarian, A. ShabestaniMonfared, A.A. Sharafi, M. Bakhshayeshkaram and M.R. Ay,(2017)" Evaluation of Radiation Exposure to Staff and Environment Dose from [18F]-FDG in PET/CT and Cyclotron Center using Thermoluminescent Dosimetry"PMCID: PMC5401128/PMID: 28451574

39-Thomas Beyer, Johannes Czernin and Lutz S. Freudenberg " Variations in Clinical PET/CT Operations: Results of an International Survey of Active PET/CT Users"Journal of Nuclear Medicine February 2011, 52 (2) 303-310; DOI: h

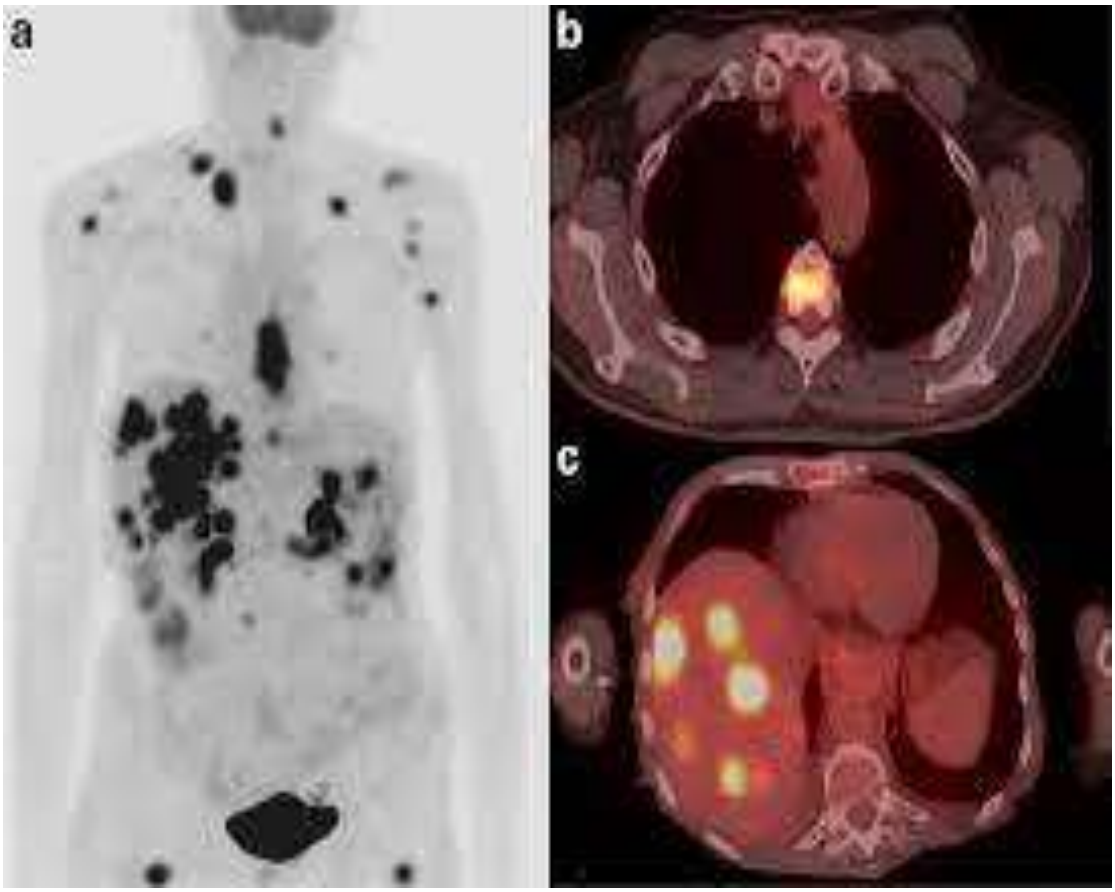
40- K Dalianis, G Kollias, J Malamitsi, R Euthimiadou, J Andreou, E Georgiou and V Prassopoulos. "Doses to medical workers operating in A PET/ CT department after the use of new dynamic techniques.

"Journal of Physics: Conference Series, Volume 637International Conference on Bio-Medical Instrumentation and related Engineering and Physical Sciences (BIOMEP 2015) 18–20 June 2015,

41- Ronald Boellaard, Mike J. O'Doherty, Bernd J. Krause "FDG PET and PET/CT: EANM procedure guidelines for tumour PET imaging"*European Journal of Nuclear Medicine and Molecular Imaging* volume 37, Article number: 181 (2010)

42- Benjamin Guillet , Pierre Quentin, Serge Waultier, Marc Bourrelly, Pascale Pisano, Olivier Mundler (2005) " Technologist radiation exposure in routine clinical practice with 18F-FDG PET"PMID: 16145226

Appendices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