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Estimation of Effective Dose to Patients Who Undergone Whole Body 18F-FDG PET-CT Examinations in North Palestine

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Declaration

I declare that, except where explicit reference is made to the contribution of others, this thesis is substantially my own work and has not been submitted for any other degree at the Arab American University or any other institution

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Dedication

I dedicate this thesis to the mentors who have given me countless hours of preparation and focused analysis. Their help with the techniques in radiation dosimetry, and their support and impetus helped shape the commitment to excellence in patient care and radiation protection.

To my family, with deepest love and gratitude. You believed in me no matter what, you were so patient and you so encouraged me, these were the bedrock of this work. I will never forget your being such enduring strength and inspiration that you shared this journey and it's been profoundly appreciated.

I also dedicate my dissertation to Palestinian Association of Medical Radiation Technologists. I dedicate this work to friends and to all colleagues in Palestine

Sofian Jameel Mustafa Tahleesh

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Estimation of Effective Dose to Patients Who Undergone Whole Body 18F-FDG PET-CT Examinations in North Palestine

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Abstract

This study aimed to assess the total effective dose of patients who have undergone a Positron Emission Tomography (PET-CT) scan using 18F-FDG radiopharmaceutical. The sample of the study (N = 150) consisted of patients with a mean age of 51.0 ± 16.3 years old, there were slightly more male (52.0%) than female (48.0%) patients. The IDAC-Dose 2.1 program was used to measure effective doses from 18F-FDG radiopharmaceutical, which is developed by the International Commission on Radiological Protection (ICRP). Virtual Dose™ CT, a web-based Computed Tomography CT dose calculator developed by the National Cancer institute , used for external dose estimations. The mean CT effective dose was 22.61 ± 4.23 millisievert (mSv), ranging from 13.0 to 34.4 mSv, while the mean F-18 effective dose was 3.51 ± 1.28 mSv, ranging from 1.79 to 11.90 mSv, giving a mean total effective dose of 26.12 ± 4.55 mSv, ranging from 15.39 to 37.47 mSv.

Keywords: Effective Dose, 18F-FDG, PET-CT Examinations

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List of Definitions of Abbreviations

Abbreviations	Title
PET	Positron Emission Tomography
CT	Computed Tomography
^{18}F-FDG	Fluoro-deoxy-D-glucose
ED	Effective Dose
mSv	Millisievert (the effective dose unit)
mGy	milli-gray (the absorbed dose unit)
DLP	Dose Length Product
CTDIvol	CT Dose Index Volume
kVp	kilovoltage peak
mAs	milli-Ampere-seconds
ALARA	As Low as Reasonably Achievable
DICOM	Digital Imaging and Communications in Medicine
WHO	World Health Organization
NCI	National Cancer Institute
SNR	Signal-to-Noise Ratio
CNR	Contrast-to-Noise Ratio
ICRP	International Commission on Radiological Protection
IDAC	Internal Dose Assessed by Computer
AEC	Automatic Exposure Control
TCM	Tube Current Modulation
SUV	Standardized Uptake Value
IR	Iterative Reconstruction
FBP	Filtered Back Projection
OLINDA/EXM	Organ Level Internal Dose Assessment/Exponential Modeling
IDAC-Dose	Internal Dose Assessed by Computer - Dose
MIRD calc	Medical Internal Radiation Dose calculation
EANM	European Association of Nuclear Medicine
IAEA	International Atomic Energy Agency
UNSCEAR	United Nations Scientific Committee on the Effects of Atomic Radiation
NCRP	National Council on Radiation Protection & Measurements

SD	Standard Deviation

Chapter One: Introduction

1.1 Background

Positron Emission Tomography (PET-CT) scanners are invaluable diagnostic modalities for oncological purposes, but their potential use requires scrutiny of the radiation exposure. Patients undergoing PET-CT scans are exposed to both internal and external radiation.

Whereas apart from the single modality imaging techniques (CT, PET) patients receive dual exposure, that is, not to external Computed Tomography (CT) or internal (PET) radiation, but only when both are present. Consequently, PET–CT confers an excellent pairing of functional and anatomic information, still the risk of cumulative radiation dose must be weighed appropriately against potential diagnostic value, particularly in vulnerable populations, such as those at risk for increased radiosensitivity or who may undergo multiple scans.

In particular, this radio sensitivity combination is problematic for patients in the patient population where this radio sensitivity increases (such as children or patients on multiple follow-up scans) (Huang et al., 2009).

As a result, scan protocols must be optimized to achieve good diagnostic image quality while reducing the radiation burden. Techniques include reasonable choice of CT parameters in conjunction with alternative imaging modalities when appropriate and good communication of risks and benefits to patients as well as referring physicians. Although PET-CT scanners are tremendously helpful at elucidating the main constellation of diagnosis, concern about radiation dose is valid. Patients are exposed more than one radiation sources in PET-CT.

Continuing education and training topics for Health Care Workers, for patients, and the public are needed for the radiation awareness as well as for the radiation protection culture in medicine. Since ionizing radiation is employed in various imaging techniques that include CT and PET-CT, radiation induced-cancer a delayed outcome of ionizing radiation exposure, is a concern in medical imaging (Adeleye & Chetty, 2018).

Clinicians and patients need to be aware of what influences this risk so that imaging decisions are appropriate, procedures are warranted, and safety measures are taken. Thus, the interaction between radiation with the human body is a delicate one and requires more attention and research.

With an increasing use of combined Positron Emission Tomography-Computed Tomography (PET-CT) in medical imaging, it becomes increasingly important to acknowledge concepts that contribute to radiation safety in healthcare professionals, patients, and regulatory bodies.

While bringing considerable diagnostic value, this dual-modality imaging technique exposes patients to both external radiation from the CT scan and internal radiation from the administered radiopharmaceutical (Huang et al., 2009). As a result, proper radiation dose could be influenced and patient safety enhanced in the use of PET-CT Technology, with understanding of that magnitude of radiation dose and potential risk.

The main aim of radiation protection is to keep radiation dose at the lowest level as possible. This has to be optimized in a careful manner both for PET and CT acquisition parameters in the context of PET-CT. The radiation dose delivered to the patient is strongly dependent on the CT scan parameters (tube voltage, mAs, pitch, and scan length), (Kaushik et al., 2013).

PET-CT creates medical imaging radiation that gives multiple stakeholders the responsibility for radiation safety: medical physicists, technologists, radiologists, nuclear medicine physicians, and referring clinicians.

Medical physicists are vital to optimization of scan protocols, calibrating the equipment, and verifications of accurate dose calculations. It is technologists' responsibility to have the patient positioned properly, administer the radiopharmaceutical, and do so as it is required by established safety procedures. Radiologists and nuclear medicine physicians read the images; they pass along their findings to referring clinicians who determine patient management (M. Y. Chen, 2014).

An essential component of PET-CT radiation safety is effective communication of radiation risks and benefits to patients and referring physicians. Patients should be counseled regarding the magnitude of radiation dose that they will undergo, and the associated risks as well as the benefits of the examination in their particular clinical indication (Villoing et al., 2020).

Because PET-CT scanner and dose calculations are required to be accurate and consistent, regular quality control and quality assurance programs are essential. Such includes daily, monthly, quarterly, and annual quality control tests for CT and PET components, and periodic calibration of all other radiation measurement devices (survey meters, CT and PET dose calibrators etc.) (Adeleye & Chetty, 2018). Equipment may malfunction and correct dose reporting is at risk unless adherence to established quality control procedures is adhered to.

In addition, local Diagnostic Reference Levels (DRLs) would be established for PET-CT and aid in optimizing radiation protection practices and keeping doses within acceptable ranges (Adeleye & Chetty, 2018 ;Salah et al., 2020). After deriving DRLs from surveys of typical doses for specific procedures, they act as benchmarks to compare against, and help identify outliers that should be further investigated.

Further improvement in radiation safety can also be achieved by the development and implementation of patient-specific dosimetry calculations, sensitive to patient size, weight, and organ masses. Thus, patient-specific mods to standardized phantoms can be achieved using software tools like OLINDA/EXM that facilitate more accurate estimates of organ doses and effective dose (Stabin & Siegel, 2018). In particular, this personalized approach is particularly relevant in therapeutic nuclear medicine applications where precise dose calculation is crucial for treatment planning.

The use of dose reduction techniques can be utilized to further reduce radiation exposure during PET-CT, such as patients shielding. For instance, Bismuth breast shields can deliver clinically significant reductions in breast dose during CT acquisition while maintaining adequate image quality (Salah et al., 2020).Similarly, before the PET scan administration of intravenous fluids or diuretics may increase urinary excretion of the radiotracer and decrease radiation dose to the bladder (Adeleye & Chetty, 2018).

New PET-CT technologies, such as time-of-flight PET and iterative reconstruction algorithms have the potential to further increase image quality and lower patient radiation dose (Quinn et al., 2016). Low injected activities are theoretically possible if information about time-of-flight can be used to improve image contrast and reduce noise. More commonly used to improve image quality and reduce noise, iterative reconstruction incorporates statistical models into image reconstruction, therefore, potentially permitting lower mAs settings in CT.

PET-CT technology is undergoing extensive research and development to increase radiation safety and to extend the boundaries of diagnostic imaging. Sensitive new detector materials, such as lutetium ox orthosilicate (LSO), and improved detector design have enabled PET scanner sensitivity to develop and potentially shorter scan times or lower injected activities (Wu et al., 2004) .In the same way, dual-source CT and iterative recon – advances in CT technology – have decreased doses without degrading image quality.

Future benefits from these and similar advancements will depend on continued collaboration between researchers, clinicians, and manufacturers towards maximizing potential, and with judicious use of PET-CT technology.

The remarkable diagnostic capabilities of PET-CT come with a cost: the threat arising from exposure of the patients to radiation. Although this risk per se is low, the magnitude that it might precipitate lifelong impairment is not small. The total amount of radiation patients receive during PET-CT exam consists of the amortized dose of the radiopharmaceutical and the CT dose.

This is because though the effective dose from ^{18}F-FDG is comparatively low, the dose from the CT component is significantly higher and may contribute from 50% to80% total radiation dose in many instances (Khamwan et al., 2010; Kaushik et al., 2013;Mettler et al., 2008). The ability to use PET-CT to increase the patient care while reducing patient risk is to optimize the dosimetry and different protocols to generate the required diagnostic images while minimizing patient exposure to radiation.

The two-step measurement involves PET and CT, which form the basis of PET-CT dosimetry and can be a major hurdle, owing to the need to estimate the contribution of radiation from the ^{18}f-FDG radiotracer and the CT scan separately (Huang et al., 2009).The injected ^{18}f-FDG undergoes internal radiation dose as a result of decay of the administered tracer and reflects the biokinetics, uptake, distribution and clearance of the tracer and the amount of the tracer activity that was administered (Brix et al., 2005).

The external radiation dose from CT scanner source depends on tube voltage, current, scan time and collimation (Ahmad & Ewaidat, 2013).They are commonly relevant to patients who receive multiple sources of radiation and may at times need individualized data in order to evaluate the total dose of radiation. Other patient and CT clinic sources of variability include variability in the biokinetics of ^{18}f-FDG and variability in the CT protocols (Quinn et al., 2016).

Subsequently, the use of biokinetic models coupled with the framework for dose calculation also possesses potentially large errors intrinsic to the biological variability of physiology, diseases, and medications (Stabin, 2008).

Also similarly, the CT protocols may slightly differ from one institution to the other as well as within the same facility depending on clinical indication or the amount of diagnostic information required for a specific study (Adeleye & Chetty, 2018). This further strengthens the argument that to attain the most accurate dosage assessment, what is required is clinic-specific dosing, which is more than the routine reference dosing and does factor in patient-specific parameters.

1.2 Problem Statement

The lack of prior dosimetry studies for ^{18}f-FDG PET-CT in Northern Palestine is a major knowledge gap in the assessment of regional radiation exposure. PET-CT scanners were first introduced to the region in 2018 and after to installation, no formal dose assessments have been done for patients being imaged using these devices.

Absence of this data limits the ability to compare local practices with global standards, to optimize scanning protocols to local patient demographics, and to formulate such risk communication strategies as are appropriate to this population. This study is the first to quantify radiation doses from ^{18}F-FDG PET-CT in Northern Palestine and provides a baseline against which to evaluate and improve radiation safety practices in the region.

While current dosimetry data gives us valuable generalized estimates, these tend to be rather general and aren't specific to particular populations or practices. To address the important need to evaluate accurate doses in Northern Palestine, where no data is available on ^{18}F-FDG PET-CT procedures and related radiation dose, this study focuses on this.

Given the increasing use of ^{18}F-FDG PET-CT for oncologic imaging, accurate dose estimates and region-specific risk assessments are needed to protect patients from unsafe doses and optimize radiation protection (Huang et al., 2009).

Moreover, the lack of regional information on CT check specifications, patient demographics and also provided tasks produces a space in recognizing the real radiation concern to this certain populace. As a result, this research study attends to the vital requirement for precise efficient dosage estimation of ^{18}F-FDG PET-CT at Northern Palestine.

1.3 Aims of the Study

The main objective of the study is to estimate the effective dose for patients who underwent PET-CT examination using ^{18}F-FDG . By estimating the effective dose resulting from the CT and PET components, the total effective dose will be obtained. Through this study, the gap in the current literature can be addressed by analyzing the effect of different factors including patient age, weight and gender.

The research will explore the relative contribution of the computerized tomography CT components to the total effective dose, and this will be a valuable reference for future research and the clinical practice. The research will check the relationship between radiation dose and Body Mass Index (BMI) of patients.

1.4 Research Hypothesis

1. The effective doses received by Palestinian patients who undergone whole-body ^{18}F-FDG PET-CT scans are comparable with international results.
2. There are no significant differences between the patient's effective dose and international procedures and the results of this research.
3. Higher effective doses will result in elder age patients.

4. There is no difference between different patient's body mass indexes BMI and the resultant effective dose.

1.5 Research Questions

1. What are the effective doses received by Palestinian patients who undergone whole-body 18F-FDG PET-CT scans?
2. Is there a main difference between the results found and the international similar procedures?
3. How do patient demographic data such as age and sex affect the received effective dose when undergoing whole body ^{18}F-FDG PET-CT scans?
4. How much is the relative contribution of the computerized tomography CT to the total effective dose of ^{18}F-FDG PET-CT scans in north Palestine?
5. Is there a correlation between BMI and the effective dose received when undergoing whole-body ^{18}F-FDG PET-CT scans?

1.6 Thesis Outline

This thesis has been categorized into five chapters:

- Chapter one: introduction.
- Chapter two: literature review and theoretical framework.
- Chapter three: materials and methods.
- Chapter four: results of the study.
- Chapter five: discussion, conclusions, and recommendations of the study.

Chapter Two: Literature Review

2.1 Introduction

In this chapter, the theoretical bases of radiation dosimetry in medical imaging, with particular emphasis on PET-CT scanning, are described in detail. It examines basic concepts for radiation interactions with matter including absorbed dose, and effective dose and uses as a basis for quantifying radiation exposure.

This chapter synthesizes these disparate findings to present a broad overview of what is known about PET-CT dosimetry today, and to consider areas for future research and advancement. The data presented in this literature review provides a foundation for the subsequent chapters that describe original research on optimizing radiation dose and image quality in PET-CT scanning.

In addition to this, this chapter reviews the technical aspects of image acquisition and reconstruction from PET and CT images towards patient. Add to that, it covers established dose estimation methods and software tools such as IDAC, Virtual Dose, standard phantoms and reference data used for these calculations. This study looks into one of the most important issues in modern medical imaging at North Palestine: quantification of radiation exposure from 18F-FDG PET-CT scans.

This thorough review of the theoretical as well as technological facets of PET-CT dosimetry offers a structure for comprehending the obstacles as well as possibilities in improving radiation defense. By presenting a comprehensive explanation of the theoretical and technical issues involved in PET-CT dosimetry, this overview establishes the framework for understanding the issues and choices associated with optimizing radiation protection for this dual modality imaging technique.

A vital testimonial of the literary works on PET-CT dosimetry exposes a variety of reported radiation dosages showing variants in scanner innovation, imaging procedures, coupled with client populaces. Research studies have actually checked out the impact of CT check specifications (kVp, mAs, pitch …etc.), provided radiotracer task client dimension as well as weight using dosage decrease methods on the reliable dosage (Brix et al., 2005) exposure from 18F-FDG PET-CT scans. As PET-CT use continues to be employed in oncologic diagnostic and staging applications, reduction of the radiation dose becomes increasingly important (Salah et al., 2020) .

This is a dual modality scan involving the addition of the anatomical imaging in CT, to the metabolic imaging of PET using the glucose analog 18F-FDG. It offers excellent diagnostic capabilities, but it exposes the patient to both modalities' ionizing radiation, and even raises concerns about potential long term stochastic effects like cancer induction (Huang et al., 2009).

2.2.Background

2.2.1 The Biological Effects of Radiation

The mechanism through which these biological effects occur due to ionizing radiation originating externally by diagnostic and other purposes and internally through the use of radiotracers involves several physical chemical and biological processes with immediate and chronic effects.

At the cellular level the ionizing radiation can affect DNA directly through the direct ionization and produce lesions which could be strand breaks and other types of lesions or indirectly through the formation of free radicals which interact with DNA and other molecules in the cell (Quinn et al., 2016).

Effectiveness or otherwise of DNA damage depends on various factors which include radiation dose, dose rate, kind of radiation and inherent radiosensitivity of the exposed cells. The radiological effects from the exposure vary from mild or temporary to severe or fatal. Deterministic effects (tissue reactions) are threshold effects: In many cases, no response is noted up to a specific dose, then, as dose increases past that mark, severity rises as well.

Inherent in CT imaging, ionizing radiation interacts with biological tissues and initiates a cascade of events at the cellular and molecular levels likely resulting both in beneficial diagnostic outcomes and potentially harmful biological effects. Broadly, these biological effects are considered deterministic versus stochastic by their dose response relationship and clinical manifestations (ICRP 2007;Adeleye & Chetty, 2018). This serves to optimize CT protocols and to maximize diagnostic benefits while minimizing patient risk of this powerful imaging modality.

For deterministic effects, also referred as tissue reactions, it is a threshold dose below which, no effect is observed. For increasing dose, the effect is more severe than above this threshold.

Detemistic effects are rarely observed on the basis of standard diagnostic scans because the doses are usually lower than the thresholds of deterministic injury. Nevertheless, deterministic effects such as skin erythema or epilation may occur during the occurrence of certain interventional CT procedures including high radiation doses and long fluoroscopy times. These effects are generally transient and reversible however, and serve to highlight the need for attentive dose monitoring and optimization in high dose procedures (ICRP, 2015).

Unlike deterministic effects, stochastic effects are probabilistic - the chance of their occurrence but not their severity increases with increasing radiation dose. Stochastic effects are lower dose effects that do not retreat a threshold dose; a small dose of radiation still has a risk albeit a minor one. Concerns are two primary stochastic effects, cancer induction and hereditary effects.

The risk of these effects from a single diagnostic CT scan is small, but it is not zero, and it increases over a lifetime. Repeated exposures, especially in younger patients or patients undergoing long-term surveillance, may result in acquisition of an increased risk of lifetime cancer (Huang et al., 2009).

While hereditary effects and the carcinogenic properties of radiation are well established, radiation induced carcinogenesis is a very stochastic process that constitutes a major challenge in risk assessment. But the long latency period, of years or even decades that can elapse between a CT scan and the diagnosis of a cancer that it has contributed to, makes it hard to prove a link between a single such scan and a subsequent diagnosis.

At the same time, it's complicated to estimate risk because of how difficult it is to attribute certain cancers to radiation exposure compared to other risk factors. Although epidemiological studies, such as those in atomic bomb survivors, are valuable sources of information concerning radiation related cancer risks, taking into account the differences in dose ranges, exposure situations, and population, they cannot be ecnaly applied directly to diagnostic CT exposures.

The risk of stochastic effects from diagnostic CT scans usually amounts to a small fraction of 10 percent but is not zero and individual clinicians have to carefully balance the benefit of a CT scan with the risk of radiation exposure from such a scan.

Factors which should be considered include the patient's age, medical history and clinical indication for the scan, and the overall risk and benefit balance should be considered for this assessment (Quinn et al., 2016). However, additional dose optimization strategies including decreasing CT parameters and using iterative reconstruction techniques whenever possible should be used in order to reduce radiation exposure (Mettler et al., 2008).

By judicious balancing of diagnostic benefit and potential risk of CT imaging, and by applying indication-based dosimetry and other appropriate dose reduction strategies, clinicians can responsibly and ethically use CT imaging. Some of the deterministic effects include skin erythema; epilation; cataract; bone marrow suppression. Most often, these effects are not seen in diagnostic imaging procedures since the doses are normally well below the deterministic damage. However, ionizing doses of the same magnitude are intentionally used in therapeutic radiation application targeting affected tissues.

While stochastic effects are random in nature, probability of occurrence of these risks rises with the dose, though severity of the consequence actually experienced is not dependent on the amount of dose absorbed. The principal stochastic effects of interest are cancer induction and hereditary effects. These effects can manifest at any dose level; there is no "safe" dose below which risk is zero. Stochastic effects may appear years or even decades after exposure, making it difficult to establish a causal relationship between a particular exposure and a subsequent health outcome.

