Sudan University of Science and Technology

College of Graduate Studies

Estimation of Patient Radiation Dose during Nuclear Medicine Examinations in Sudan

تقدير الجرعة الاشعاعية للمريض اثناء فحوصات الطب النووي في السودان

A thesis submitted for full Requirement of PhD degree in Nuclear Medicine Technology

By:

Osama Omer Ali Musa

Supervisor:

Prof. Dr . Mohammed Alfadil Mohammed

Co- Supervisor:

Prof. Dr. Abdel Moneim Adam Suliman

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قال تعالي:

﴿ شَهِدَ اللَّهُ أَنَّهُ لَا إِلَٰهَ إِلاَّ هُوَ وَالْمَلَائِكَةُ وَأُولُو الْعِلْمِ

قَائِمًا بِالْقِسْطِ ۚ لَا إِلَٰهَ إِلاَّ

هُوَ الْعَزِيزُ الْحَكِيمُ ﴾

سورة آل عمران الآية (١٨)

Dedication

To doses of the cup blank to give me a drop of love
To those of the fingers to give us a moment of happiness
To reap the thorns out of my way for me to pave the way science
To heart the great my father
Of whom breastfed of love and healing balm my Mother
To the heart as pure whiteness my family and to all my friends

Acknowledgements

First and foremost, I would like to express my deepest gratitude to Prof.Dr. Mohamed Elfadil , without his help this work could not have been accomplished

I also would like to thank My wife Shima Babeker and for her support.

Deep thanks to my family for their consistent mental support finally,

I would like to thank my friends.

Abstract

The aim of this study to Estimate of Patient Radiation Dose in Sudan for patients are referred to nuclear medicine departments for thyroid and kidneys and bone scan, were the number of patients was 322 patients. The study was conducted in the following hospital: Radiation and Isotope Center of Khartoum, Royal Care International Hospital, Al nilain Medical Diagnostic Center, National Cancer Institute, Shandi Hospital in period from Feb 2018- Aug 2021. The Dose calculated using RADAR software. The results showed that the correlation between the effective dose with patients age for renal scan were the change of effective dose increase by rate of 0.0042 for each year of the patients. And for patient's height foe renal scan were the change of effective dose increase by rate of 0.0017 for each cm of the patients. And for patients' weight for renal scan were the change of effective dose increase by rate of 0.0047 for each kg of the patients.

And for patient's body mass index for renal scan were the change of effective dose decrease by rate of 0.0017 for each kg\cm^2 of the patients. And for patients age for thyroid scan were the change of effective dose increase by rate of 0.0015 for each year of the patients. And for patient's height for thyroid scan were the change of effective dose increase by rate of 0.0007 for each cm of the patients. And for patients' weight for thyroid scan were the change of effective dose increase by rate of 0.0122 for each kg of the patients. And for patient's body mass index for thyroid were the change of effective dose increase by rate of 0.0011 for each kg\cm^2 of the patients. And for patients age for bone scan were the change of effective dose increase by rate of 0.0091 for each year of the patients. And for patient's height for bone scan were the change of effective dose increase by rate of 0.0049 for each cm of the patients. and for patients' weight for bone scan were the change of

effective dose increase by rate of 0.0082 for each kg of the patients. and for patient's body mass index for bone scan were the change of effective dose decrease by rate of 0.0136 for kg\cm^2 of the patients.

In conclusion the study showed that comparing between the present study with international studies worldwide, were the present study show the lowest value of dose and effective dose form all others studies for all examination's thyroid, bone and renal scan.

مستخلص الدراسة

تهدف هذه الدراسة إلى تقدير الجرعة الاشعاعية للمريض المحول إلى أقسام الطب النووي في السودان, لفحوصات الغدة الدرقية والكلى وفحص العظام ، حيث بلغ عدد المرضى 322 مريضاً. أجريت الدراسة في المستشفيات التاليه: مركز الإشعاع والنظائر بالخرطوم ، مستشفى رويال كير الدولي ، مركز النيلين للتشخيص الطبي ، المعهد القومي للأورام ، مستشفى شندي في الفترة من فبراير 2018 إلى أغسطس 2021. الجرعة محسوبة باستخدام برنامج رادار.