Biological damage also depends on the type of radiation, i.e. on the nature of the emitted particles or photons (ICRP, 2007). Radiation of different kinds, such as X rays, gamma rays, alpha particles and beta particles have different energy deposition patterns and then biological effectiveness. Alpha particles being larger and more highly charged penetrate a less distance and deposit their energy in a smaller volume and with a higher probability of serious cellular damage than X-rays or gamma rays.

The radiation weighting factors in the calculation of equivalent dose are primarily based on the relative biological effectiveness of various radiation types, with weighting factors higher for those radiations considered more damaging. Another crucial determinant of biological damage, is the inherent radiosensitivity of the cells and tissues exposed to radiation (ICRP 2007).

2.2.2 Radiation Induced Carcinogenesis

The effect of ionizing radiation on DNA the building block of life is the central theme of radiation-induced carcinogenesis. As it has been seen, ionizing radiation whether from an external source like Computerized Tomography (CT) scanner or internal source like radiotracer affects the DNA structure adversely.

Direct ionization can lead to strand breaks, the breakage of the double helix and thus put a halt at the various fundamental functions of the cell. Indirect ionization produces free radicals, which cause further chemical changes in the cell, and the indirect method also damages the bases of DNA and other molecular structures. The type of damage inflicted by radiation depends to variable degrees on its energy and kind (X- or gamma radiation, and so forth), dose rate, surrounding environment of the irradiated cells, and the latter's inherent vulnerability.

One of the difficulties of risk assessment is the long time from exposure to radiation to the development of cancer (ICRP 2007), cancers can take many months or even years to develop and therefore radiation exposure does not have to happen at the time of developing cancer symptoms.

The long time period taken for cancer to develop also poses difficulty in differentiating cancers that have been induced by radiation and that could have occurred anyhow, therefore, a poor way of predicting the risks associated with cancers from radiation exposures. The sensitivity of cells and tissues to radiation and differences in this sensitivity between people add to the complexity of the matter.

2.2.3 X-ray Discovery

At 1895, Wilhelm Conrad Röntgen discovered on of the most important modalities, which was a turning point of science and medicine, made a new start of new scientific field.

When working with cathode rays, a phenomenon seen in vacuum tubes, Röntgen made this invisible form of radiation while experimenting. His methodical observations and excessive experimentation resulted in his discovering the particular features of x-rays. The property to pass through matter, shed shadows on photographic plates etc.

Rontgen's first experiments consisted of placing objects between a cathode ray tube and a fluorescent screen and seeing what level of transparency to the newly discovered radiation the objects presented. The ones that seemed to penetrate the easiest were paper and wood while the other materials, like metal and bone, created distinct shadows on the screen. He made the first ever x ray image of his wife hand with bones and ring this observation led him to do that statement of Rontgen's exploration in December 1895 sent out shockwaves with the clinical area and also the general public alike.

The capability to graph the interior frameworks of the body without surgical treatment was proclaimed as a clinical wonder catching the creativity of both researchers as well as the nonprofessional press. Within months X-ray equipment's were being created plus released in healthcare facilities and also centers worldwide changing analysis capacities together with bring about many clinical advancements.

For the first time, medical professionals can imagine cracks, displacements, international bodies together with various other inner irregularities without intrusive surgical procedure. This newfound capacity to "" see"" inside the body changed analysis methods, boosted person end results, as well as led the way for the advancement of various other imaging techniques.

Rontgen's exploration likewise had a profound influence on various other clinical areas consisting of physics, chemistry, and also biology. X-rays supplied a brand-new device for researching the framework of issue, bring about developments in crystallography as well as products scientific research.

The discovery of Rontgen's X-ray was to be transformative, and he remained remarkably modest and dedicated to scientific inquiry despite the transformative impact of his discovery. But discouraged with losing his job as a civil engineer and without the support of the local Royal Society, he was unwilling to patent his invention, feeling that scientific discoveries should, in fact, be shared with others in humanity. He was awarded the first Nobel Prize for Physics in 1901, but donated this money to his university so that further research might be supported.

Big challenges were faced with diffusing X-ray technology into medicine. The first X-ray machines were quite crude, and correspondingly so were the associated doses of radiation that many worried (rightly so) might put one's health in peril. But over time x ray tube design and shielding techniques, and image intensifiers improved somewhat to reduce the radiation dose and improve the quality of the X-ray images (Parghane & Basu, 2018).

Rontgen's discovery, however, was far from a one-off, and the legacy of his discovery is great. Today, X-rays are used in many fields of scientific research, in materials analysis, in industry, in conjunction with industrial inspection and security screening. In addition, they have become an indispensable tool in modern society: we use them for the feats we might otherwise see as impossible: seeing through walls, inspecting aircraft engines, analyzing the composition of materials, and probing the mysteries of the universe.

But the discovery of x-rays also came with the discovery of a new kind of radiation protection, as scientists and physicians quickly realized the dangers of ionizing radiation. These standards, protective shielding, and dosimetry techniques minimized the risks of X-ray exposure, but using x-rays is a powerful technology for which proper procedures exist (Chen, 2014).

2.2.4 The Development of Computerized Tomography CT

Despite providing important information about the shape and density of internal organs and tissues, conventional X-ray had major drawbacks in its ability to represent spatial organization of tissues. This search for three-dimensional imaging capability resulted in one of the most momentous developments in the early 1970 with the development of computerized axial tomography or CT scan by Godfrey Hounsfield of Great Britain.

This revolutionary technology integrating the capability of X-ray and other advanced mathematical operations produced clear cross-sectional images of the human body. CT made it possible for the physician to see in detail the density variations of internal structures and to reproduce out of these densities three dimensional pictures of internal anatomy(Ahmad & Ewaidal).

At the same time, CT technology has also developed out of an effort to reduce patient radiation dose. However, with the help of suitably sophisticated mathematical models to reduce image noise while retaining diagnostic image quality, techniques such as iterative reconstruction algorithms have made it possible to achieve substantial dose reductions. Tube current modulation is adjusted automatically based on patient size and anatomy, optimizing radiation dose even more.

CT has evolved into an indispensable imaging modality of modern times at both diagnostic and therapeutic sites. This is a remarkable achievement in medical imaging technology, transforming the way physicians look at, and assess the human body.

CT imaging utilizes the differential X-ray absorption density technique. When X-rays shoot through the body of the patient, which they do to form images of his/her internal organs, they interact in different ways with the tissues of the body. Tissues that are denser than the others, like bones, overlap X-rays more than less dense tissues or air in the body, for instance, soft tissues.

CT scanners use a single X-ray source that rotates around the patient while fixed intensity detectors surrounding the patient capture the transmission of the X-ray intensity. These measurements are then passed through a series of complex computer software and programming to create images of the cross-sectional body.

Traditional radiography could be said to be diverging from CT development. For the most part, a conventional X-ray produces a single projection image corresponding to the combined superimposed shadows of all the structures through which the X-ray beam passes. This superposition can, however, hide subtle lesions or anatomical features. Unlike CT, superposition again is a problem, so radiography acquires multiple projections from different angles and separates and reconstructs individual tissue slices (the problem of superposition is eliminated), and radiography reveals subtle anatomical details not present in conventional X-ray images.

CT made itself an impact on the medical diagnosis of various specialties. Clinicians gained a powerful tool for evaluating a great variety of conditions such as traumatic injuries or complex diseases, by means of its ability to non-invasively visualize internal organs, tissues and lesions. The greatest impact of CT on oncology was in localized, staged tumor localization, and in treatment planning accuracy.

CT Technology has continued to further advance its diagnostic capabilities. Much more was done to reduce scan times and improve image resolution than was done with spiral or helical CT, where the X-ray source and detectors continuously rotates around the patient (and the patient walks through the scanner). Multidetector Computed Tomography (MDCT), with multiple rows of detectors, further decreased scan times and allowed scanning with thinner slices to help the smallest lesions be seen (Salah et al., 2020).

2.2.5 Radiation Dose Standard Phantoms and Their Limitations

The science of quantifying the absorption of ionizing radiation in biological tissues. Radiation dosimetry has traditionally relied on the use of standardized phantoms, either physical or computerized representations of the human body, used to model radiation interactions and account for dose distribution (ICRP 2007).

These phantoms, generally based upon typical physical information from a certain population, offer a referral for dosage estimations and also help with contrasts with various imaging strategies. However, restrictions, if any type of it is offered in common phantoms to catch interindividual variation in human composition plus physiology for advanced imaging methods

The growth of voxel phantoms, based upon clinical imaging information from genuine individuals, stands for a significant development in radiation dosimetry, resolving the limitations of acted phantoms with thorough ethnic details (Andersson et al., 2017). Voxel Phantoms fractional CT or created from MRI photos in which the voxels to the person's body are represented as 3D frameworks, each with specifically appointed cell types and also dimensions (Stabin & Siegel, 2018) .

The outcome of comprehensive physical design enables approximation of power launch as well as gas transportation, which produces an increasing number of exact dosage price quotes compared to conventional methods. In addition, voxel phantoms make it possible for analysis of dosage circulation in vascular systems coupled with below-vascular systems, promoting even more targeted danger analysis and also individualized therapy preparation.

Nevertheless, voxel phantoms position a number of obstacles, such as the computational needs of photo division and also the opportunity of moving photo artifacts to dosage computations (Adeleye & Chetty, 2018). However, the precision of the application of voxel phantoms relies on the high quality of the given image information as well as the top quality of the segmentation procedure.

In addition, the need for voxel-based dosimetry can be very large with respect to the computer resources of it as well, especially in high resolution detectors with many voxels and can be affected by factors such as image noise and partial dose effect.

To overcome limitations of stylized and voxel phantoms, hybrid phantoms have been constructed that combine stylized representations of some organs and voxel representations of other organs (Andersson et al., 2017). Phantoms in this work utilize stylized models of such organs with fairly consistent anatomical features (e.g., brain, lungs) and voxel-based models for such organs with larger anatomical variability (i.e., gastrointestinal tract, bladder).

The objective here is to balance anatomical accuracy with computational efficiency while fitting the proposed construction setting. However, the realization of such gray matter phantoms requires balancing between these two attributes and choosing the best anatomical regions for each representation method.

Moreover, the development of patient-specific phantoms based on individual patient CT or PET-CT scans serves as the final goal of personalized dosimetry, as the most accurate and precise dose estimation is rendered possible.

Bolch et al. (2015) introduced these phantoms as the only ones capable of characterizing the individual's unique anatomy, including organ size, location, and tissue composition, to allow for personalization of risk assessment and treatment planning. Nevertheless, the generation of patient-specific phantoms is currently a time-consuming and computationally intensive process, preventing their use in routine clinical practice.

However, as computational resources and dosimetry software continue to increase, patient-specific and hybrid phantoms, and new dose calculation algorithms will likely continue to be more important in CT dosimetry.

These advancements will lead to more accurate and precise dose estimations, which will be associated with more targeted risk assessment and a more personalized radiation protection strategy. The ability to develop automated phantom generation and dose calculation tools continues to be an extremely promising avenue for scrubbing the variability out of personalized CT dosimetry workflows, while simultaneously making them more accessible in routine clinical practice.

It is obvious that the use of standard phantoms, for example, ADAM and EVA, has certainly played a crucial role in improving radiation protection and dosimetry in CT imaging. Nevertheless, they have become less satisfactory at capturing the diversity of human anatomy, laying bare their inherent limitations of representing the diversity of human anatomy and their dependency on simplified radiation transport and biokinetic models (Villoing et al., 2020).

By developing voxel-based, hybrid, and patient-specific phantoms coupled with advanced Monte Carlo simulations, more accurate and patient-focused tools for dose estimation have been acquired, and further, these allow more accurate risk assessment and use of tailored dose optimization strategies. As computational resources keep improving and dosimetry software gets more and more sophisticated, these sophisticated methods will be more important in implementing personalized CT dosimetry, thus reducing the irradiation dose burden and optimizing patient care (Andersson et al., 2017).

Continuous research and development in phantom design and dose calculation set of rules development is needed to refine dosimetry practices and to ensure that CT imaging is finished with the lowest possible radiation dose. Ultimately, this partnership among researchers, clinicians, and producers will ensure secure and beneficial use of CT, in order that CT imaging is used so that its miles used safely and efficiently to growth diagnostic gain at the same time as reducing patient chance.

2.2.5.1 Improved Calculating Methods

With the considerable application of Computed Tomography (CT) in existing medication and also the expanding interest to relevant danger aspects there has actually been the facility of unique radiation strategies for density optimization. With the goal of fixed precision as well as individual distribution of air high quality mistakes which might result in mistakes (ICRP 2007). Comprehensive strategies, consisting of voxel-based dosimetric along with Monte Carlo simulations, consisted of modeling together with representing as such there has provided the opportunity for personalized radiation protection in CT.

Voxel-based dosimetry, a very efficient dosimetry device readily available today, relies on patient-specific physical information drawn directly from CT or MRI images to figure out dosage distributions of high spatial resolution (Quinn et al., 2016).

By modeling the client's body as a 3D range of voxels, for details cells as well as density. Voxel-based dosimetry can provide a much more faithful representation of patient anatomy as opposed to stylized phantoms. This thorough physiological information enables a specific decision of a person's physical resistance plus dosage, which subsequently promotes as well as helps with the process of danger decision to build a perfect therapy strategy.

Widespread CT use in present-day medicine and increasing knowledge about related risk factors have fostered the introduction of sophisticated radiation methods for density control with the intent of statistically accurate and individualized application of air pollution measurements, exposed errors may arise (ICRP 2007).

Methodical methods such as voxel-based dosimetry as well as Monte Carlo simulations, were qualified by modeling as well as taking into consideration. These constraints as well as presenting opportunities of customized radiation defense in CT.

Because of this high-resolution composition, it is feasible to properly establish the physical endured as well as dosage of the individual as well as this subsequently makes it possible for and also motivates the danger evaluation in order to prepare to the distribution of an effective therapy.

This personalized dosimetry technique can allow even more notified scientific choices relating to clinical indication for CT assessments, while looking for to make the most of the prospective advantages of diagnostic information, with every one of the attendant threats of radiation direct exposure. However, it is of wonderful relevance to recognized the computational power of these high-performance medicine shipment design architectures.

But it is of great importance to known the computational energy of these high-performance drug delivery architectures. Voxel-based total dosimetry and Monte Carlo simulations are computationally demanding and invoke specific software, which may limit their large application, especially when dealing with complex features (Andersson et al., 2017). With further increases in the sophistication of PC hardware, dosimetry software, these advanced methods become increasingly convenient and are bound to play a pivotal role in routine clinical practice.

Primarily, patient-specific CT dosimetry looks for to make individual direct exposure to radiation as couple of as feasible as well as maximize the analysis functions of the software program examining individual demographics, composition, as well as scientific indications in the accumulation with scanning methods (Andersson et al., 2017;Quinn et al., 2016).

As an example, kid typically, people require less air circulations about grownups offered greater radiosensitivity coupled with strength . Individuals with a big body dimension might additionally require alterations in experiment criteria to boost image (ICRP 2007).

As our understanding of the complex radiation dose, image quality and biological response balance improves, personalized radiation protection in CT become more effective, as continuous improvement in quantitative measurement practices is essential to ensure patient safety, improve diagnostic accuracy and to maximize clinical utility of

CT and applications, potentially by taking advantage of advanced gain algorithms and machine learning techniques, can make personalized radiation may significantly improve safety in CT.

Lastly, withstood education and learning of medical care specialists associated with CT imaging is vital to raise awareness of radiation dosage plus associated risks as well as to share awesome methods at range in best handling plus radiation security. Health care professionals must be equipped to make educated selections around client treatment as well as radiation safety and security.

2.2.5.2 IDAC 2.1

It depends on its application of an "" digital posting"" strategy for sharing dosage coefficients. This layout enables quick updates concerning modifications of dosage info as brand-new study appears or as biokinetic designs are fine-tuned. Consequently, the dose approximates produced by IDAC 2. 1 show one of the most existing clinical understandings of radiopharmaceutical habits.

Estimations for degeneration of particular radionuclides in IDAC 2.1, making certain detailed evaluation of radiation problem from parents and children's advantage. As an example, when ^{18}F-FDG, the software application computes the exhausts from the small child component. This is an important function, because failure to pay the small girl items can result in unreliable dose price quotes, particularly for longer lived radionuclides.

Additionally, the software application permits picking in between several cells weighting aspect collections supplied in ICRP Publication 60 and ICRP Publication 103 allowing for the use of varied threat assessment constructions . Therefore, individuals are able to dressmaker the dosage approximates to specific controlling or expert needs.

2.2.5.3 CT Dose Calculations using Virtual Dose™ CT

The platform constructs personalized dose estimates using Monte Carlo simulations on detailed anatomical models with patient specific CTDIvol (volume CT dose index) and DLP (dose-length product). Utilizes Monte Carlo simulations based on detailed anatomical models, incorporating patient-specific parameters like CTDIvol and DLP to generate personalized dose estimates. It offers relatively increased accuracy compared to generalized dose calculators based on standardized phantoms, because it takes into account the individual variation in body size, or scan length, individual variations in radiological exposure.

Virtual Dose™ CT makes dose estimation so simple that it requires minimal user input and an easy user interface. Patient demographics (age, and sex), CT scan parameters (kVp, mAs, pitch, slice thickness, and scan length) and the scanner model are entered by users. It then accesses a comprehensive database of organ dose coefficients based on the entire body of Monte Carlo simulations using the ICRP reference computational phantoms.

The radiation transport calculations performed by the software, combined with patient specific parameters and these coefficients, lead to the generation of personalized organ dose and effective dose estimates.

Virtual Dose is particularly attractive, as it facilitates dose optimization and risk communication. The software provides patient specific dose estimates for a CT examination, so that clinicians can evaluate the potential dose risk of such an examination and make an evidence-based decision regarding its justification. Additionally, the use of Virtual Dose allows the radiation dose from different CT protocols and scanner models to be compared and informs decision making regarding the use of lower dose techniques wherever feasible clinically. This results in promotion of the ALARA principle of keeping the patient's radiation burden low while maintaining image quality.

Due to its automated calculation features and user-friendly interface, the device is valuable to clinicians, researchers and radiation safety personnel for whom specialized dosimetry expertise is not required. The Virtual Dose continues to develop and expand, refining patient dose estimates towards becoming a key component in automated CT imaging CT with respect to improving radiation safety.

2.2.6 PET-CT Discovery

PET-CT, a new hybrid imaging modality heralding a new era of imaging with the ability to combine metabolic insights of positron emission tomography (PET) with precise anatomical localization of CT, was born. Combined with this synergistic fusion, clinicians now possess a holistic understanding of form and function meaning they can improve on diagnostic accuracy as well as implement personalized medicine solutions.

The origin of PET-CT was brought about by the recognition that standalone. PET did not have sufficient spatial resolution to allow accurate anatomical correlation, but with its ability to provide metabolic information it significantly improved on standalone CT.

The idea of PET-CT finally came along only in the late 1990s, when researchers started to think about combining these two modalities in an attempt to overcome shortcomings associated with either for the first time. Essentially, early prototypes consisted of two separate PET and CT scanners located very close proximally such that software algorithms were used to co-registration the images (ICRP 2015; Huang et al., 2009).

While the first attempts to fuse these images showed promise for the use of image fusion, patient movement between scans and poor image registration accuracy limited these initial attempts to obtaining visually satisfactory results.

The growth of incorporated PET-CT systems where both PET and also CT scanners are housed within a solitary bunch noted a considerable technical jump ahead. This incorporated layout removed the demand for person repositioning in between checks enhancing process performance along with decreasing the danger of misregistration artifacts. Additionally, the close closeness of the detectors permitted extra precise attenuation improvement a crucial action in PET image restoration that represents the absorption as well as spreading of photons as they take a trip via the body (Brix et al., 2005).

Like PET technology, the evolution of CT technology with multi slice CT and iterative reconstruction techniques has been important to the evolution of PET-CT. Significant reduction in scan times and improvement in z-axis resolution were achieved with Multi slice CT by acquiring multiple slices simultaneously. As in PET, CT image quality and radiation dose were improved by iterative reconstruction (Chen et al., 2020; Adeleye & Chetty, 2018).

Dual source CT further extended the ability of PET-CT to provide cardiac imaging. Dual source CT (collision) improves tissue characterization by using two X-ray tubes and two detector arrays and simultaneous acquisition of images at different energy levels, thereby reducing motion artifact. Of particular value, however, has been this technology in evaluating coronary artery disease and other cardiac conditions.

PET-CT has been applied in such a wide variety of clinical applications beyond oncology with cardiology, neurology and infectious disease imaging spending the PET-CT use growing. PET-CT is currently used in cardiology for assessing myocardial viability, for evaluating coronary artery disease, and for planning the cardiac surgery .

PET-CT is used in neurology to diagnose as well as to monitor neurological disorders, including Alzheimer's disease and Parkinson's disease .PET-CT is used in infectious disease imaging to detect and localize infections, to assess treatment response, or to guide antibiotic therapy (Parghane & Basu, 2018).