أظهرت النتائج ان الارتباط بين الجرعة الفعالة للمرضى بالنسبة لعمر المريض في المسح الكلوي هو زيادة الجرعة الفعالة بمعدل 0.0042 لكل سنة من عمر المريض, وبالنسبة للمسح الكلوي بالنسبة لطول المريض هو زيادة الجرعة الفعالة بمعدل 0.0017 لكل سم من طول المريض, وبالنسبة لوزن المرضى لفحص الكلى زيادة الجرعة الفعالة بمعدل 0.0047 لكل كيلوغرام من وزن المريض, وبالنسبة لمؤشر كتلة جسم المريض لفحص الكلى نقصان الجرعة الفعالة بمعدل 0.0017 لكل كجم / سم2 من مؤشر كتلة جسم المريض, وبالنسبة لعمر المرضى في فحص الغدة الدرقية تم زيادة الجرعة الفعالة بزيادة قدرها 0.0015 عن كل عام من عمر المريض, وبالنسبة لطول المرضى بالنسبة لفحص الغدة الدرقية زيادة الجرعة الفعالة بمعدل 0.0007 لكل سم من طول المريض, وبالنسبة لوزن مرضى فحص الغدة الدرقية زيادة الجرعة الفعالة بمعدل 0.0122 لكل كيلوغرام من وزن المريض, وبالنسبة لمؤشر كتلة الجسم بالنسبة للغدة الدرقية هو زيادة الجرعة الفعالة بمعدل 0.0011 لكل كجم / سم 2 من مؤشر كتلة الجسم للمريض, وبالنسبة لعمر المريض في فحص العظام زيادة الجرعة الفعالة بمعدل 0.0091 لكل عام من عمر المريض, وبالنسبة لطول المرضى لفحص العظام زيادة الجرعة الفعالة بزيادة قدرها 0.0049 لكل سم من طول المريض, وبالنسبة لوزن المرضى لفحص العظام زيادة الجرعة الفعالة بمعدل 0.0082 لكل كيلوغرام من وزن المريض, ومؤشر كتلة الجسم للمرضى لفحص العظام نقصان الجرعة الفعالة بمعدل 0.0136 للكيلو جرام \ سم 2 من مؤشر كتلة جسم المريض.

في الختام أوضحت الدراسة أن المقارنة بين الدراسة الحالية والدراسات الدولية في جميع أنحاء العالم ، حيث أظهرت الدراسة الحالية أقل قيمة للجرعة والجرعة الفعالة من جميع الدراسات الأخرى لجميع فحوصات الغدة الدرقية والعظام والفحص الكلوي.

Contents

List of tables

List of figures

List of abbreviation

DRL	Diagnostic Reference Level
ICRP	International Commission of Radiation Protection
ACR	American College of Radiology
IAEA	International Atomic Energy Agency
AA	Administer Activity
SPECT	Single Photon Emission Computed Tomography
PET	Positron Emission Tomography
Bq	Becquerel
Ci	Curie
Sv	Sievert
ED	Effective Dose

Chapter One

1.1 Introduction:

Diagnostic reference Levels (DRLs) have been introduced by the International Commission on Radiological Protection ICRP publication 60(ICRP, 1990) and 37 (*ICRP 73 - PubMed*, 1990) and by European Directive 97/43/Euratom for assisting the optimization of radiological investigation(Union, 1997).