With ongoing innovation in PET-CT technology and continual development of new radiotracers and sophisticated image processing techniques, PET-CT offers continuing promise to further augment diagnostic and therapeutic uses of this powerful imaging modality. It's anticipated that this integration of artificial intelligence, machine learning, and other cutting-edge technologies will further revolutionize PET-CT imaging creating more accurate and more personalized medicine. The future of PET-CT promises to usher in today’s new era of patient care and enable a better understanding of human health and disease.

2.2.7 PET-CT Balance between Benefit and Risk

Although PET-CT is at the cutting edge of diagnostic care with unparalleled diagnostic sensitivity, the dual nature of radiation exposure associated with the procedure itself poses a unique dosimetric challenge. To combine an internally administered radiotracer with an external CT scan, radiation dose optimization must be conducted with extreme care, in order that the diagnostic benefits outweigh risk to radiosensitive patients (Huang et al., 2009; ICRP 2007).

This skillful balancing act demands the appreciation of factors that affect both internal and external dose, the limitations of current dosimetry, and ongoing efforts to refine protocols with attendant radiation burden without compromising the diagnostic efficacy.

The internal dose emitted from the administered radiotracer, typically ^{18}F-FDG , depends on the radiopharmaceuticals biokinetic profile including uptake and retention in different organs as well as clearance pathways and the physical half-life. The factors which determine residence time within the body affect total internal radiation exposure, that is, the magnitude of internal radiation exposure and duration of exposure.

Internal dose estimation is further complicated by inter-individual variability of these parameters that depends on physiological factors, medical conditions and concomitant medications (Stabin, 2008).

Based on technical parameters of CT acquisition including kVp, mA, scan time, collimation, and pitch , external radiation dose resulting from the CT component of the PET-CT image acquisition depends. Tube current modulation (TCM) can greatly impact the external dose by changing the tube current depending on the patient anatomy and improves image quality while reducing the radiation dose.

In addition, CT protocols across institutions as well as within the same institution vary according to clinical indications and diagnostic requirements, resulting in important variations in external dose abuse of the sum of internal and external radiation exposure in PET-CT, dose optimization must be considered in a global perspective, taking into account the additive effect from both components. Minimizing dose from each modality alone is not sufficient; it also requires optimization of PET and CT acquisition parameters interplay to achieve lowest possible radiation burden while preserving diagnostic image quality.

The susceptibility to the effects of stochastic ionizing radiation is an inherent stochastic effect, which is greater for more rapidly dividing cells (such as children and pregnant women) and such susceptibility is enhanced during longer life expectancy (ICRP 2007).

This increased sensitivity therefore necessitates even more careful dose reduction strategies employing age-appropriate scanning protocols as well as other imaging modalities when possible. Mostly they are vulnerable populations who have to be balanced between the diagnostic benefit and the risk.

Patient specific dosimetry with both patient specific anatomical and biokinetic data also provides additional ways to personalize dose assessment and treatment planning.

Responsible use of the diagnostic power of PET-CT requires knowledge of the radiation dose associated with this power and knowledge of continuous dose optimization. This powerful imaging modality is fully exploited by the clinician, balancing between patient and mission needs, patient versus awareness and application of the most up to date dose reduction techniques, and within the internal and external dose contributions.

2.2.8 The Diagnostic Value of PET-CT

PET-CT has become a paradigm shift in medical imaging, dramatically adding to diagnostic accuracy, as well as to disease management across almost all clinical disciplines.

The integration of functional metabolic information of PET with CT precision anatomical detail provides an unparalleled level of diagnostic insight with this powerful hybrid modality. In oncology, PET-CT has particularly proven valuable because it can localize and quantify metabolic activity in the body and hence identify and characterize early disease and accurately stage disease for effective therapy planning and enhanced patient outcome.

As a recently developed imaging modality, PET-CT has transformed medical imaging and offers new and indispensable information about the human body in an unprecedented manner and potentially changing patient care for many clinical specialties.

It represents a sophisticated hybrid modality that combines the functional metabolic information of PET with the precise anatomical detail of CT to bring this power synergy for a boost in diagnostic accuracy and refinement in disease management (H. Chen et al., 2020).

In oncology, monitoring changes in learned behavior due to drugs is a key indicator of their therapeutic potential, and this can be detected and quantified by PET-CT. However, it's much more effective than that: It's useful in cardiology, neurology, and infectious diseases, where it has demonstrably improved diagnosis and disease management (H. Chen et al., 2020).

The dominant strength of PET-CT is its ability to find metabolically active lesions that are so small or hidden in the anatomy that they are not visible otherwise. PET, a radiotracer such as ^{18}F-fluorodeoxyglucose (FDG), an analogue of glucose, is a target of the increased metabolic activity commonly seen in most cancerous tumors.

PET-CT has a metabolic focus, which allows it to find tumors the conventional imaging modalities (CT, MRI) look for because they depend on anatomic changes. PET and CT provide the metrological basis for PET-CT: By combining the metabolic sensitivity of PET with the anatomical resolution of CT, small or early-stage tumors can be accurately identified and characterized (Brix et al., 2005).

2.2.9 Technological Advancement in Refining PET-CT Dosimetry

Methods for reducing PET-CT dosimetry and doses are ongoing research and development. In the development of new PET radiotracers with smaller radiation burdens, optimization of CT acquisition parameters and device modulation as well as use of advanced image reconstruction techniques to reduce noise and increase image quality at less radiation doses (Adeleye & Chetty, 2018).

While ongoing research and development efforts exist in many areas, the quest for maximizing diagnostic benefits while minimizing the radiation dose associated with PET-CT is an ongoing endeavor. Since both the administered radiotracer and CT component from PET-CT provide internal and external radiation, a multi-pronged approach to dose optimization is necessary. It implies not only refinement of PET-CT individual components but also its interplay optimization, which leads to the minimal possible radiation burden while maintaining diagnostic image quality .

The first area of research is focused on designing new PET radiotracers which are inherently better (i.e. produce lower radiation burdens). This is forcing exploration of new, shorter-lived radioisotopes with decay schemes that result in lower energy particles to reduce patient internal radiation dose. In addition, the use of higher specificity targeted radiotracers to the tissues or organs of interest is being investigated, enabling increased use of lower administered activities with retained diagnostic image quality.

An important role in reducing the external radiation dose from the CT portion of PET-CT is playing optimizing CT acquisition parameters. This is the art of selecting tube voltage (kVp), tube current (mA), scan time, collimation, and pitch so as to deliver the prerequisite level of diagnostic information at the minimal radiation dose (Devine & Mawlawi, 2010).Further optimizing dose is achieved through use of tube current modulation (TCM), where tube current is dynamically adjusted based on patient anatomy, providing greater radiation exposure tailored to the individual patient.

The new algorithms also specifically reduce image noise and leaf position error in order to reduce radiation dose (i.e. at less radiation dose) while providing diagnostic quality images. Process of iterative reconstruction methods has grown sophisticated and the modality of iterative reconstruction methods have become increasingly efficacious and clinical utility of dose optimization strategies expanded.

Further important key to dose optimization in PET-CT is careful selection of CT protocols. Wherever they are not needed for practice, low dose CT protocols and with about half the radiation exposure of diagnostic quality CT scans, are able, instead, to provide attenuation correction and anatomical localization (Quinn et al., 2016;Kesner et al., 2023)

By combining this approach with X-ray dose minimization in the CT component and sufficient information in terms of attenuation correction and anatomical correlation in the PET component, it minimizes X-ray dose during the CT component with simultaneous provision of sufficient information to perform anatomical correlation and attenuation correction of the PET data.

Technological advancements are not the only factor for PET-CT radiation dose optimization; patient specific dosimetry is also growing in relevance. More precise and individualized dose assessment is obtained by including single patient characteristics such as body size and composition into dose calculations. Patient specific dosimetry provides even further clinical tailoring of CT acquisition parameters and radiotracer activities to individual patient studies by reducing radiation burden, while maintaining diagnostic accuracy.

The aim is maximum diagnostic benefit and minimum risks in the quest for refined PET-CT dosimetry and dose reduction strategies. Future PET-CT imaging with further reduced radiation exposure with improved patient care and safety will be promoted through development of novel radiotracers, optimization of CT acquisition parameters and construction of CT data sets, development of improved imaging and reconstruction capabilities, and incorporation of patient specific dosimetry (Chen et al., 2020).

2.2.10 Effective Dose and Risk Communication

The most accurate assessment of effective dose links dosimetry, the use of x-rays and other forms of radiation with biological impairments and connects dosimetry with biological manifestations, making possible the direct comparison of risks associated with different imaging studies. It provides a structured method for risk assessment, which proves very useful in supplementing decision makers especially in the health care scope in terms of patients' selection, reasons for examinations, and protocols fine tuning (ICRP 2015) .

The effective dose can be derived by the summation of weighted equivalents of doses absorbed by organs or tissues of the human body. The absorbed dose to an organ or tissue is calculated from the absorbed dose by multiplying it by the radiation weighting factor which brings the irradiation produced by the various forms of radiation entities to a common reference level which is equivalent to gamma rays.

This equivalent dose is then multiplied by the tissue weighting factor which described the detriment of that organ or tissue as compared to the body as a whole. The sum of these multiplied by the equivalent doses throughout the body calculates the effective dose, a total measure of danger from irradiation.

The estimation of effective dose is based on the determination of dose to individual tissues, which in practice is not easy because of the limitations of dosimetry assessment. It is usually impossible to measure the absorbed dose directly to each organ of an irradiated organism. Consequently, a number of techniques is applied for estimating organ doses such as stylized phantoms and Monte Carlo calculations that model the transport of radiation (ICRP 2015).

Due to the possibility of estimating the effective dose according to the specific scanning parameters, radiation exposure is minimized while acceptable diagnostic image quality is obtained. These can be fine-tuned when performing the scan; tube current-time product, voltage, slice thickness, scan length, and pitch can be set and also remain consistent with the As Low as Reasonably Achievable (ALARA) concept.

Besides, the technique of optimization of the best practice is applied to the situations connected with radiation risk and patient counselling. It provides a quantity of predictable determination that may take a seat of presence and eradication with first discourse to patients concerning the conceivable pecuniary profits and losses belonging to the PET-CT imaging. The effective dose has to be explained to the patients; this could enable patients to compare them with other radiation sources much as health care practitioners recommend (T. H. Wu et al., 2004).

2.2.11 Reduction of Effective Dose in PET-CT

For purposes of determining the likelihood of harm in abscess patients who undergo imaging procedures involving ionizing radiation, the value of the effective dose has to be ascertained. This calculation is crucial in order to compare the risk that is usually related with a given imaging technique as well as choose the right imaging modality for a given patient.

Using the concept of Effective dose, we achieve direct comparison of the potential radiation risk associated with imaging utilizing ionizing radiation (PET-CT) with imaging that does not utilize ionizing radiation (MRI or ultrasound). Such a comparison makes it easier for patients and practitioners to know the dangers and the chances involved with specific imaging studies and arrive at an informed decision about which of the options available is best (Ibrahim, 2021).

There are usual approaches made to make the PET-CT scanning protocols efficient and ideal in diagnosis. PET-CT suffers from high internal and external radiation doses that necessitate a comprehensive dose optimization of the whole system. Typically, this entails not only reducing the amount of radiation dose from a single modality but also taking synergistic effects with all of the concurrent modalities into account.

Strategies that include lowering the CT tube current and voltage; optimizing scan protocols; and using iterative reconstruction techniques may reduce radiation dose without dramatically compromising image quality (Ibrahim, 2021)

PET-CT imaging is of an inherent nature associated with radiation exposure, and knowledge of the sources as well as the factors that influence the dose to patients is vital in order to optimize protocols and maintain safe patient care. Careful thought is needed into the contributions from both internal and external dose and the ongoing research and development of dose reduction strategies is required.

Dose is the key factor in optimizing scanning paradigms for PET-CT for production of accurate images in the minimization of radiation dosage to patients. This includes setting bands on factors like tube current, voltage, slice thickness, scan length and pitch so as to improve image quality and lower patient radiation dose.

This optimization process plays an important role of enhancing the diagnostic value of PET-CT as much as possible while suppressing other harms that may be associated with the modality in the long run.

2.2.12 Radiation Protection in PET-CT

A multi-dimensional approach to patient safety in radiation medicine, especially in more complex advanced imaging modalities such as PET-CT needs technology design; conditions; personnel; data collection, and communication exchange.

Intense effort is needed to recognize and potential of the risks to the patient from radiation exposure and stochastic effects of ionizing radiation from PET-CT protocols, radiation doses, and a culture of safety in the medical community.

Data on radiation doses such as Palestinian radiation doses could be shared to understand how radiation doses are actually practiced and then optimize doses. This has also been as important, increasing public awareness of PET-CT scan benefits and risks so patients can make more educated healthcare decisions.

Dual nature of exposure inherent in the PET-CT radiation procedure is a priority in the task of optimization of PET-CT radiation dose. Both internal radiation from administered radiotracer and external radiation from the CT component are delivered to the patients undergoing PET-CT (Huang et al., 2009).

This dual exposure requires a global approach to dose optimization enabling simultaneous optimization of both internal and external radiation sources. Dose reduction strategies (e.g. lowering CT acquisition parameters, using low dose CT protocols for attenuation correction, and developing new radiotracers with reduced radiation burdens) can be used along with the use of these strategies to reduce dose while maintaining diagnostic efficacy on the radiation doses to patients, as used in the Palestinian radiation dose study, represents a unique chance for benchmarking, what is not perfect yet, and standardization in different hospitals and regions. Collaborative learning with such data sharing initiatives can create evidence-based guidelines for radiation protection in PET-CT.

Improvement in radiation medicine patient safety requires public awareness and education. Healthcare professionals that provide PET-CT scans should openly disclose the potential benefits and risks associated with a scan to patients, enabling them to make informed health (T. H. Wu et al., 2004). This involves telling them why the scan is being done, the amount of radiation they’re likely to receive, potential short- and long-term effects of this radiation exposure. Clear and concise information about radiation safety gives patients a sense of trust and working together as a patient turns and their care as a partner.

Data on patient radiation doses from PET-CT, though valuable, typically exists mainly in one of three forms: limited in scope, including patients from a particular demographic, clinical indication or geographic region. A limitation of this is that the generalization of these findings is limited because of less comprehensive data collection and analysis. By reporting standardized patient demographics, CT acquisition parameters, radiotracer reports, and dosimetric quantities, data can be compared and analyzed to develop evidence-based guidelines for radiation protection in PET-CT (Adeleye & Chetty, 2018).

Additionally, the limited availability of patient specific biokinetic data presents a challenge of accurate internal radiation dose estimation. Typically, biokinetic models based on average data of a group of individuals, while accurate on average, might not accurately describe an individual patient's body (Stabin, 2008).Though resource intensive, acquiring patient specific biokinetic data can increase accuracy of internal dose estimations and facilitate increasingly personalized dose optimization.

Improving patient safety also requires cultivating a safety culture among members of the medical community beyond technical advancement and data sharing initiatives. It includes fostering generalizations in terms radiation protection principles, endorsing compliance with prescribed rules and regulations and supervision of continuous quality improvement programs aiming at optimizing the dose and patient safety.

Open communication among both healthcare professionals, physicists, and technologists is important within this culture of safety that ensures that PET-CT imaging will be used responsibly.

2.2.13 CT as Dominant Radiation Source in PET-CT

The main source of radiation direct exposure is CT, as several research studies found (Huang et al., 2009;Kaushik et al., 2013;Mahmud et al., 2014;Khamwan et al., 2010;Adeleye & Chetty, 2018;Brix et al., 2005). Because of early stated maintain the image quality with optimized CT protocols is needed here critically.

PET-CT imaging, a significant factor to consider is the radiation concern troubled people from the PET along with the CT component of the evaluation. This prominence highlights the demand to enhance CT purchase criteria to acquire analysis photo high quality without extreme radiation dosage.

Although significance on accomplishing premium images crucial for precise medical diagnosis as well as therapy preparation, these images add to enhancing degrees of radiation generated prospective radiation dangers such as cancers cells, there is a trouble in between this requirement for top quality image along with minimizing of radiation dangers particularly those which are possibly random (stochastic).

CT supplies a significant part of the complete efficient dosage in PET-CT; as a result, dosage optimization should entail a multi-faceted strategy that consists of technological advancements coupled with step-by-step changes. Various other innovations such as TCM coupled with step-by-step iterative reconstruction algorithms (IR), have actually added a lot to minimize radiation dosage without endangering photo high quality (Hassan Salah et al, 2021).

Step-by-step restoration approaches enhance image high quality (lowers noise, artifacts), by minimizing dosage sound together with artefacts at reduced dosage degrees with TCM. The tube existing modifications in actual time, adjusting the direct exposure specifications for each and every person based upon person reductions. The reduced radiation dosages without any loss of analysis precision are feasible with these improvements.

To decrease radiations direct exposure, several changes can be done like correct option of check specifications with sticking to DRL. Check size can be more maximized to cover the diagnostically crucial physiological area, hence lowering the overall radiation worry plus pitch can be changed to decrease piece overlap for this reason minimizing dosage adhering to DRLs, the criteria dosage worths for typical CT exams, radiation direct exposures are maintained within the appropriate restriction in doing that it guarantees standardization as well as optimization of CT imaging methods amongst various professional setups.

Enhancing CT procedures calls for taking patient-specific elements, such as age, sex, weight or body make-up, right into account for radiation dosage. The young are much more radiosensitive than the old considering that young individuals with swiftly splitting cells together with their longer life span go to danger for impacts occurring from radiation-induced damages (ICRP 2007).

Similar to body make-up such as body mass index (BMI) X-ray attenuation differs plus as a result the taken in dosage (Salah et al., 2020). It is as a result needed to dressmaker CT criteria to each people' features in order to minimize radiation threat as well as make best use of image high quality.

Specifying the tradeoff in between image top quality plus radiation dosage is very important due to the fact that greater photo high quality (decreased noise, boosted spatial resolution) usually comes with greater radiation dosage (Adeleye & Chetty, 2018). Extreme image top quality over what is essential scientifically has the proclivity of subjecting to needlessly high radiation dosages.

As a result, it is vital to establish an 'acceptable' image top quality degree proper for analysis information however decreasing individual dosage. This requires job by a collective initiative amongst the radiologists, physician along with engineers in producing photo top quality requirements for the essential medical job along with individual.

Although medical care specialists and also producers take duty for handling as well as maximizing CT dosage in PET-CT it stays primarily underutilized. For its component, the feature of radiologists, clinical physicists and also professionals are to pick ideal check specifications the application of DRLs and also to take on approaches for minimizing dosage in their professional technique (M. Y. Chen, 2014).

CT modern technology designers, producers together with suppliers have actually played a significant function in creating dosage minimizing attributes, such as TCM as well as iterative reconstruction and also offering individuals support when urged to maximize CT methods (Adeleye & Chetty, 2018). To progress CT dosage optimization together with person safety and protection, collaboration required in between healthcare expert as well as producers.

2.2.14 The Crucial Play Between Quality and Dose in Nuclear Medicine and CT

In the section of analysis imaging particularly in nuclear medication together with CT the objective of getting the most effective image top quality is important, to accomplish precise medical diagnosis plus to outline the reliable therapy. Images of high-grade function like sharp comparison, reduced noise, high spatial resolution plus minimal artifacts enabling visualization of refined physiological information coupled with help with discovery together with personality of pathological sores (Adeleye & Chetty, 2018).

Nevertheless, however seeking greater image top quality features enhanced radiation dosage, which can produce an inconvenient random threat to patients from radiation caused cancers cells such as that reported (Ibrahim, 2021). Because of this it is necessary to have a mutual understanding of the effective link between the picture top quality as well as the radiation dosage made use of in imaging for ample medical diagnosis yet the demand to lower the radiation direct exposure.

Because of the facility usually vice versa proportional partnership in between picture high quality as well as radiation dosage, the obstacle in enhancing picture top quality while decreasing radiation dosage occurs. Greater picture high quality (i. e., reduced noise and also far better spatial resolution) normally is accompanied by higher radiation dosage for greater photon change or reduced power degrees.

On the other hand, reduced radiation dosage, a crucial concept within the ALARA (as reduced as fairly possible) teaching, can lessen image top quality with raised sound along with minimized spatial resolution equilibrium is carried out on different elements such as what professional job it is, what is the person's attributes as well as what imaging devices can.

A variety of research studies on CT picture top quality and also radiation dosage has actually been made examining the partnership in between these 2 essential specifications with trade-offs in between those two (Hassan Salah et al, 2021). In these researches enhancing radiation dosage did not constantly create a proportional renovation in image top quality, and also various other elements such as scanner type, reconstruction algorithms together with collimation were revealed to add considerably.

Additionally, these high image high qualities might bring about needlessly high radiation dosages to individuals while exceedingly scientifically needed, showing a demand to lessen gotten image top quality to a degree that is required in order to meet the demands of the particular analysis job.

This difficulty is faced with the European Commissions' principle of " just acceptable" image top quality, such that particular minimal demands in image high quality need to be satisfied for particular professional signs (Adeleye & Chetty, 2018).With this strategy picture purchase occurs at the most affordable dosage called for to get analysis info. Yet it's tough to specify what's simply appropriate image high quality: These subjectivity obstructing variables are radiologist experience photo screen features, together with exactly how intricate the physiological area present is.

Quantifiable actions of image top quality unbiased image top quality metrics such as contrast-to-noise ratio (CNR) along with spatial resolution can be made use of to contrast image high quality both in between CT scanners along with methods (scanners and protocols) (Adeleye & Chetty, 2018). Regrettably, these metrics alone might not consistently show the viewed top quality of images as people view them which is the essential requirement in analysis.

As a result, the consolidation of human onlooker researches, such as a visual grading analysis (VGA), right into image high quality analysis will certainly produce some understanding of the partnership in between unbiased metrics as well as subjective image top quality.

Nonetheless, technological progress, including the use of iterative reconstruction technique and TCM, has decoupled the image quality and radiation dose relation (Ibrahim, 2021). Iterative reconstruction methods, on the other hand, use iterative reconstruction methods to improve image quality at lower dose levels by reducing the noise and artifacts, while tube current modulation techniques (TCM), on the other hand, optimize radiation exposure with tube current modulation according to patient attenuation.

Every one of these very same training programs as well as academic sources need to highlight the value of suitable option of check specifications, patient dosage diagnostic reference levels, and adoption of radiation dose retention methods to minimize radiation exposure while not affecting diagnostic quality.

2.2.15 CT dose variability

Many elements have an effect on the powerful dose with signifiable vary in accordance the scanner because of :

- Scanner technology: Modern scanners monitor much less doses in comparison with older generations(Brix et al., 2005;Adeleye & Chetty, 2018).

- Manufactures: there is a one-of-a-kind in dose output depending on the manufacture company (Siemens, GE, Philips). The generation and design affect the consequent patient dose (Mahmud et al., 2014;Khamwan et al., 2010).
- Material of Detectors: the cloth utilized in scanner have an impact on the efficiency and sensitivity which impacts the added dose (Brix et al., 2005).
- Technologies used for dose reduction: the contemporary scanners use numerous dose reduction techniques, for instance AEC), and iterative reconstruction which extensively affect the patient dose (Brix et al., 2005;Quinn et al., 2016).

2.2.16 Variable CT Dose: A Multifaceted Challenge for Radiation Protection

CT vital analysis device in contemporary medication, offers crucial high resolution composition imaging for medical applications. However ,the radiation benefits of CT are gone along with by a little greater radiation strength over various other analysis imaging expenses which elevates worry regarding subordinate cancer cells threats (Mettler et al., 2008).

In practice, these observables from one patient to another are as large as they are complex in interplay between observables happening all the time and between scanner technologies, products acquisition parameters and anatomy affected by time and so strongly influencing the other and both not trivial as for knowledge and control of such variabilities ,are intrinsically important to the optimal CT devices and to avoid mass mess importance of these variabilities, with respect minimal radiation exposure and optimal patient tong observables from one patient to another, scanner technologies.

The aspects associated with the expertise along with control of these variabilities are non-insignificant if anything else. Optimal CT device coupled with monitoring of very little radiation direct exposure plus maximal individual's safety all, are naturally essential concerns.

The reason for distinction in CT price at the scanners is among the significant impactors remains in the generation of the scanners. Older generations like multi-slice reduced resolution scanners normally have a high purchase price to their newer sibling's enhancement can be credited to developments in the modern technology of detectors, light beam aviation as well as image restoration formulas, that produce greater dosage performance along with a reduced radiation dosage in the brand-new generation scanners.

Plus incorporated with various other technical options Modern CT scanners have considerably enhanced the price of exchange (Hassan Salah et al, 2021; Adeleye & Chetty, 2018). One more resource of pitch is the innovator of the CT scanner. Various suppliers such as Siemens, GE along with Philips make use of various innovations plus layouts which can impact radiation discharges also for scanners of the exact same generation (Mahmud et al., 2014; Khamwan et al., 2010).

These variables include detector, beam geometry, filtering, . resulting from differences in image reconstruction procedures, which can affect image quality and radiation dose so direct comparison of dose values across different scanners and images requires consideration of these technical issues and their impact it is very possible on dosimetry

The diagnostic features utilized in CT scanners additionally play a vital duty in figuring out the effectiveness of dosage, as well as therefore the variety of diagnostic attributes in patients populaces exists level of sensitivities, have actually been shown relative to X-rays to impact the variety of photons required to accomplish appropriate image top quality It is possible (Brix et al., 2005).

The application of dosage decreases modern technologies such as automatic exposure control (AEC) ,as well as iterative repair additional added to variants in CT quantity amongst various scanner methods (Adeleye & Chetty, 2018; Quinn et al., 2016;Brix et al., 2005). The AEC automatically adjusts the tube current based on patient size and attenuation, optimizing exposure parameters in real time to reduce radiation dose iterations.

Patient dose plus composition likewise affects radiation dosage as bigger individuals have a tendency to require bigger tube currents to obtain great picogram dimension as well as this leads to raised radiation dosage (Ibrahim, 2021) .

The X-ray hostility in addition to soaked up dosage circulation within the body, relies on physiological modifications such as the cells components and also density. Consequently, it is very preferable to customize CT procedures to patients in order to lessen their direct exposure to radiation while maintaining diagnostic imaging, excluding their duration and anatomy.

The great variety of medical and diagnostic factors for computed tomographic (CT) imaging, besides providing quantity variability, also contributes to the number of experiments that requires exotic parameter and protocol combinations. , e.g., CT scanning for trauma is commonly larger than typical of the field scanning Angiography and perfusion studies, and may also include higher radiation exposure due to optimized acquisition parameters that are specific to this use case (Almasri & Inayyem, 2021).

Finally, surgical revel in and adherence to established protocols can also have an effect on CT dose conversion. Technologists and radiologists are tremendously skilled in optimizing scan parameters and implementing dose reduction strategies, ensuing in reduced radiation dose to sufferers (Chen, 2014) and also, following frequently set up protocols and diagnostic reference degrees and therefore variability radiation publicity and wishes to be reduced as a result to make sure feasibility and inexpensiveness is consequently vital.

2.2.17 Factors affecting on CT radiation Dose

CT has actually come to be an essential device in modern-day clinical imaging, offering high-resolution physiological images necessary for a selection of scientific applications. Nonetheless, the benefits of CT featured the danger of radiation direct exposure is intricate, increasing problems concerning prospective unintentional impacts, especially radiation-induced cancer cells optimizing protocols to lower radiation dosage while protecting analysis image high quality is consequently a significant problem in radiation safety, and requires consideration of various scan parameters and their effects on independent patients insert it carefully.

CT optimizing protocols to lower radiation dosage while protecting analysis image high quality is consequently a significant problem in radiation safety, and requires consideration of various scan parameters and their effects on independent patients insert it carefully.

The CT protocol incorporates predefined scan parameters that control the acquisition of CT images, and ultimately affects the radiation dose delivered to patient's

Key scan parameters include scan length, volume, tube current time product (mAs), and tube voltage (kVp) (Quinn et al., 2016;Adeleye & Chetty, 2018).

Scan length, the size of the body area covered by the scan directly affects the overall radiation load, because a larger scan number exposes a larger area of the patient's body X-ray, counter-gantry turning plus light beam width. The proportion of table feed influences dosage performance where high pitch worths generally lead to reduced dosage as a result of reduced acquisition time (Hassan Salah et al, 2021).

Tube current (mAs) determines the number of incident X-ray photons, which directly affects image quality and noise, while tube voltage (kVp) x -Affects the energy of the ray photon, which affects contrast between the image and the ventilation rate.

2.2.18 Dose-Reduction Vs Image Quality

Image quality and patients' dose, directly affected by tube current (mAs), which is the most significant factor in reducing radiation dose during CT. Nevertheless, the benefits of CT included the threat of radiation direct exposure is intricate, increasing issues concerning possible unexpected results especially radiation-induced cancer cells.

CT maximizing procedures to minimize radiation dosage while maintaining diagnostic image with high quality is consequently a significant worry in radiation defense, as well as needs factor to consider of numerous check specifications plus their results on independent clients place it very carefully.

Thus, it is essential to determine the best use of mAs value for every clinical situation based on a trade-off between these two competing factors depending on diagnostic task being performed, patient condition, and the ability range of the CT scanner and reconstruction algorithm.

Many papers have been conducted to look into the performance of mAs reduction strategy in reducing CT radiation dose while minimizing image quality loss, (Adeleye & Chetty, 2018) has shown a significant dose decrease in abdominal CT using reduction of mAs by 50% without significant effect on image quality.

mAs identifies the variety of occurrence X-ray photons which straight impacts image top quality as well as sound, while kVp affects the power of the ray image, which impacts comparison in between the picture along with the air flow price.

2.2.19 Patient Characteristic in CT Dosimetry

CT has revolutionized diagnostic imaging, providing unparalleled anatomic images of medical importance. Nevertheless, these numerous benefits have dangers as a result of radiation direct exposure, even more worried the possibility of carcinogenesis (Adeleye & Chetty, 2018) which indicates a growing number of mindful factors to consider and also cautious usage is needed with feasible methods adjustments.

Mindful factors to consider are needed, consists of numerous aspects and also check criteria. The lasting results such as carcinogenesis have to well balanced with uncounted advantages .

Youngsters stand for a specifically prone populace to CT imaging as their fast cell department as well as long-life period make them specifically at risk to unintentional radiation direct exposure (ICRP 2007). Comparative the high danger of there to locate cancer cells and also altering CT prepare for pediatric medicines additionally require to guarantee photo top quality.

In a similar way, variations in patient dimension plus framework structure can noticeably influence radiation dosage and also image high quality, demanding modifications to experiment specifications for first-rate analysis results.

Larger patients normally need high mAs to attain appropriate infiltration together with picture positive, on the other hand, reduced mAs might not be needed for smaller sized patients as well as can produce picture sound and also in many cases, concession analysis precision. Hence image remarkable as effectively as radiation dosage should be maximized for private patient size by customizing mAs setups (Hassan Salah et al, 2021).

As with any other X-ray attenuation and distribution of absorbed dose quantity within the frame, body composition including variations in tissue density and fat material more also influence (Salah et al., 2020). Since many individuals with greater body mass indexes (BMI) have increased cells thickness, the reductions mores than with a leaner person and also can influence image respectable plus need adjustment of experiment criteria.

Variability adds to the difficulty of patient-specific dose measurement. Radiopharmaceuticals distribution and radiation absorption pattern of the radiation incidence can be substantially affected (Adeleye & Chetty, 2018). By differences in organ size, location, and surrounding tissue, and the presence of metal implants or other foreign bodies is likely to cause artifacts influencing CT images etc. on Requires adjustment of scan parameters other techniques if metal or foreign bodies are used in image.

By distinctions in body organ dimension, area, and also bordering cells and also the visibility of steel implants or various other international bodies is most likely to create artifacts affecting CT images and so on. Needs change of check specifications various other strategies if steel or international bodies (metal or foreign bodies) are made use of in image.

More crucial in contemporary medical care the principle of tailored medication highlights therapies as well as analysis treatments customized to the requirements as well as signs and symptoms of a patient. In CT imaging, this implies embark on to enhance check routines based upon details functions to lessen radiation direct exposure while protecting illness precision. Consideration of medical information, individual demographics along with imaging abilities to create tailored check methods that decrease radiation problem and make certain enough image top quality (Almasri & Inayyem, 2021;Devine & Mawlawi, 2010).

In CT imaging, this means undertake to optimize scan schedules based on specific features to minimize radiation exposure while preserving disease accuracy Consideration of clinical data, patient demographics, and imaging capabilities to develop customized scan protocols that minimize radiation burden and ensure sufficient image quality.

Computed tomography (CT) makes possible the kinds of anatomical detail that revolutionize diagnostic imaging for precise diagnoses and appropriate treatment decisions in virtually all fields of medicine. Although CT has benefits, it does so with respect to its relatively high radiation exposure compared to other imaging modalities, which raises concern for the stochastic risk of radiation induced cancer primarily probability of radiation induced cancer (Drzezga et al., 2012).

As radiation dose is not evenly distributed within the body and patient specific characteristics can have a major impact on the radiation burden, CT protocols need to be optimized to minimize exposure with maintaining diagnostic accuracy. Body Mass Index (BMI), ranges, both a significant factor in determining radiation dose in CT imaging. Notable variations of dose have been reported based on BMI, which suggests that the need exists for tailored protocols and individualized dose optimization strategies (Hassan Salah et al, 2021).

In patients with thicker body tissues, higher BMI values can necessitate larger mAs for equivalent image quality. Higher absorbed doses can also trail from this, and lead to higher radiation risks. Along with BMI various other patient certain aspects, consisting of age, sex and also body make-up, likewise have a big impact on CT dosimetry.

Also, tissue density and fat distribution variations, not fully accounted for by BMI alone, contribute to variations in X-ray attenuation and consequently in absorbed dose, and therefore precise dosimetry should take into account detailed body composition data (Salah et al., 2020).

Furthermore, variants of individual anatomic framework can influence dramatically on radiation dosage plus image high quality. Radiopharmaceutical circulation as well as radiation absorption might vary according to body organ dimension, place coupled with bordering cells; for that reason, scan parameters and protocols must be adjusted (Adeleye & Chetty, 2018)

Together with advances in dosimetry tools such as voxel dosimetry and Monte Carlo simulations, and with the increasing availability of detailed anatomical information and radiation transport modeling (Kesner et al., 2023), it has now become possible to predict more accurate and therefore more personalized dose estimates.

As computational resources and dosimetry software improve, the application of these advanced techniques should become more important in-patient specific CT dosimetry. As calculation sources as well as dosimetry software application enhance, the application of these sophisticated techniques needs to come to be more vital in-patient certain CT dosimetry.

2.2.20 Factors that effecting PET-CT radiation Dose

The factors affecting the radiation dose received by patients during a PET-CT examination range from the PET to the CT component. In PET, dose is mainly deployment as activity of administered radiopharmaceutical. Administered activity level is higher, which increases the radiation exposure, but may improve image quality and decrease scan time (Parghane & Basu, 2018;Dhalisa et al., 2016).

However, patient weight and body composition will influence PET dose distribution as well, because different organs and tissues take up tracer at different degrees (Kaushik et al., 2013). Residence times and, therefore, organ doses are also influenced by biokinetic factors such as tracer uptake and clearance rates (Stabin, 2008). The biodistribution must therefore also be seen as affected by patient motion during the uptake phase and may require repeat injections to achieve similar values, increasing radiation exposure (Boellaard et al., 2015).

The total radiation dose to the patient is largely associated with CT, but this also depends on technical parameters and on other aspects of the PET-CT system. Therefore, the dose (as calculated by our system) is proportional to the tube current (mAs) in a direct and linear fashion. The quantity and quality of photons (dose and image contrast) depend on the tube voltage (kVp) and other factors.

As a rule, higher kVp increases dose, but also increases signal and potentially reduces the mAs. Dose is inversely proportional to pitch which is the table feed per gantry rotation. Scan time and exposure decrease as the pitch increases, as does image quality. As dose increases, the scan length is directly proportional to the quantity of radiation the tissue is exposed to (Salah et al., 2020). The slices thickness also has a play; smaller slices require higher dose so that the image quality remains high (T. H. Wu et al., 2004).

Appropriate shielding and patient positioning combined with clear communication of referring physicians as well as technologists and radiologists is also important for the maximization of radiation safety .These factors should be closely taken in to account along with ALARA principles (As Low as Reasonably Achievable), in order to optimize patient dose in PET-CT. Protocols can be standardized, diagnostic reference levels should be used, and dose reduction techniques, especially for the CT part, may be employed to minimize radiation exposure, while keeping diagnostic image quality (Boellaard et al., 2015).

2.2.21 The Effects of Patient Size on Radiation Dose in 18F-FDG-PET-CT

As considered that 18F-FDG PET CT is getting scientific usage in modern medication specifically in oncology, focus is paid to the radiation direct exposure coupled with its feasible lasting ramification on people. Patient size is one of the most important factors in determining radiation dose in PET-CT because larger patients in general require higher radiation dose to achieve the same image quality.

Essentially, a patient size dependent controller, its basic principle of CT image, however, caters to the patient size dependent attenuation of X-rays. The larger patients have higher x ray exposures than the smaller patients as a result of higher attenuation and higher than the smaller patients attributable to higher attenuation in order to obtain adequate image penetration and contrast in image (Khamwan et al., 2010;Quinn et al., 2016).

The assistant rise in reductions nevertheless calls for adjustments in check criteria (tube current (mAs); tube voltage (kVp) to endure image top quality as well as analysis precision specifically, leading to straight rise in dosage. CT imaging for larger patients postures the essential problem of locating an ideal concession in between the requirement for image high quality as well as the requirement for dosage minimization.

Other factors, such as body composition and organ size further complicate this relationship with patient size and radiation dose. It can result in differences in its dose distribution throughout the body, even for patients of the same size. Moreover, depending on where the organs are located and the relative organ size, radiation received by certain organs differs from radiation received to other organs present in close proximity to the primary imaging field.

Organ size, location, and tissue composition vary from average sized people, and phantoms based on average anatomical data on average sized people may not be adequate representations of these variations in larger patients. In this case the actual dose may be under or overestimated if an estimate based on a standardized phantom is not precise for the larger people.

Yet, patient size can be overcome in CT dosimetry using modern dosimetry techniques like volumetric dosimetry and Monte Carlo simulations (Kesner et al., 2023). Voxel based dosimetry makes use of person certain composition info achievable from CT or MRI photos for determining high spatial resolution dosage circulations that hinge on body dimension plus cells make-up variants.

On top of dimension certain dosage quotes CT scanners apply AEC systems that readjust check criteria in actual time based upon individual reduction (Hassan Salah et al, 2021). To fit variants in person dimension and also body structure AEC systems regulate tube present (mAs) instantly to keep photo top quality while reducing individual dosage.

On top of size specific dose estimates, CT scanners implement AEC systems that adjust scan parameters in real time based on patient attenuation (Adeleye & Chetty, 2018). To accommodate variations in patient size and body composition, AEC systems modulate tube current (mAs) automatically to maintain image quality while decreasing patient dose. Adjusting the scan parameters now atomically gives this improved dose efficiency, thereby requiring less technologist intervention.

2.2.22 The Influence of Gender and Age on Radiation Dose in 18F-FDG PET-CT

In medical imaging procedures involving ionizing radiation such as 18F-FDG PET-CT, different patient specific factors require careful consideration to maintain radiation dosimetry, as radiation burden is inherent and patient specific and radiation risk can be increased or mitigated.

Two such essential variables on both biodistribution of the radiopharmaceutical and ability of body organs coupled with cells to radiation caused results consisting of sex plus age. The complex relation between gender, age and 18F-FDG PET-CT radiation is investigated at the level of physiological and anatomical factors as well as associated dosimetric challenges and regarded strategies for personalized radiation protection (Adeleye & Chetty, 2018).

Composition variants in body organ dimension, area as well as cell's structure play an essential impact were sex influences radiation dosimetry. Females normally have smaller sized body organs along with different fat circulation than guys, this will certainly influence 18F-FDG biodistribution and also taken in dosage to some body organs.

While women also have breast tissue, a radiosensitive organ whose absence in men necessitates appropriate breast dose assessment considerations for female patients undergoing PET-CT, their lower lung volumes require that they are CT scanned with more careful attention to a range of factors, including breathing, to produce an image equivalent in radiation exposure to men. However, the presence of these anatomical differences underlines the significance of gender specific dosimetry models and phantoms for such accurate dose estimation.

Radiation dosimetry is likewise based on age mostly for factors of adjustments in body organ radiosensitivity as well as physical feature throughout the life process. Radiation dosimetry is also dependent upon age, primarily for reasons of changes in organ radiosensitivity and physiological function throughout the lifespan. For example, children are more vulnerable to certain stochastic effects of radiation as a result of undergoing rapid cell division and a longer life span during which radiation can lead to cancers (ICRP 2007).

Radiopharmaceuticals biokinetics and distribution of absorbed dose can be affected as individuals age, if organ function and metabolic activity decline. Additionally, age related decreases in body composition such as decreased muscle mass and increased of fat content can affect radiation attenuation and dose distribution (Salah et al., 2020).

Relative to PET-CT the included impacts of sex as well as age make complex dosimetry even more, because, for instance outside radiation direct exposures must be taken into consideration in addition to internal direct exposures.

Jender and age-related variant in body dimension coupled with make-up likewise influence exterior dosage from CT along with change of check specifications is made use of to maximize photo high quality while decreasing radiation direct exposure (Kaushik et al., 2013). Therefore, a full dosimetry in PET-CT requires consolidation of not just the results old and also sex however likewise of various other person details elements.

Modern dosimetry strategies consisting of voxel dosimetry coupled with Monte Carlo simulation stand for appealing ways for the incorporation of physical and also physical client attributes right into radiation dosage computations (Kesner et al., 2023).

Optimization of CT procedures and also to aid maintain radiation direct exposures ALARA need the growth as well as application old and also sex particular analysis recommendation degrees (DRLs). Criteria for examining dosages as well as finding high dosages are acquired DRLs based upon studies of common dosages of typical CT assessments in a selection old as well as sex groupings.

The adherence to DRLs assists in systematizing of imaging techniques together with in dosage optimization initiatives to make sure that the dosage offered is proper to the individual age plus sex.

Communication and decision making between these professionals is open and combined to build CT protocols tailored to each individual patient needs, minimize radiation exposure, and maintain radiation safety in PET-CT imaging (T. H. Wu et al., 2004).