The use of diagnostic reference levels as an important dose optimization tool is endorsed by many professional and regulatory organizations, including the ICRP, American College of Radiology (ACR), American Association of Physicists in Medicine (AAPM), United Kingdom (U.K.) Health Protection Agency, International Atomic Energy Agency (IAEA), and European Commission (EC).(McCollough and Clinic, 2010)

A Diagnostic Reference Level (DRL), is defined by the International Commission on Radiological Protection (ICRP) as; "a form of investigation level, applied to an easily measured quantity, usually the absorbed dose in year, or tissue-equivalent material at the surface of a simple phantom or a representative patient*(ICRP*, 2010)

The Council of the European Union2 defines DRLs as; "dose levels in medical radio diagnostic practices or, in the case of radiopharmaceuticals, levels of activity, for typical examinations for groups of standard-sized patients or standard phantoms for broadly defined types of equipment. These levels are expected not to be exceeded for standard procedures when good and normal practice regarding diagnostic and technical performance is applied, the objective of (DRLs) is to help avoid radiation

dose to the patient that does not contribute to the clinical purpose of a medical imaging task(*RPSP*, 2007).

This accomplished by comparison between the numerical values of the DRLs (delivered from relevant regional, national of local data) and the mean or other appropriate value observed in practice for a suitable reference group of patients or a suitable reference phantom, the national DRL is the 75th percentile (third quartile) of the spread of the median doses of common protocols as recorded from data submitted to the National Diagnostic Reference Level Service. A local facility reference level (FRL) is defined as the median value of the spread of doses for common protocols surveyed at the local radiology facility, the development of DRLs will be derived from the ongoing data submitted to the National DRL Service, which it is assumed, have produced images of acceptable diagnostic quality as defined by the reporting specialist, committee 3 of ICRP encourages authorized bodies and/or universities and institutions to set DRLs that best meet their specific needs and that are consistent for the regional, national or local area to which they apply (ICRP, 2001).

Dose surveys should be repeated periodically to establish new reference levels, which can demonstrate changes in both the mean and standard deviation of the dose distribution. The concept of DRLs is not based on the 75th percentile but on the AA necessary for good image quality during a standard procedure. They are established both regionally and nationally, and considerable variations have been seen across both regions and countries. The use of diagnostic reference levels has been shown to reduce the overall dose and the range of doses observed in clinical practice, in nuclear medicine, the effective dose is directly proportional to AA. Therefore, it is highly important to give guidance for

a dosage and the following effective dose, especially concerning pediatric patient(EUROPEAN CRP N° 180 Part 2/2, 2018).

U.K. national dose surveys demonstrated a 30% decrease in typical radiographic doses from 1984 to 1995 and an average drop of about 50% between 1985 and 2000, While improvements in equipment dose efficiency may be reflected in these dose reductions, investigations triggered when a reference dose is exceeded can often determine dose reduction strategies that do not negatively impact the overall quality of the specific diagnostic exam. Thus, data points above the 75th percentile are, over time, moved below the 75th percentile, with the net effect of a narrower dose distribution and a lower mean dose(Wisely, 2001)

There is no table for the patient's size versus the dose table given which would be used as a baseline or reference for all patients.so the researcher wants to set this lack information about Sudanese DRLs. The ICRP recommends the estimation of diagnostic reference levels as a tool for optimizing the radiation dose delivered to patients in the course of diagnostic procedures. And there was no yet local previous study set a DRLs for Sudanese in diagnostic nuclear medicine procedures.

1.2 Study problem

The ICRP recommended the Estimate of Patient Radiation Dose as a tool for optimizing the radiation dose delivered to patients in the course of diagnostic procedures and there was no yet local previous study set dose reference level for Sudanese in diagnostic nuclear medicine procedures and there is no table for the patients. So, the researcher want to set this lack information about Estimate of Patient Radiation Dose of NM examination in Sudan.

1.3 Study objectives

1.3.1 General objective:

- The aim of the study to Estimate of Patient Radiation Dose of nuclear medicine examinations in Sudan.