2.2.23 CT Dose Contribution Variability in 18F-FDG PET-CT

Where 18F-FDG PET-CT has actually considerably raised its usage in contemporary medication, offering important analysis and also restorative worth the enhanced radiation worry created. In addition to it has actually created worry around lasting impacts to patients. Computed tomography (CT), which is a crucial factor to total radiation dosage in PET-CT as well as offers essential physiological proof to help in image blend and also attenuation adjustment is a big part of the radiation dosage from PET-CT (Brix et al., 2005).

Though, the CT dose contribution is highly variable, as it is affected by a host of complicated interplays between CT technology, protocol and patient parameters. Knowledge and solution of this variability are necessary in achieving the optimization of PET-CT protocols, reduction of radiation exposure and the preservation of patient safety.

CT dose contribution to PET-CT has been quantified in numerous studies, reporting a broad range of values due to the use of different imaging protocols and different scanners (Huang et al., 2009; Brix et al., 2005; Quinn et al., 2016; Adeleye & Chetty, 2018).

As known, the radiation exposure must be as low as possible. Many factors affect the amount of radiation to patients, for example, patient age, sex, weight and acquisition parameters (Ibrahim, 2021).The research study done at King Faisal professional as well as Research Center in Saudi Arabia, the client's direct exposures plus the resultant efficient dosage of 636 patients with various health problem problems researched.

The importance of radiation reduction and accurate patient exposure highlighted in this study and other studies. Up to 81% CT contribution of the total effective dose to patients (Huang et al., 2009) so, a nation-wide dose assessment, more staff awareness and optimization of acquisition parameters and parameters will maximize patient benefit and reduce the amount of patient's effective dose.

This variability, however, emphasizes the multitudinous nature of CT dosimetry and the necessity of a personalized approach to radiation protection that takes into account patient specific needs and clinical indications.

The PET component provides a fairly constant internal radiation dose due to the amount of activity and 18F-FDG biokinetic distribution, while the external dose from CT can be highly variable, dependent on scan parameters and the scanner technology(Devine & Mawlawi, 2010). Therefore, CT protocol optimization to minimize radiation burden is a primary aim in PET-CT dose optimization.

The generation of the scanner utilized are just one of the primary elements affecting CT dosage payment. Particularly older CT scanners particularly single slice, coupled with very early multi slice systems normally offer greater dosages than their contemporary equivalents primarily as a result of absence of sophisticated dosage conserving innovations (Brix et al., 2005; Adeleye & Chetty, 2018).

CT scanners of modern time include features like automatic exposure control (AEC), and iterative reconstruction techniques, which while significantly reducing the radiation dose keeps the image quality the same or even be (Brix et al., 2005; Huang et al., 2009).

Contributing to the CT dose contribution is the idiosyncrasies of the specific CT protocol (tube current-time product (mAs), tube voltage (kVp), scan length, pitch, and collimation). Improved image quality through less noise comes with compensation of higher mAs, which proportionally increases radiation dose .

Likewise, lower kVp settings, while possibly achieving lower dose, will also increase image noise and decrease lesion detectability especially in larger patients. The specific clinical indication and patient characteristics are to be optimized based on image quality versus radiation dose for these parameters (Kaushik et al., 2013;.Brix et al., 2005)

PET-CT uses also play a role in shaping the CT dose contribution as through the different tasks (diagnostic/staging) different levels of interest and detail in CT image are needed. For example, a significant increase in radiation dose, when oncologic staging involves whole body CT with IV contrast enhancement (H. Chen et al., 2020) .

2.3 Previous Studies

Effective doses have been quantitatively assessed in patients with ^{18}F-FDG PET-CT in several studies, and they have been attributed to CT protocols, patient characteristics, and scanner technology. The total effective doses are estimated using TLDs in a phantom and ICRP 80 dose coefficients, according to (Brix et al., 2005). CT doses ranged from 1–20 mSv, PET dose 7 mSv, the total effective doses 24–26 mSv, and 54%–81% contributed to CT.

Similarly, Huang et al., (2009) also used TLDs and ICRP report 80, the CT doses measured was of 7–32 mSv, PET doses of 6.2 mSv, and total doses was 13–32 mSv (54–81% from CT). The organ doses from CTDI values, OLINDA/EXM software and ICRP 106 were calculated by Kaushik et al. (2013) for ^{18}F-FDG and ^{18}F-FDOPA PET/CT. Tracer and anatomical region (e.g. whole body vs. brain) were used as variables producing mean effective doses. However, (Quinn et al., 2016) included patient specific organ masses and used ImPACT software with mean effective doses of 9 mSv (PET), 5–15 mSv (CT) and 14–24 mSv (total) with CT contributing 35.7 or 63.2% (depending on protocol).

Salah et al., (2020) used RADAR methodology, CTDIvol from patient data and ICRP 102/103 conversion factors to estimate of 30 mSv mean CT dose, 8 mSv mean PET dose and total effective dose of 38 mSv (79% from CT). CT dose of 8− 24 mSv (1 system), of 8− 27 mSv (others) and of 32%−79% due to CT was used from CT-Expo dedicated to CT and ICRP 106 for PET dose, respectively by (Adeleye & Chetty, 2018). The CT dose was measured by TLDs and the PET dose was estimated with ^{18}F-FDG, 370 MBq PET dose and dose coefficients according to ICRP recommendations (Mahmud et al., 2014). They reported the total mean effective dose were in the range of 13.65 – 38.58 mSv, of which the CT contributes 54 – 81 % of the total.

Table (2.1): Contribution of CT and PET effective dose of previous studies

Authors	Mean PET ED (mSv)	Mean CT ED (mSv)	Mean PET/CT ED (mSv)	Mean % CT	Calculation Method
Brix et al. (2005)	7.0	19.4	26.4	73.5	TLD measurements in phantom, ICRP 80 dose coefficients
Huang et al. (2009)	6.2	26.0	32.2	80.7	TLD measurements in phantom, ICRP 80 dose coefficients
Khamwan et al. (2010)	4.4	14.5	18.9	76.7	ICRP 106 dose coefficients, CTDIvol measurements, k coefficient
Kaushik et al. (2013)	6.3 (^{18}F-FDG) / 2.9 (^{18}F-FDOPA)	8.2 - 11.5 (^{18}F-FDG) / 6 - 8.5 (^{18}F-FDOPA)	14.4 (F)/ 11.8 (M) (^{18}F-FDG) / 11 (F)/9.1 (M) (^{18}F-FDOPA)	~66 (^{18}F-FDG) / ~81 (^{18}F-FDOPA)	CTDI values, OLINDA/EXM software, ICRP 106 dose coefficients
Quinn et al. (2016)	9.0	5.0 (std CT) / 15.4 (diagnostic CT)	14 (std CT) / 24.4 (diagnostic CT)	35.7 (std CT) / 63.2 (diagnostic CT)	Patient-specific organ masses, ImPACT software, ICRP 103 weighting factors
Salah et al. (2020)	8.0	30.0	38.0	79	ICRP 103 & 102 conversion factors, CTDIvol from patient data, radar methodology
Adeleye and Chetty (2018)	5.4	2.6-18.7 (depending on system and protocol)	8-24 (one system) / 8-27 (another)	32-77	CT-Expo (CT), ICRP 106 (PET)
Mahmud et al. (2014)	6.3	7.22-32.18	13.65-38.58	54-81	TLD measurements, ICRP 80 & 103 dose coefficients, ImPACT CT dosimetry calculator

ED: Effective Dose, mSv: milliSievert .TLD: thermos -luminescent dosimeter . std: standard, ICRP: International Commission on Radiological Protection. CTDIvol: Computed Tomography Dose Index, volume. DLP: Dose Length Product. k coefficient: A conversion factor used to estimate effective dose from DLP. OLINDA/EXM: Organ Level Internal Dose Assessment-Exponential Modeling. ImPACT: Imaging Performance Assessment of CT scanners. Radar: Radiation Dose Assessment Resource (RADAR) group.

Chapter Three: Methodology

3.1 Introduction

This chapter outlines the methodological approach adopted to examine the major research question: estimating effective dose in ^{18}F-FDG PET-CT scans. The study, outlines the study design, the data collection procedures, the dose calculation methods and the statistical analysis techniques, in a transparent and reproducible account of the research process.

It indicates reasons for choosing certain methodologies, this rigorous methodological framework allows the validity and reliability of the findings, ensuring the findings can be meaningfully interpreted and applied to the greater radiation safety issues in PET-CT imaging.

A retrospective cohort study was thus realized including patients who had been referred in Patients' Friends Society - Nablus Positron Emission Tomography Imaging departments, where they were located at Northern Palestine. All patient demographic data as age, sex, weight, height was recorded. Moreover, the administered activity of ^{18}F-FDG, and implicated Computed Tomography scan parameters, i.e., kVp, mAs, pitch, slice thickness and scan length were simultaneously extracted as study variables.

With this comprehensive data set, it's possible to investigate in detail the factors that affect radiation dose and more specifically, make personalized dose estimations for each individual patient. All data sources are standardized using data extraction protocols to make sure all data sources are consistent and accurate. Exact dosage evaluation is required to recognize also regulate the radiation direct exposure from this significantly crucial analysis modality.

3.2 Study Design

This retrospective study used a framework to calculate the amount of radiation dose received by adult patients in North Palestine from ^{18}F-FDG PET-CT scans. The study population included 150 adult patients who underwent ^{18}F-FDGPET-CT scans at Patient Friends' Society-Nablus.

The framework of the study is divided into three categories, beginning from the assurance of data accessibility and implementation of data collection. The second category comprised the validation of patient demographic data and its appropriateness for the next steps of calculations and analysis. The final category included the utilization of specific software programs to precisely calculate the radiation doses from PET-CT procedures and analysis of results.

3.3 Inclusion Criteria

The included patients were male and females >18 years old, with documented oncology indicated patients who had reliable and consistent data. The samples were collected in a random way . All requested demographic data and scan parameters were extracted from archived system. While the excluded criteria were the Patients were 30 patients due to missed requested data, and pediatric patients age <18 years.

3.4 Administered Activity and Dose Optimization

Because the administered activity of 18F-FDG is based on patient weight and standardized recommendations for adult and pediatric populations, the internal radiation dose is typically based on patient weight. The European Association of Nuclear Medicine (ENAM) indicates pediatric administered dosages, while adult dosages are often standardized on the basis of weight. Add to that, the radioactive tracer ranged from 3 to 20 mCi, which equals range from 111 to 740 MBq.

In PET-CT, a dose optimization is made to minimize radiation exposure whilst still meeting diagnostic image quality requirements, frequently with adjustment of CT scan parameters to decrease external dose contribution.

3.5 PET-CT System

For a wide range of diagnostic applications, The Philips Ingenuity TF Imaging systems are a family of integrated diagnostic X-ray CT and Positron Emission Tomography (PET) systems suitable, CT scanner system is 64 -slice. The used system is comprised of patients table, CT gantry system, PET gantry system, and gantry separation system.

PET-CT feature a 70 cm bore size, which makes it easy to access to patient at any time if needed. Add to that, it allows to separate the PET and CT components and operate the system as a stand-alone CT system or PET system. This system is designed to make a high-quality PET images with anatomical diagnostic images from CT system. It also has tools for quantification of results obtained from PET-CT images. The fused images of PET-CT can be reviewed simply.

This PET-CT system allows to the worker to reconstruct three-dimensional, high resolution imaged of the metabolic and biochemical processes of organs of the body scanned. The use of this system with radiopharmaceuticals allows to obtain internal distribution of radiotracer within the organ of the scanned body. In order to reduce patient dose as possible, while keeps high level of quality, this system uses has more than option helps in dose reduction. Depending on as low as reasonably achievable, this system has Dose Right, Z Modulation, and 3D Modulation.

Figure (3.1): Shows the used PET-CT System (The Philips Ingenuity TF Imaging systems)

3.6 Patient preparation

It is important to communicate with the patient all through the PET-CT process to support their comprehension and teamwork. So, technologists go through all the steps for the patient, answers any questions, and attend to any worries. When the doctor and patient communicate well, it reduces stress, encourages the patient to follow the directions, and guarantees good image results. It is important to explain that patients should lie still during the test and carefully follow the pre-scan and post-scan guidelines.

PET-CT scan requires that the patient is prepared following steps such as scheduling, receiving clear instructions, going through reception protocol, undergoing tests, being given a radiotracer, and being guided after the scan. Patients are always given instructions for a PET-CT scan to ensure the best results and minimize risks of side effects. To help with the scan results, patients are advised to fast for a few hours (6-8 hours) before the scan which results better tumor uptake of the radiotracer. It is advised to refrain from simple carbohydrates, drinks with caffeine, and alcohol, as they might affect how FDG is uptake in the scan.

Add to that, strong physical exercise is not advised at least 24 hours prior to the scan, because it can interfere with how the FDG is absorbed in the muscles. For patients with diabetes, the doctor may direct them to stop taking certain medications or to take them differently before the scan. Certain meals, along with some drugs, can change the results of the scan and interfere its accuracy.

Upon getting to the PET-CT department, the patient is met by a technologist who reads through the instructions, confirms the patient is fasting, and obtains the patient’s basic medical and medication history. The patient’s height and weight taken routinely, as it is essential for setting the appropriate dose of radiotracer. Then, blood glucose test to find out the glucose concentrations in the patient’s blood. If the results of the blood sugar test are high, the patient may need to have their scan rescheduled or undergo further preparation before imaging. If needed, an intravenous line is placed to help keep a patient hydrated, give necessary medications, and address the risks of adverse reactions caused by the contrast agent.

Figure (3.2): Patient Reception Room of PET-CT section

Usually, trained nurses or technologists use a proper sterile technique to insert a peripheral intravenous (IV) cannula. Once the cannula is taped down, the process of hydration with normal saline begins. Intravenous injection of the radiotracer, at this department ^{18}F-FDG is used, carried out automatically. In accordance with institutional protocols and the ALARA principle, the administered activity for each patient was calculated using a weight-based formula of 0.08 mCi per kilogram of body weight.

Figure 3-3 shows the automatic injector used, which is automatic injector designed for PET radiotracer, it's designed for efficient and safe radiopharmaceutical delivery, results of less exposure to both patients and medical team. The displayed screen shows an ongoing infusion, likely of ^{18}F-FDG. The key parameters shown includes injected activity, flow rate, and whole volume.

Figure (3.3): Radiotracer Automatic Injection room of PET-CT section (MEDRAD Intego PET Infusion System)

After the radiotracer injection, the patient directed to a quite dim waiting room for about one hour so that the tracer can reach and be stored in the right areas in the body (uptake period). To get the best image result, patients should sit still and don't do anything else that can consume extra FDG. Having comfort levels remain good for patient is really important during this process. If patient feels cold, he or she covered with a blanket to keep warm.

Before entering the scan room, patients asked to empty the bladder to reduce urinary tract activity, the scan time average scan usually lasts from 10 to 30 minutes. The patient is placed on the exam table so that they are comfortable and immobile to keep the image clear. The scan length from the head to below the knees to all patients, so the patient asked to put up his arms beside head. Instructions to patients includes stay still and take breaths when the imaging is taking place.

Patients are given post-scan directions to make sure they stay safe and get rid of the tracer from their body. Most patients are advised to drink lots of fluids to help the body eliminate the FDG radioactive material. Restrictions for being in close contact with babies, children, or pregnant women advised for a limited time. Doctors also make sure patients are aware that side effects of the CT contrast agent may be allergic reaction or nephropathy after a while, and they leave them with information on how to contact the team if any concerns arise.

3.7 Data Acquisition and Patient Demographics

In the first phase of the methodology, comprehensive patient data were collected from the patients Friend's Society-Nablus at the north Palestine. It also included getting demographic information such as age, sex, weight, and height, which are needed to assign individual patient specific dose estimates. The study sample was (N 150) consisted of male and female patients, ranged from 18-82 years old, who are grouped to 4 groups as the following (18-30, 31-45, 46-60, > 60 Y). Also, the Patients BMI grouped to 4 groups (underweight, normal weight, overweight, obese).

Additionally, CTDIvol (volume CT dose index) and DLP (dose length product) obtained from the CT scanner, as dosimetric information, are required as inputs for the dose calculations. For different clinical indications, according to both systems PET-CT systems, imaging acquisition parameters were gathered. The collected data included the fixed tube voltage used (120 kVp), tube current time product (mAs), the administrated activity(A, in MBq),and dose length product (mGy.cm). Patients received CT dose index ranged from 8.50 to 19.70 mGy, and the total DLP ranged from 1282.20 to 3157.20 mGy.cm. Add to that, the tube current ranged from 130 to 301 mAs.

3.8 Software-Based Dosimetry (Internal and External Dose)

This research utilizes advanced dosimetry software for intermediate and external radiation dose estimation from 18F-FDG PET-CT. The IDAC 2.1 software is used to estimate internal dose using its patient specific anatomical data and most recent versions of the ICRP biokinetic models (Andersson et al., 2017). In order to ensure the proper internal dose calculations, this software used, which takes into account the specific characteristics of patients, while Virtual Dose™ CT used for CT dose calculation.

3.8.1 Internal Dosage Analysis by Computer System (IDAC)

The Internal Dosage Analysis by Computer System (IDAC) software application, version 2.1, stands for a substantial innovation in patient-specific interior dosimetry estimations for nuclear medication treatments. Leveraging a voxel-based method with sensible, anatomically exact computational human phantoms stemmed from ICRP Publication 110.

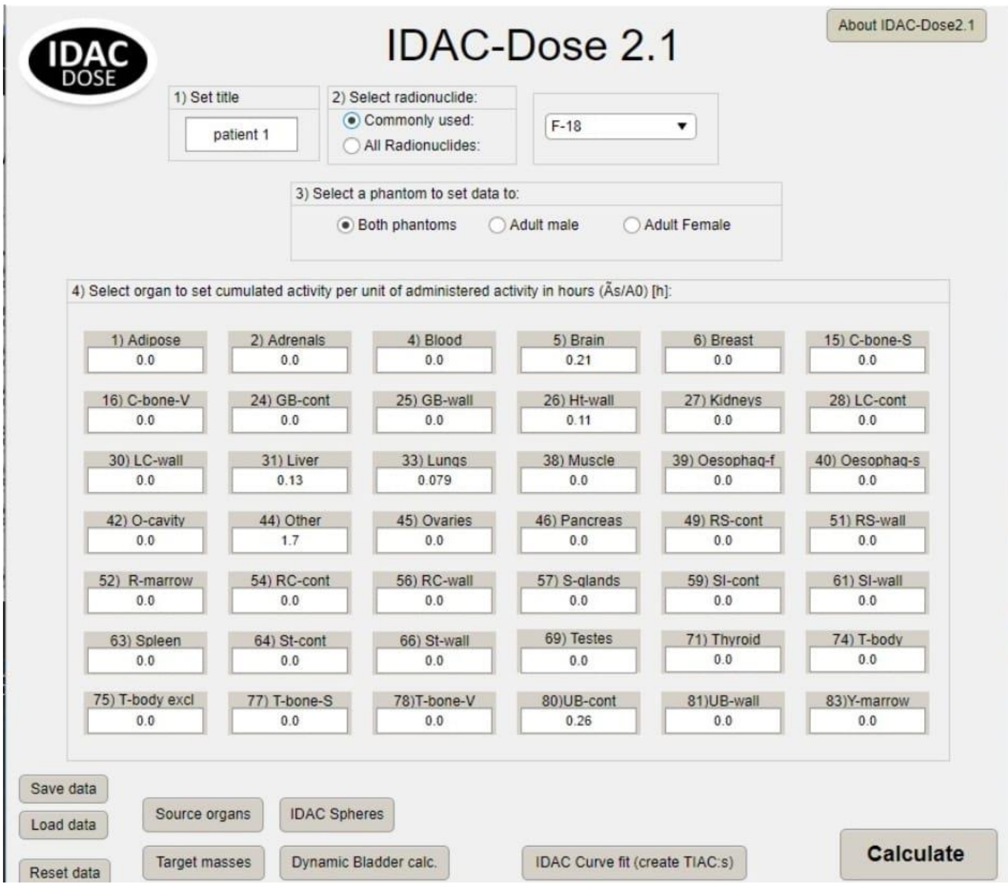


Figure (3.4) shows the interface of IDAC 2.1

Figure (3.4) shows the user interface of IDAC-Dose 2.1, which is used to calculate doses of internal radioactivity. This time, the program is programmed to find the dose for

^{18}F-FDG, since this tracer is commonly used with Positron Emission Tomography (PET). It is possible to pick different phantoms (anatomical models) in the interface, and the software also has a module for estimating dose to spherical structures (such as tumors). The user provided biokinetic data for ^{18}F-FDG, indicating how many hours of cumulated activity there are per administered dose in each of the involved organs.

Some important values are 0.21 for Brain, 0.13 for Liver, 0.079 for Lungs, 1.7 for Other (other tissues), and 0.26 for UB-content (urinary bladder contents). The values show the part of the administered ^{18}F-FDG remaining in each organ over a given period, which represents its biokinetic behavior. Since the user selected "Both phantoms," the calculations will cover the adult male and adult female ICRP reference phantoms.

The next step is selection of the source organs, The source organ selection panel seen in the IDAC-Dose 2.1 software is shown in figure 3-5, and is used to figure out internal radiation doses from radiopharmaceuticals. With the 83 listed source organs, users can perform detailed dose calculations by counting on different tissues and body structures.

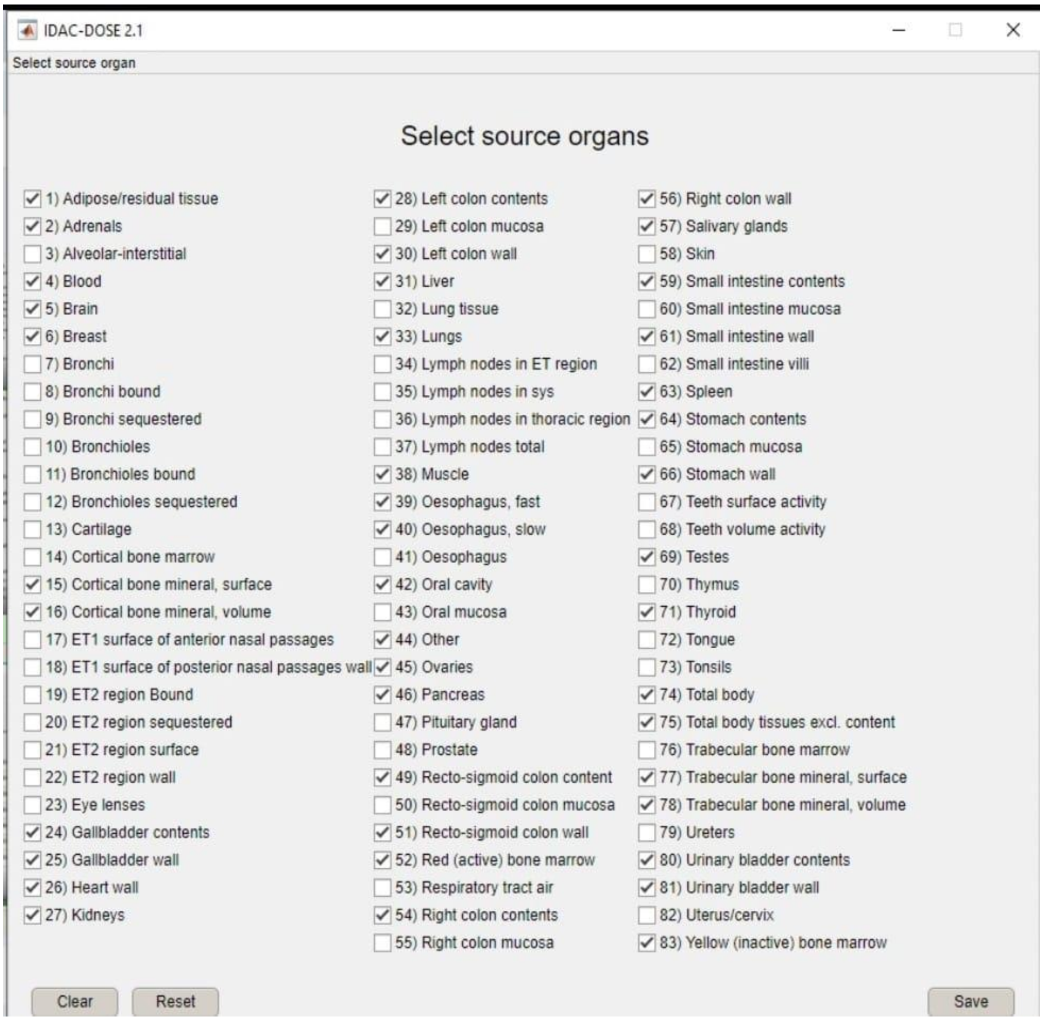


Figure (3.5): Shows the interface of IDAC 2.1 for selecting source organs

Being able to consider many organs in the list helps precisely simulate the movement and effects of radiation in the body. This can be more accurate in our dose estimates since this program includes several sub-regions of the respiratory and gastrointestinal tracts. When using the other category, the user can add tissues that are not explicitly described in the model. It is more accurate to use this software for internal dose calculations than to use models with simpler phantoms. Figure 3.6 shows the next step is selection of the target organs, for effective dose calculations there is two options (ICRP 60 and ICRP 103 weighting factors). The panel lists 49 target organs and tissues.

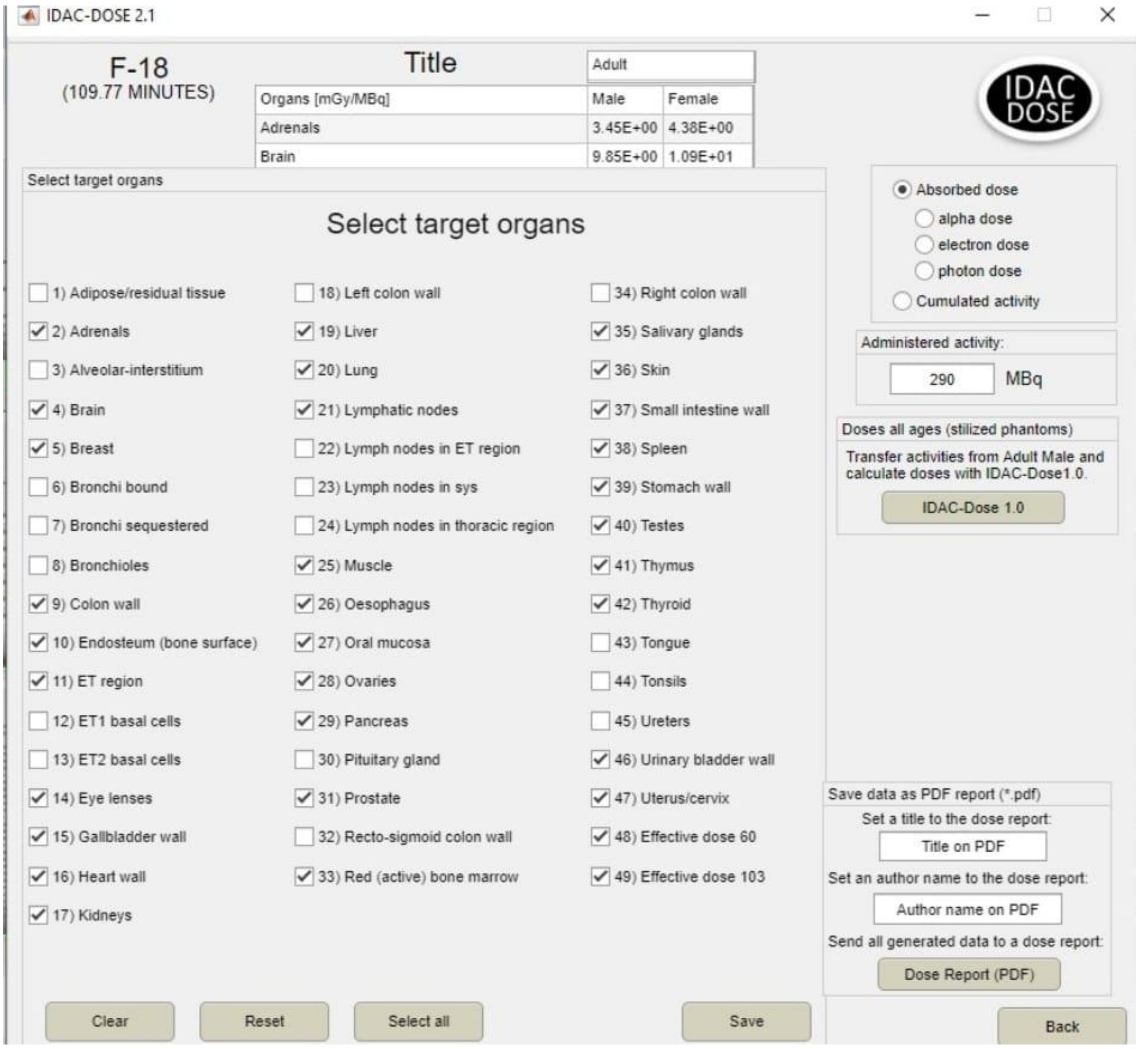
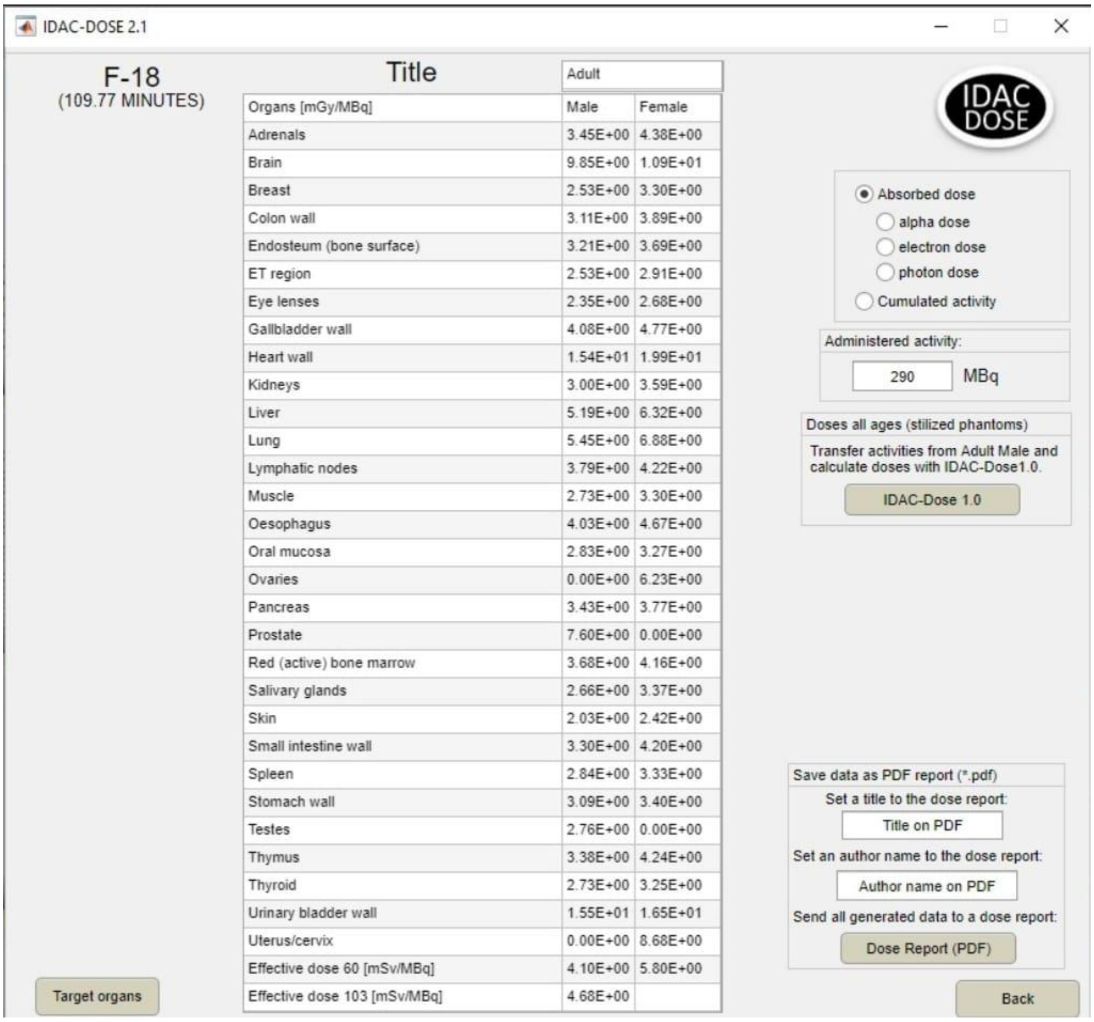


Figure (3.6): Shows the interface of IDAC 2.1 for selecting target organs

The final step calculating the dose is output screen, figure 3.7 shows the results of an internal dose calculation done with IDAC-Dose 2.1. An absorbed dose calculation was done for the ^{18}F-FDG radiotracer (half-life: 109 minutes) which is a material mainly used for PET scans. The administered activity is 290 MBq. Results are given for both the male and female adult ICRP reference phantoms.



Organs [mGy/MBq]	Male	Female
Adrenals	3.45E+00	4.38E+00
Brain	9.85E+00	1.09E+01
Breast	2.53E+00	3.30E+00
Colon wall	3.11E+00	3.89E+00
Endosteum (bone surface)	3.21E+00	3.69E+00
ET region	2.53E+00	2.91E+00
Eye lenses	2.35E+00	2.68E+00
Gallbladder wall	4.08E+00	4.77E+00
Heart wall	1.54E+01	1.99E+01
Kidneys	3.00E+00	3.59E+00
Liver	5.19E+00	6.32E+00
Lung	5.45E+00	6.88E+00
Lymphatic nodes	3.79E+00	4.22E+00
Muscle	2.73E+00	3.30E+00
Oesophagus	4.03E+00	4.67E+00
Oral mucosa	2.83E+00	3.27E+00
Ovaries	0.00E+00	6.23E+00
Pancreas	3.43E+00	3.77E+00
Prostate	7.60E+00	0.00E+00
Red (active) bone marrow	3.68E+00	4.16E+00
Salivary glands	2.66E+00	3.37E+00
Skin	2.03E+00	2.42E+00
Small intestine wall	3.30E+00	4.20E+00
Spleen	2.84E+00	3.33E+00
Stomach wall	3.09E+00	3.40E+00
Testes	2.76E+00	0.00E+00
Thymus	3.38E+00	4.24E+00
Thyroid	2.73E+00	3.25E+00
Urinary bladder wall	1.55E+01	1.65E+01
Uterus/cervix	0.00E+00	8.68E+00
Effective dose 60 [mSv/MBq]	4.10E+00	5.80E+00
Effective dose 103 [mSv/MBq]	4.68E+00	

Figure (3.7): Shows the interface of IDAC 2.1 of result screen

The results are a list of absorbed doses (in mGy) for different organs in both phantoms. For both genders, the highest absorbed doses can be noticed in the urinary bladder. The effective doses given are 4.10 mSv for males, they indicate the risk the individual experiences after undergoing PET imaging, given the different sensitivities of areas in the body.

3.8.2 Virtual Dose

Virtual Dose™ CT, a web-based CT dose calculator developed by the National Cancer institute ,which is used for external dose estimations, available from: https://www.virtualphantoms.com/. Patient specific CTDIvol and DLP values are incorporated along with other scan parameters to estimate each individual's external dose via Virtual Dose, and then take CTDIvol and DLP values of the determined external dose and normalize them using the scanner specific CTDIvol and DLP values that were used to determine the dose per protocol, technology and scanner.

The Virtual Dose™ CT is an online dosage calculator established by the National Cancer cells institute is utilized for outside dosage estimates. Patient particular CTDIvol as well as DLP worths are included together with various other check specifications to approximate each patient outside dosage through Virtual Dose, and after that take CTDIvol as well as DLP worths of the established outside dosage together with stabilize them making use of the scanner certain CTDIvol as well as DLP worths that were made use of to figure out the dosage per method.

The accurate measurement of radiation exposure which patients experience during PET-CT testing demands detailed evaluation of CT-specific equipment choices. The National Cancer Institute (NCI) developed Digital Dose which functionality offers precise customized external dosage reports to patients at specific contingencies through a strong integrated system.

This Online Dose calculator estimates personalized external dose estimates through adopting CTDIvol and DLP values extracted from CT image Digital Imaging together with Communications in Medicine (DICOM) headers. Prior knowledge of CT segment relative dose values in PET-CT scans helps develop radiation protection approaches to peak effectiveness. CT scan exposure typically represents a majority of PET-CT procedure radiation dose so healthcare providers should optimize CT settings for the best possible results.

The software requires input about age combined with weight and height followed by BMI to select the correct 'virtual patient' which functions as a computational model of patient anatomy. The use of international weight categories determines which virtual phantom model the software system selects according to patient BMI measurements. The specific dosimetric characteristics of scanners vary between units so scanner information that includes make and model of unit needs to be provided .

The CT assessment setups made use of are shown in the scan protocol details. These would certainly consist of kVp or the highest power of x-ray, mAs or the radiation output, pitch or the dose efficiency and beam collimation or the width of the x ray beam.

The bowtie filter used, which shapes the x-ray beam, influences dose distribution, requires input for accurate dose calculations, as does the z over ranging length, extending the radiation exposure beyond the intended scan length.

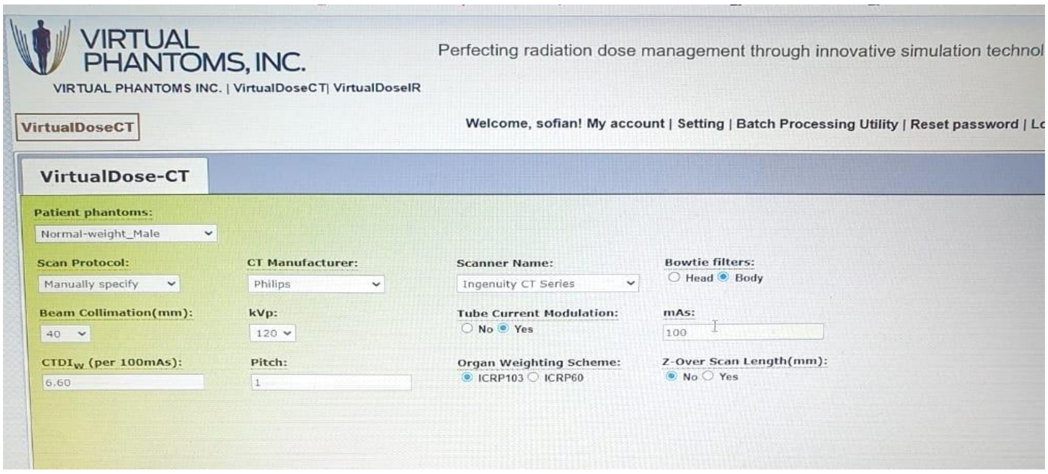


Figure (3.8): Shows the interface of Virtual Dose™ CT

The input interface for Virtual Dose™ CT can be seen in figure (3.8), which shows a web-based CT dose estimation software from Virtual Phantoms, Inc. This web-based software works with mathematical models and Monte Carlo methods to estimate the doses to different organs and the whole body of the patient. So, the selected scan parameters for a normal-weight male phantom using a Philips Ingenuity CT Series system. The beam collimation to 40 mm, selected 120 kVp, a CTDIw of 6.60 mGy per 100 mAs, and a pitch of 1, mAs value of 100 is used for the enabled tube current modulation. The selected ICRP103 organ weighting scheme, add on a body bowtie filter, and turn on z-over scanning when calculating effective dose.

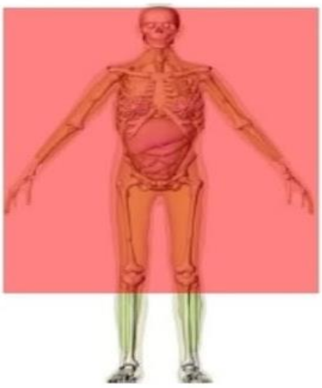
They allow the computer to calculate specific doses corresponding to the selected scanner and setup. Following data input, Virtual Dose™ CT provides the organ doses and effective dose; by using Virtual Dose™ CT, one can estimate doses received by patients during CT scans, thus helping in efforts to reduce radiation risk and inform changes to protocols.

VirtualDose™
A product of Virtual Phantoms, Inc.

CT Dose Report

Report Date: 10/23/2024 10:03 AM

Scan Parameters	
Protocol	Manual Range
CT Scanner	Philips Ingenuity CT Series
kVp	120
Collimation	40 mm
Bowtie filter	body
mAs	271
nCTDIw	6.60 mGy
Pitch	1
TCM applied	Yes
CTDIvol	17.88 mGy



Phantom Used: Adult Female - Overweight

Organ Dose	
Organ/Tissue Name	**Dose (mGy)**
Bladder	36.63
Bone Surface	31.14
Bone-marrow (red)	24.46
Brain	7.58
Breast	35.81
Colon	43.38
Gonads	34.55
Liver	49.46
Lung	39.39
Oesophagus	20.31
Remainder Tissues (ICRP 103)	34.74
Salivary glands	11.19
Skin	24.94
Stomach	39.72
Thyroid	13.27
Effective Dose (mSv)	34.40

Remainder Organs	
Organ/Tissue Name	**Dose (mGy)**
Adrenals	45.45
Extrathoracic Region	12.90
Gall Bladder	32.73
Heart	37.35
Kidneys	47.73
Lens of the eye	10.62
Lymphatic Nodes	31.66
Muscle	32.30
Oral mucosa	11.88
Pancreas	36.78
Small intestine	40.94
Spleen	54.38
Thymus	35.33
Uterus/Cervix (female) or Prostate (male)	32.15

Figure (3.9): Shows the output report of Virtual Dose™ CT

This report includes a CT dose report from Virtual Dose CT, a web-based application made by Virtual Phantoms, Inc. The dose report was prepared that details how much radiation different organs and the whole body were exposed to as the results of this scan. The calculation took into consideration a "Manual Range" protocol on a Philips Ingenuity CT Series device, with a 120 kVp, 40 mm collimation, and 271 mAs. A body bowtie filter, pitch 1 and TCM were applied in the protocol. The calculated CTDIvol is 17.88 mGy. The overweight adult female phantom was used for the calculation of organ doses. The estimated effective dose is found to be 34.40 mSv.

3.9 Quality Assurance and Validation

To ensure the accuracy and reliability of the dose estimates, quality assurance procedures are implemented throughout the study. This includes verifying the accuracy of data entry, validating software calculations against published data or phantom measurements, and assessing the consistency of dose estimations across different CT scanners and protocols.

3.10 Ethical Considerations

This retrospective study utilizes anonymized patient data collected from medical center at North Palestine, with appropriate ethical approvals obtained to ensure patient privacy and confidentiality. The study adheres to the principles of informed consent, ensuring that patients are provided with information about the potential risks and benefits of participating in research involving their medical data.

Furthermore, the study methodology is designed to minimize any potential harm or discomfort to patients, and data analysis is performed in a manner that protects patient anonymity. Subsequently, the study methodology was reviewed and approved by the ethical committee to ensure compliance with ethical guidelines and protect patient privacy, the approval code "R-2024/A/153/N".

3.11 Data Collection and Analysis

Data were collected from November 1, 2024, to January 1, 2025, as excel sheet and the form included patients' data (age, sex, weight, height, CT scan parameters and dosimetric information (CTDIvol, and DLP) are collected from Patient's Friends' Society-Nablus in North Palestine. IDAC 2.1 and Virtual Dose used to calculate internal and external radiation doses. Then, total effective dose for each patient calculated by summing an internal and an external dose estimate.

After conducting the statistical analysis on the data, which included descriptive statistics, correlation analysis, and some regression modelling to determine the relationship between effective dose and a series of patient and scan parameters. Proper techniques to ensure the accuracy of data used. Data completeness assessed before any analysis of the data.

3.12 Data Security

To ensure patient information is secured, store of data will be electronically with password protection. Data collection didn't include name or ID of patients, which replaced by numbers. If there is any identifiable information of patients, it was removed from all data before any analysis of data. All the collected data were adhered according to ethical committee and guidelines, especially at the publication time.

3.13 Statistical Analysis

Descriptive Statistics was conducted to measure the Mean, standard deviation to explore the relationships between the effective dose and patient scan parameters. Then regression Analysis and Correlation performed to evaluate the relationships between patients' demographic data (BMI, weight, height) and effective dose, linear regression models used to analyze these relationships. Spearman Correlation test was used to test the direction and strength of the correlations between continuous demographic factors and the parameters. Statistical significance used at a p-value < 0.05.

Gender Dependent Analysis: the results of effective dose between male and female tested to show the different of results (if there is). These descriptive statistics had given a thorough view of the effective dose distribution in the studied population and provided information about possible trends or variations in effective dose due to some specific patient or scan characteristic. The relationship between the effective dose and different patient specific factors (age, sex, weight, BMI and CT scan parameters (kVp, mAs, scan length, pitch) is assessed using correlation analysis. This analysis allowed quantification of the most significant radiation dose influencing factors and can guide dose optimization strategies.

Chapter Four: Results

4.1 Introduction

The research built on existing requirements for radiation optimization in medical imaging to systematically measure effective dose exposure among procedure patients. This chapter provides detailed results which expose patient doses at their present levels while illustrating the share of both CT and radiopharmaceutical use.

Research findings enable strategic evaluations of regional practices to determine their alignment with worldwide standards and drive continued progress in North Palestinian patient radiation protection initiatives. Next, the researcher will examine these findings through a detailed presentation which follows the main research objectives.

This chapter explains the descriptive and analytical results of the current study, where the descriptive results are concerned with the frequencies and percentages of patients' categorical variables, as well as the means and standard deviations of the scale variables and PET-CT related parameters. The analytical results show the differences in specific parameters across the patients' demographic factors, as well as the correlations between them.

4.2 Demographic Data of The Patients

The sample of the study (N = 150) consisted of patients with a mean age of 51.0 ± 16.3 years old, where more than one third of them (37.3%) were older than 60 years old, ranging from 18 to 82 years old. Also, there were slightly more male (52.0%) than female (48.0%) patients, with a mean weight of 77.2 ± 19.9 kilograms, and a mean height of 167.3 ± 11.2 centimeters. Moreover, the patients had an overall BMI of 27.6 ± 6.7, which indicates an overall overweight status, with 34.0% of the patients categorized as having obesity. The following charts illustrate the distribution of patients' demographic factors.

Table (4.1): Distribution of the demographic data of the patients (N = 150)

Variables	Values	Frequency	Percentage
Age	18 - 30 YO	20	13.3%
	31 - 45 YO	35	23.3%
	46 - 60 YO	39	26.0%
	> 60 YO	56	37.3%
	Mean ± SD	51.0 ± 16.3	
Gender	Male	78	52.0%
	Female	72	48.0%
Weight (in Kilograms)	Mean ± SD	77.2 ± 19.9	
Height (in Centimeters)	Mean ± SD	167.3 ± 11.2	
Body Mass Index (BMI)	Underweight	13	8.7%
	Normal weight	43	28.7%
	Overweight	43	28.7%
	Obese	51	34.0%
	Mean ± SD	27.6 ± 6.7	

SD = Standard deviation, BMI = Body mass index.

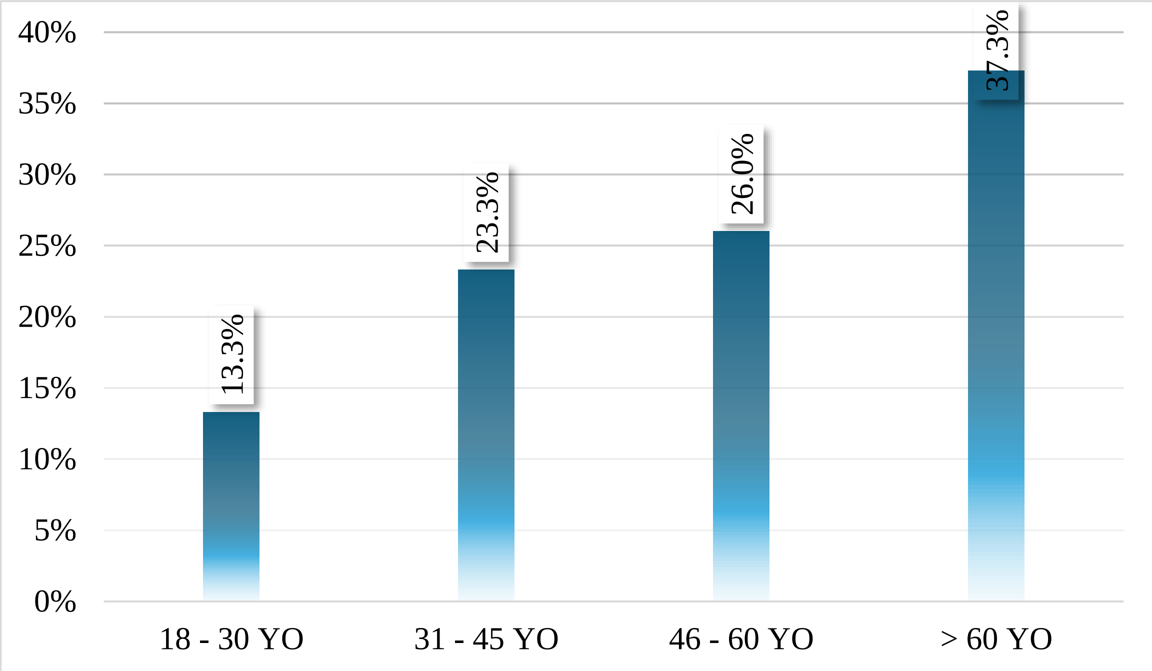


Figure (4.1): Distribution of Patients' Age

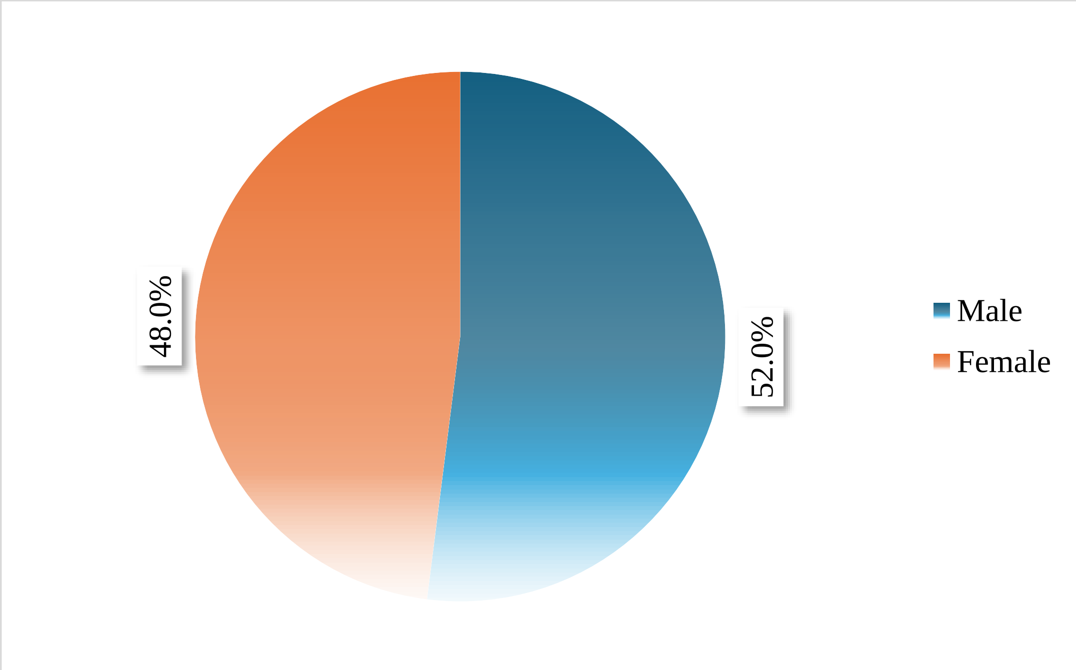


Figure (4.2): Distribution of patients' gender

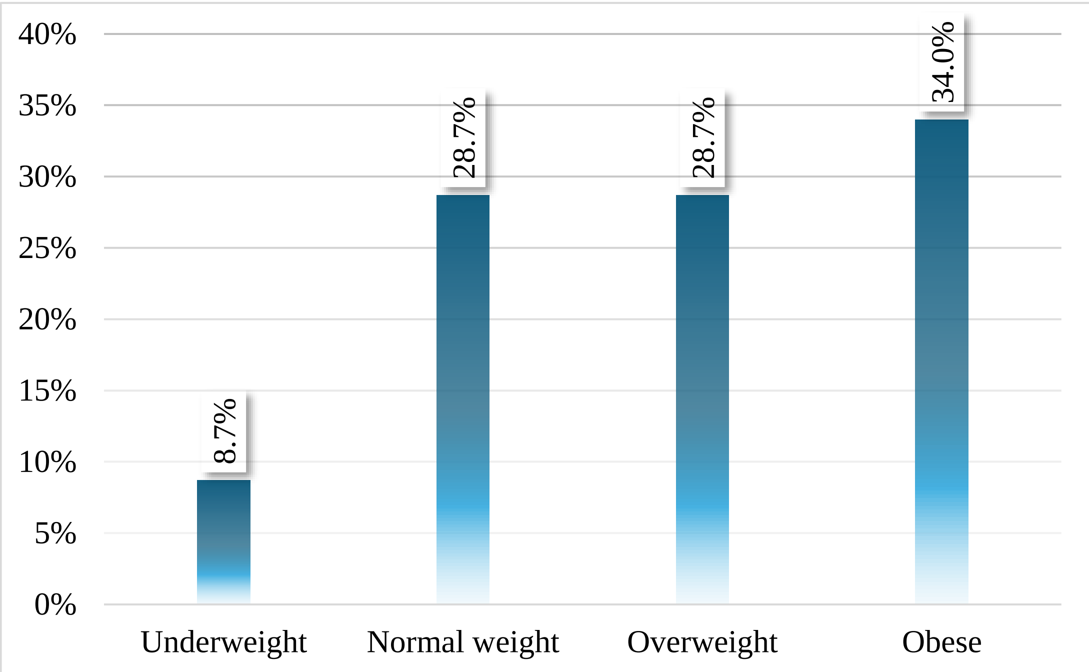


Figure (4.3): Distribution of Patients' BMI

4.3 Description of PET-CT scan parameters

The parameters of PET-CT scans that were conducted are described in the following table (Table 4.2). All patients received computed tomography dose index (CTDI) of 0.085 milli gray (mGy), as well as a kVp of 120. In terms of the rest of the parameters, the patients received a mean CT dose index of 16.23 ± 2.70 mGy, ranging from 8.50 to 19.70 mGy, while the total DLP had a mean of 2294.54 ± 422.79 milli gray-centimeter (mGy.cm), ranging from 1282.20 to 3157.20 mGy.cm.

Also, the mean of tube current in the exposure time was 247.53 ± 41.04 milliampere-second (mAs), ranging from 130 to 301 mAs. In addition, the mean amount of radioactive tracer was 5.88 ± 2.15 millicurie (mCi), ranging from 3 to 20 mCi, which equals to a mean of 217.68 ± 79.52 Megabecquerel(MBq) ranging from 111 to 740 MBq.

In terms of the effective doses, the mean CT effective dose was 22.61 ± 4.23 millisievert (mSv), ranging from 13.0 to 34.4 mSv, while the mean f-18 FDG effective dose was 3.51 ± 1.28 mSv, ranging from 1.79 to 11.90 mSv, giving a mean total effective dose of 26.12 ± 4.55 mSv, ranging from 15.39 to 37.47 mSv. The percentage of CT dose out of the total dose had a mean of 86.51 ± 4.33 percent, ranging from 62.70% to 93.09%.

Table (4.2): Description of PET-CT scan parameters among the sampled patients (N = 150)

Parameters	Mean	SD	Minimum	Maximum
surview CTDI volume	0.085	0.000	0.085	0.085
CTDI volume	16.23	2.70	8.50	19.70
DLP total	2294.54	422.79	1282.20	3157.20
mAs	247.53	41.04	130.00	301.00
kVp	120.00	0.00	120.00	120.00
Activity in mCi	5.88	2.15	3.00	20.00
Activity in mBq	217.68	79.52	111.00	740.00
CT effective dose	22.61	4.23	13.00	34.40
f-18 FDG effective dose	3.51	1.28	1.79	11.90
Total effective dose	26.12	4.55	15.39	37.47
CT dose percentage	86.51	4.33	62.70	93.09

CTDI = Computed tomography Dose Index, DLP = Dose Length Product, mAs = Milliampere-second, kVp = Kilovolt peak, mCi = millicurie, MBq = Mega becquerel, CT = computed tomography, SD = standard deviation.

4.4 Analytical Results

The analytical results part was conducted using the suitable inferential statistics, including mean differences of specific parameters across the categories of demographic factors, using independent samples t-test for dichotomous demographics and one-way ANOVA for non-dichotomous demographics. In addition, Spearman Correlation test was used to test the direction and strength of the correlations between continuous demographic factors and the parameters.

In Table (4.3), the relationships between patients' demographic factors and mAs were tested, and showed that it was significantly higher among patients with older age, where the highest mean current was found among patients within the age group of 46 – 60 years old (mean = 256.3 ± 36.7 mAs), compared to 18 – 30 years old (mean = 219.8 ± 47.9 mAs, p-value = 0.009), with a significant positive, but weak, correlation between patient's age and tube current (r = 0.168, p-value = 0.047).

The correlation between patient's weight and current was also moderately significant in a positive way (r = 0.586, p-value < 0.001), with a significant correlation between patient's BMI and current (r = 0.557, p-value < 0.001), indicating and overall higher current with patients in the obese category (mean = 270.0 ± 21.6 mAs) compared to underweight category, for example (mean = 189.2 ± 38.3 mAs, p-value < 0.001). There was no significant relationship between patient's gender or height and current (p-value > 0.05).

Table (4.3): Relationship between patients' demographic factors and tube current(mAs)

Factors	Values	Mean mAs	SD	p-value
Age	18 – 30 YO	219.8	47.9	0.009
	31 – 45 YO	247.4	32.1	
	46 – 60 YO	256.3	36.7	
	> 60 YO	251.4	43.0	
	Correlation	r = 0.163		0.047
Gender	Male	251.7	39.6	0.193
	Female	243.0	42.4	
Weight	Correlation	r = 0.586		< 0.001
Height	Correlation	r = 0.150		0.066
Body mass index (BMI)	Underweight	189.2	38.3	< 0.001
	Normal weight	231.0	47.1	
	Overweight	255.2	27.9	
	Obese	270.0	21.6	
	Correlation	r = 0.557		< 0.001

SD = standard deviation, mAs = Milliampere-second

Similarly, Table 4.4 shows the relationships between patients' demographic factors and the total effective dose they have received(from CT and PET). It shows that the total effective dose was significantly higher among male patients (mean = 27.30 ± 4.31 mSv) compared to female patients (mean = 24.83 ± 4.48 mSv, p-value = 0.001). Also, the total effective dose was significantly correlated in moderate ways with patient's weight (r = 0.415, p-value < 0.001) and height (r = 0.313, p-value < 0.001), indicating and overall higher effective dose with taller and heavier patients.

In parallel, the total effective dose was significantly correlated with patient's BMI (r = 0.274, p-value = 0.001), indicating and overall higher total effective dose among patients in the obese category (mean = 27.15 ± 3.83 mSv) compared to underweight patients (mean = 21.25 ± 4.34 mSv, p-value < 0.001). There was no relationship between the age of the patient and the total effective dose (p-value > 0.05).

Table (4.4): Relationship Between Patients' Demographic Factors and Total Effective Dose

Factors	**Values**	**Mean mSv**	**SD**	**p-value**
Age	18 - 30 YO	24.63	5.53	0.371
	31 - 45 YO	26.89	4.28	
	46 - 60 YO	26.06	3.97	
	> 60 YO	26.21	4.71	
	Correlation	r = 0.034		0.679
Gender	Male	27.30	4.31	0.001
	Female	24.83	4.48	
Weight	Correlation	r = 0.415		< 0.001
Height	Correlation	r = 0.313		< 0.001
Body mass index (BMI)	Underweight	21.25	4.34	< 0.001
	Normal weight	25.64	5.32	
	Overweight	26.85	3.60	
	Obese	27.15	3.83	
	Correlation	r = 0.274		0.001

The relationships between patients' demographic factors and the percentage of CT dose of the total effective dose were also tested and shown in Table 4.5. It shows that the percentage was significantly different across age groups (p-value = 0.005), with the highest percentage among patients with 18 – 30 years old (mean = 88.55 ± 2.54) and lowest among patients between 46 and 60 years old (mean = 84.68 ± 3.73), but does not have a specific correlation (r = - 0.125, p-value = 0.128), indicating an overall decrease in the percentage with older ages, but is insignificant.

Moreover, the correlation between the CT percentage of total effective dose was significantly correlated with weight (r = - 0.812, p-value < 0.001) and height (r = - 0.225, p-value = 0.006), indicating a significantly strong correlation between more weight and lower percentage, and a moderate correlation between taller height and lower percentage.

This was also reflected in the relationship between patient's BMI and CT dose percentage, where the highest percentage was among underweight patients (mean = 90.39 ± 1.46) compared to obese patients (mean = 82.74 ± 4.52, p-value < 0.001), with a significant correlation between BMI and CT dose percentage (r = - 0.730, p-value < 0.001), indicating a strong negative correlation between higher BMI score and lower CT dose percentage. The gender of the patient was found to have no significant impact on the percentage of CT dose (p-value = 0.240).

Table (4.5): Relationship between patients' demographic factors and CT effective dose percentage

Factors	Values	Mean %	SD	p-value
Age	18 - 30 YO	88.55	2.54	0.005
	31 - 45 YO	87.21	5.12	
	46 - 60 YO	84.68	3.73	
	> 60 YO	86.62	4.29	
	Correlation	r = -0.125		0.128
Gender	Male	86.11	4.57	0.240
	Female	86.94	4.03	
Weight	Correlation	r = -0.812		< 0.001
Height	Correlation	r = -0.225		0.006
Body mass index (BMI)	Underweight	90.39	1.46	< 0.001
	Normal weight	89.51	1.90	
	Overweight	86.80	2.59	
	Obese	82.74	4.52	
	Correlation	r = -0.730		< 0.001

4.5 Conclusion

The results of the current study showed that 52.0% of the patients were males, with a mean age of 51.0 years, mean height of 167.3 cm, mean weight of 77.2 kg, and mean BMI of 27.6. The tube current (in mAs) was significantly higher among older patients (r = 0.163, p-value = 0.047) and who have higher BMI score (r = 0.557, p-value < 0.001).

The total effective dose (in mSv) was significantly higher among patients who are males (p-value = 0.001), heavier (r = 0.415, p-value < 0.001), taller (r = 0.313, p-value <

0.001) and having higher BMI score (r = 0.274, p-value = 0.001). The percentage of CT effective dose out of the total effective dose was higher in patients within 18 – 30 years old (p-value = 0.005), with no significant correlation with overall patient's age (r = -0.125, p-value = 0.128), while it was significantly lower in heavier patients (r = -.812, p-value < 0.001), taller patients (r = - 0.225, p-value = 0.006), and who have higher BMI score (r = - 0.730, p-value < 0.001).

Chapter Five: Discussion

5.1 PET and CT Effective Dose

The objective of this study was to estimate the effective radiation dose from FDG PET-CT scans given to northern Palestine. The effective radiation doses resulting from the whole body FDG PET-CT examinations were similar to other studies but ranged from 8.8–24.7 mSv (Brix et al., 2005), due to different approaches used (hardware, standards, and clinical objectives). The same difference can also be attributed to difference in CT scan parameters and PET scanner models used in acquisition of image.

Therefore, individual estimation needs to be performed on the basis of patient parameters (patient age, patient gender and weight, and scanner parameters). This suggests that for the majority of the radiation dose in PET-CT examination CT provides the bulk of the radiation dose: from 54 to 81% (ICRP 2007; Huang et al., 2009).In order to assess risk benefit ratios as pertaining to a given procedure, radiation doses and risks need to be worked out and be understood.

The effective dose from PET-CT in this study (26.12 mSv) was within the previously reported range 13.4-32 mSv (Huang et al., 2009) or 25 mSv (Brix et al., 2005). The implication is that current protocols with their associated considerable radiation exposure have been brought into and in some cases are closer to, or even down to previously reported levels. However, the wide reported effective doses highlight the need for more precise and individualized dose assessments merging patient and scanner parameters, clinical objective and scanning protocol. This supports this need for more dose optimization in PET-CT, particularly in tailoring protocol to the study needs and minimizing the CT component whenever possible.

Adeleye and Chetty (2018) analyzed the level of variation when it comes to both systems and protocols of CT dose. They found out that the dose variations between PET-CT systems and protocols were 4.3-15 %. The authors explain such variances by the use of the CT model, the scanner itself and the protocols used. This fact underlines the importance of the choice of the scanner technology to be used and the protocol design that is crucial in footing the patient dose. This means, therefore that strict protocols to be tailored according to the scanner should be developed and implemented to ensure that diagnostic images are achieved at a low radiation dose in CT aspect particularly.

Optimization of the technical parameters, such as tube voltage, tube current time product, pitch, collimation and filtration, using automatic exposure control (AEC) systems, and employing iterative reconstruction whenever possible are also included. Additionally, clinical experience is highlighted for reducing radiation dose since when technologists are experienced at optimizing scan protocol and low dose techniques, patient dose can be greatly reduced, without sacrificing image quality.

However, CT dosimetry has traditionally used standardized models and phantoms likely representative of 'average' patients and have little ability to incorporate additional information on individual variations in body size and composition (Stabin & Siegel, 2018;H. Chen et al., 2020). In the study, CT plays a role of near 86.51 % in effective dose in PET-CT scans.

The percentage is similar to other studies, which reported a lower quantity in others, ranging 35% to 80.7%; this range of reported values reinforces the need to optimize CT acquisition parameters (Salah et al., 2020).It allows recommendation of CT scanning with a lower dose rather than CT scan at a higher radiation dose. Nevertheless, voxel based, hybrid and patient-specific phantoms have been developed in recent years and show a significant step towards more accurate and personalized dosimetry (Andersson et al., 2017).

While results from this study are interesting, a larger population study with greater range in ages and genders would yield more substantial results due to more variation in numerical data analyzed (and in biokinetic and tissue responses). The results provided will be useful in regulating professionals and regulatory bodies to give out optimum dose levels for different examinations in the use of ionizing radiation.

Development and implementation of more sophisticated image protocols, such as usage of lower tube voltage and current (mAs) for CT scans without compromising image quality on the other hand presents one promise way to reduce dose. In certain applications dose reduction of up to 50% is achievable without loss of diagnostic information (Adeleye & Chetty, 2018).

New radiotracers, with lower radiation burdens or more targeted radiopharmaceuticals, which selectively accumulate in the tissues or organs of interest. will in turn further decrease the dose. Diagnostic image quality would be maintained while using lower administered activities. However, radiation dose to certain organs such as the urinary bladder can be reduced by optimizing patient preparation (e.g. proper hydration and frequent voiding) (ICRP 2007).

In some clinical situations, the use of advanced imaging modalities like PET-MRI might serve to replace PET-CT both with respect to an alternate sequence of function, and in so doing it might eliminate or reduce the radiation dose of the CT component (Drzezga et al., 2012). Available, PET-MRI provides superior soft tissue contrast as well as simultaneously acquiring the functional and anatomical data; however, it also has limitations in acquisition time, cost and availability. PET-MRI is likely to become a viable technology for routine clinical use as PET-MRI technology develops.

This lack of PET-MRI as alternative is a major factor. Since PET-MRI combines functional imaging with magnetic resonance imaging, it avoids the sources of ionizing radiation with CT. This modality may enable patients requiring repeated imaging. Because its unavailable, it limits options (Drzezga et al., 2012).

5.2 Research Hypothesis

This research partly supports our first hypothesis that medical procedures in Palestine produce effective 18F-FDG PET-CT doses similar to worldwide results. This research confirms international evidence that patient traits particularly sex, weight, height, and BMI influence the total radiation dose received by patients. Research conducted by (Quinn et al., 2016) and (Salah et al., 2020) shows repeatedly that patient-specific factors such as sex, weight, height, and BMI impact patients' radiation exposure during PET-CT imaging.

Our assessment needs more detailed comparison works to measure effective dose similarity. Our study matches known influences to effective dose but needs more accurate knowledge about worldwide dose severity levels. This research results can better demonstrate the relationship of patient doses to worldwide standards by matching them to recognized international benchmarks. Future researches need to examine how equipment types, imaging procedures and patient characteristics affect my results when looking at multiple study regions

Patient radiation exposures from PET-CT procedures match international studies that informed our research. CT imaging delivers most of the effective dose when performing PET-CT scans based on research by (Brix et al., 2005) and others including (Adeleye & Chetty, 2018 ,Huang et al., 2009, Kaushik et al., 2013, Khamwan et al., 2010) and (Mahmud et al., 2014). Our tests showed that CT doses measured an average 22.61 mSv which accounted for 86.51% of total radiation exposure. The observed high percentage matches with studies which indicate CT delivers the greatest impact on patients' radiation exposure from PET-CT scanning. Findings indicate North Palestinian CT protocols deliver radiation exposure at levels consistent with worldwide standards.

Our research revealed that the mean effective dose arising from 18F-FDG reached 3.51 mSv. This dosimetry value matches reported dose values established in both international dosimetry compendia and guidelines (Bolch et al., 2015; Stabin & Siegel, 2018) regarding the typical administered activities and biokinetic properties of 18F-FDG. Patient doses associated with 18F-FDG PET-CT scanning activities in North Palestine meet current international guidelines for effective dose calculations. Total radiation doses measured during this investigation show compliance with the established acceptance criteria for 18F-FDG PET-CT imaging procedures.

The third hypothesis held that more radiation is used in medical scans for patients who are aged. The data indicates that tube current increases directly with patient age. Radiographers may tend to change technical settings when examining elderly patients to maintain diagnostic image quality. The examination revealed no measurable relationship between patient age and overall radiation dose. The findings indicate that although age-based changes are made in my patient cohort they do not result in measurable differences in total effective doses between groups. These findings contradict beliefs that patient age alone increases effective dose requirements so studies now explore the effects of different protocol changes.

A straightforward assumption that increasing patient age invariably results in greater effective doses in PET-CT imaging is challenged by this novel finding. Older patients are exposed to higher tube current but other factors, such as different parameters of radiopharmaceutical administration can change the balance between tube current and total effective dose.

Fourth and finally, the researcher hypothesized that there was no difference between patient BMI and resultant effective dose, which our results clearly refute. The Underweight patients mean mAs were 189.2 mAs, while the obese patients mean mAs were 270 mAs, which resulted of mean effective dose mSv 21.25 with underweight patients while obese patients showed 27.15 mSv. The researcher here reported upon such a strong positive correlation between both tube current and total effective dose and BMI. Many studies showed that larger patients need higher tube current to achieve adequate image quality and therefore higher radiation exposure (Huang et al., 2009; Mahmud et al., 2014).

This is found to be consistent with a large body of work in medical imaging. (Huang et al., 2009) as well as (Mahmud et al., 2014) and others have consistently found that patients with higher BMIs require higher tube current during CT to permit adequate photon penetration and maintain acceptable image quality. The increase in this inevitably is directly translated to higher dose of radiation which is to be delivered to these individuals.

Table (5.1): summary of the main findings of this study and the previous studies.

Author	PET ED (mSv)	CT ED (mSv)	PET-CT ED (mSv)	% CT
Current study	3.5	22.6	26.1	86.5
(Salah et al., 2020)	8.0	30.0	38.0	73.0
(Adeleye & Chetty, 2018)	5.4	39.7	24.1	77.0
(Quinn et al., 2016)	9.0	5.3	14.0	35.0
(Mahmud et al., 2014)	6.3	7.50	13.8	54.3
(Kaushik et al., 2013)	5.8	11.5	17.3	66.5
(Huang et al., 2009)	6.2	26.0	32.2	80.7

mSv = millisievert, CT = Computed Tomography, PET = Positron Emission Tomography, ED =Effective Dose.

Our results build on existing PET-CT radiation dosimetry knowledge by showing what this research adds to the field. The effective dose in both studies shows that CT procedures make up 73% and 77% of the overall dose value reported by (Salah et al., 2020) and (Adeleye & Chetty, 2018) respectively. The imaging methods used during these studies produced CT scans with greater radiation exposure compared to other methods.

The 35% CT component in Quinn et al.'s research shows that their approach delivers better chances to reduce radiation exposure. According to (Mahmud et al., 2014) and (Kaushik et al., 2013) ,their research stands as a middle point between studies showing higher and lower radiation doses in actual clinical practice. CT imaging at 26 mSv in the Huang et al. study fell within normal ranges but their CT component took up 80.7% of the total radiation dose showing strong CT dependency at this location. The different study results show how site-specific medical procedures and radiology tools drive radiation dose outcomes.

The noticeable research differences come from survey tool adjustments and scanner type since (Adeleye & Chetty, 2018) analyzed this impact, they relied on dose coefficients assumptions and mathematical simple phantoms which can produce some differences. These studies have significant weaknesses because they use standardized phantoms rather than actual patient information which this research implements through a web-based virtual dose tool.

Salah et al. (2020) supplied useful effective dose data but their CT dosimetry approach lacked customization for this study. Adeleye & Chetty (2018) researched specifics of CT model and protocols exhaustively but their research narrowed the scope when including patient-specific differences. The CT protocols used by (Quinn et al., 2016) for lower doses probably differ from other studies which makes direct analysis more difficult.

Due to its initial stages of research (Mahmud et al., 2014) likely examined a small participant group and less influencing factors than full-scale studies. Kaushik et al. (2013) researched both PET-CT methods in 2013 but didn’t mention a detailed CT parameters used with limited patients' demographic data. (Huang et al., 2009) using outdated PET-CT technology and single phantom model dose assessment approaches, which may not fully represent the variability of patients .since IDAC 2.1 (Andersson et al., 2017) now provides advanced internal dose measurement while the web-based CT dose tool models personalized external exposure. The researcher chose of this approach because it produces patient-specific CT dose estimates unlike other methods. Our results create unique patient-specific data for Palestinian patients by using advanced radiation measurement tools to benefit ongoing medical research on safer PET-CT technology.

5.3 Research Questions

The total effective dose measured for whole-body 18F-FDG PET-CT scans in North Palestine splits into two main sources for Palestinian patients. CT scans generate 22.61 mSv mean effective dose compared to the 3.51 mSv dose from 18F-FDG radiopharmaceutical use. Weathered CT examinations account for 86.51% of the entire effective dose metric while delivering 22.61 mSv on average. The experimental findings establish the standard radiation amount that patients experience when taking this nuclear medicine procedure at the clinical sites under study.

Our examination shows that the effective doses measured in North Palestine fall within typical ranges detected in international scans of this type. Our results support global dose statistics for 18F-FDG PET-CT examinations while CT scans generate the largest dose quantity (Adeleye & Chetty, 2018; Brix et al., 2005; Huang et al., 2009; Kaushik et al., 2013; Khamwan et al., 2010; Mahmud et al., 2014. International standards from Annals of the (Bolch et al., 2015) and (Stabin & Siegel, 2018) show compliance with the dosage of 18F-FDG radiopharmaceuticals. The total radiation dose patients in North Palestine receive from PET-CT imaging matches worldwide PET-CT diagnostic standards.

The effective dose received from 18F-FDG PET-CT whole body scans depends indirectly on patient demographic features through their impacting body size across the dimensions of sex and age. Larger individuals who mostly include male adults show elevated radiation attenuation during scans (Huang et al., 2009; Mahmud et al., 2014) CT scanners with Automatic exposure control systems enhance radiation output for large patients while preserving image clarity which leads to elevated absolute doses.

Nevertheless, as one nuance, our findings suggest that size metrics such as weight and BMI are correlated with effective dose, but they likely correlate also negatively with the CT dose percentage. This implies that in our setting, the patient size does not result in a proportional increase of contribution to total dose from the CT base component, likely because of standardized protocols or radiopharmaceutical dosing strategies. Although this particular observation, this is an important and crucial point of acknowledgement for variation in body size with demographic linked differences and this is to consider these variations in planning of protocols to optimize and personalize procedures to ensure that radiation doses are appropriately managed as previously mentioned for all different patient population that undergo PET-CT imaging. Responsible use of radiation in nuclear medicine demands this patient centered view.

Our fourth research question examined CT's share of total radiation exposure delivered in North Palestine. CT imaging produces the greatest amount of radiation exposure in 18F-FDG PET-CT diagnostic procedures performed on North Palestine's patient base. Our study results show CT accounts for an average value of 86.51% ± 4.33% of the entire effective dose measurement. Numerous studies (Adeleye & Chetty, 2018; Brix et al., 2005; Huang et al., 2009, Kaushik et al., 2013; Khamwan et al., 2010; Mahmud et al., 2014) have recognized CT as the principal radiation dose contributor for PET-CT imaging.

The significant data point from this study emphasizes the urgent need to optimize CT protocols throughout North Palestine because small CT dose reductions produce substantial effects on total patient doses from PET-CT examinations. This indicates that our study reflects the general finding that using CT for diagnosis comes with a specific level Our personalized CT dosimetry analysis delivers enhanced results above standard studies that depend on non-specific radiation levels.

Wed assume that BMI status establishes a direct correlation with the effective dose measured during full-body 18F-FDG PET-CT scanning procedures. Higher BMI levels present a direct connection to radiation attenuation due to body size (Huang et al., 2009; Mahmud et al., 2014). CT scanners equipped with automatic exposure control systems adjust radiation output to keep diagnostic quality despite reductions in outcome due to body size attenuation.

Patients who have higher BMI values typically get images produced with greater radiation compared to subjects who have lower BMI. The observed BMI-dependent relationship between patient size and attenuation needs protocol optimization so facilities can manage radiation doses properly for each specific patient group.

5.4 Conclusion

The CT component of 18F-FDG PET-CT procedures in North Palestine drives most patient radiation exposure leading to significant contributions in the total effective dose. Current procedures maintain both CT and radiopharmaceutical mean effective doses at levels which match abroad assessments ensuring worldwide compatibility. The dominant role of CT requires us to focus even more strongly on procedures that lower patient radiation exposure. The ongoing commitment to patient safety in nuclear medicine depends on enhancing advanced image acquisition strategies along with individualized protocols to achieve low exposure standards during PET-CT examinations in this region.

The total effective dose was significantly higher with patients who are males, taller, heavier, and the BMI is larger. While CT percentage of effective dose out of the total effective dose was higher with younger patients (18-30 y), with no significant correlation with the overall patients age, although it was lower with heavier, taller, and higher BMI score.

In summary, the overall effective doses were within international benchmarks, but the important observation was the fact that the percentage contribution to the effective dose from CT has a statistically significant negative relationship with patient weight, height, and BMI. This contradicts the conventional idea of increasing CT dose contribution in large individuals and might have been related to protocol standardization, alone or combined with radiopharmaceutical dose geared to body weight, or both, to modulate dose distribution.

5.5 Limitations

Single Centre Study: This may be a Single Center Study conducted at a few institutions only in North Palestine.

Retrospective data collection: If the data were collected retrospectively from existing patient records, it may be subject to limitations of the data from record keeping practices.

CT Protocol Variability – In the best practice, it is assumed there are efforts to standardize protocols; however, there may be CT acquisition parameters variations between different examinations (or by individual operators). This could provide a margin of uncertainty for the dose estimations and comparisons.

Patient population specificity: The study population is defined as patients undergoing 18F-FDG PET-CT scan in North Palestine. There are specific demographic characteristics and clinical profiles of this population in this geographic region and healthcare context.

Focus on Effective Dose: The effective dose metric that is widely deployed for communication about radiation risk is, in fact, a population average. It does not account for different organ doses, depending on patient anatomic and scan parameters.

5.6 Recommendations

Based on the findings of this thesis and the comparison with existing literature, several recommendations can be made:

In order to improve the radiation safety at PET-CT imaging, this thesis recommends a BMI stratified CT protocols should be implemented, tube current and kV adjusted based on BMI to minimize dose while retaining image quality. Iterative reconstruction and optimized AEC simultaneously with constant refinement of CT parameters is mandatory. Local procedures are standardized, and routine dose monitoring and audits that can be compared to the recorded local limits for each procedure review serve to adhere to the ALARA principles.

In addition, referral physician and patient education regarding radiation risks and benefits is essential to appropriate use of imaging. Future research should investigate low dose CT protocol based on BMI and long-term radiation effects on the Palestinian population. Together, collaboration and data sharing combined with other considerations of other imaging modalities as clinically appropriate will contribute to a safer and more effective PET-CT practice.

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Appendix

IRB Approval letter

Arab American University

Institutional Review Board - Ramallah

الجامعـــة العربيـــة الأمريكيـــة

مجلس اخلاقيات البحث العلمي – رام الله

IRB Approval Letter

Study Title: "Estimation of Effective Dose to Patients who Undergoing Whole Body 18f-FDG PET/CT Examinations in North Palestine".

Submitted by: Sofian Jameel Tahleesh

Date received: 16th October 2024

Date reviewed: 27th October 2024

Date approved: 27th October 2024

Your Study titled **"Estimation of Effective Dose to Patients who Undergoing Whole Body 18f-FDG PET/CT Examinations in North Palestine"** with the code number **"R-2024/A/153/N"** was reviewed by the Arab American University Institutional Review Board - Ramallah and it was approved on the 27th of October 2024.

Sajed Ghawadra, PhD
IRB-R Chairman
Arab American University of Palestine

الجامعة العربية الأمريكية . فلسطين
مجلس اخلاقيات البحث العلمي . رام الله
IRB-R
ARAB AMERICAN UNIVERSITY-PALESTINE
INSTITUTIONAL REVIEW BOARD - RAMALLAH

General Conditions:

1. Valid for 6 months from the date of approval.
2. It is important to inform the IRB-R with any modification of the approved study protocol.
3. The Bord appreciates a copy of the research when accomplished.

رام الله – فلسطين

Tel: 02-294-1999 **E-Email:** IRB-R@aaup.edu **Website:** www.aaup.edu

تقييم الجرعة الفعالة للمرضى الذين خضعوا لفحص 18F-FDG PET-CT لكامل الجسم في شمال فلسطين

إعداد: سفيان جميل مصطفى طحليش

لجنة الإشراف:

د. سامر مهنا

د. عبد الناصر عاصي

د. محمد الجمل

الملخص باللغة العربية

هدفت هذه الدراسة إلى تقييم الجرعة الفعالة الكلية للمرضى الذين خضعوا لفحص التصوير المقطعي بالإصدار البوزيتروني (PET–CT) باستخدام مادة صيدلانية مشعة تحتوي على F–FDG. 18 شملت عينة الدراسة (عدد المرضى= 150) مرضى بمتوسط عمر 51.0 ± 16.3 عامًا، وكان عدد الذكور أكبر بقليل (52.0%) من عدد الإناث (48.0%). استُخدم برنامج IDAC–Dose 2.1لقياس الجرعات الفعالة من مادة صيدلانية مشعة تحتوي على F–FDG18، والذي طورته اللجنة الدولية للحماية من الإشعاع .(ICRP) يُستخدم برنامجVirtual Dose™ CT ، وهو حاسبة جرعات للتصوير المقطعي المحوسب عبر الإنترنت، طورها المعهد الوطني للسرطان، لتقدير الجرعات الخارجية. بلغ متوسط الجرعة الفعالة للتصوير المقطعي المحوسب 22.61 ± 4.23 ملي سيفرت (mSv)، ويتراوح بين 13.0 و34.4 ملي سيفرت، بينما بلغ متوسط الجرعة الفعالة لـF– 18 3.51 ± 1.28ملي سيفرت، ويتراوح بين 1.79 و11.90 ملي سيفرت، مما يعطي متوسط جرعة فعالة إجمالية قدرها 26.12 ± 4.55 ملي سيفرت، ويتراوح بين 15.39 و37.47 ملي سيفرت.

الكلمات المفتاحية: الجرعة الشعاعية الفعالة، فلورايد 18F–FDG ، التصوير الطبقي البوزيتروني