1.3.2 Specific objective:

- To measure the radiation dose of patients during the renal, thyroid and bone scan.
- To calculate of effective dose for all patients
- To correlate between the effective dose and demographic information of the patients
- To find the diagnostic reference level for nuclear medicine for Sudanese.
- To compare between the numerical value of the activity and effective dose with international values.
- To correlate the effective dose with body mass index.

1.4 Thesis outline:

This study consisted of five chapters, with chapter one is general introduction to Diagnostic reference Levels (DRLs), presents the goal of optimizing the radiation dose delivered to patients in the course of diagnostic procedures and problem of this study there was no yet local previous study set dose reference level for Sudanese in diagnostic nuclear medicine procedures and there is no table for the patients and the objectives of this study were also mentioned in this chapter, while chapter two is describe general background and literature review about Nuclear medicine dosimetry, Dose calculation, Equivalent dose , Diagnostic reference levels : (Terminology, Definition, History, Uses for DRLs, Issues with the current use of DRLs, DRLs values should be based on

clinical practice, Technology and clinical indication affect DRL values, Local Flexibility in Setting DRLs), chapter three is describes the materials and methods used in this research to Establish National Diagnostic Reference Level for nuclear medicine examinations in Sudan and protocols of this examination , chapter four is consists of presentation of the results in tables and finally chapter five is discussion, conclusion and recommendation

Chapter Tow

Theoretical background

2.1 Nuclear medicine:

Nuclear medicine is a highly multi-disciplinary specialty that develops and uses instrumentation and radiopharmaceuticals to study physiological processes and non-invasively diagnose, stage, and treat diseases. A radiopharmaceutical is either a radionuclide alone, such as iodine-131 or a radionuclide that is attached to a carrier molecule (a drug, protein, or peptide) or particle, which when introduced into the body by injection, swallowing, or inhalation accumulates in the organ or tissue of interest. In a nuclear medicine scan, a radiopharmaceutical is administered to the patient, and an imaging instrument that detects radiation is used to show biochemical changes in the body. Nuclear medicine imaging in contrast to imaging techniques that mainly show anatomy (e.g., conventional ultrasound, computed tomography [CT], or magnetic resonance imaging [MRI]), can provide important quantitative functional information about normal tissues or disease conditions in living subjects. For treatment, highly targeted radiopharmaceuticals may be used to deposit lethal radiation at tumor sites, nuclear medicine imaging non-invasively provides functional information at the molecular and cellular level that contributes to the determination of health status by measuring the uptake and turnover of target-specific radiotracers in tissue. These functional processes include tissue blood flow and metabolism, protein—protein interactions, expression of cell receptors in normal and abnormal cells, cell—cell interactions, neurotransmitter activity, cell trafficking and homing, tissue invasion, and programmed cell death. By providing information on these processes, nuclear medicine

imaging offers a broad array of tools for probing normal and disease-related states of tissue function and response to treatment, the addition of anatomic imaging provided by computed tomography, (CT) to functional imaging of positron emission tomography (PET) and single photon emission computed tomography (SPECT) has further expanded the utility and accuracy of nuclear medicine imaging. By using, combined-modality PET/CT and SPECT/CT devices, functional processes can be localized within the body to an anatomically identified or, in some instances, as yet unidentifiable structural alteration. These devices have enhanced the accuracy with which disease can be detected, aided in the determination of the extent and severity of disease, enhanced the accuracy for identifying disease-related risk, and improved the ability to monitor patient response to therapy.(‘Advancing Nuclear Medicine Through Innovation’, 2007)

2.2 Radiopharmaceuticals:

A radioactive medication (radioisotopes) that are used to diagnose or treat cancer. These medications can be delivered orally (in pill form), intravenously (injected into a patient's vein) or interstitially (inserted into a cavity in the body). Although radiopharmacology is considered a subspecialty of radiation therapy, regulations require that the drugs be administered by a radiopharmacist, a medical professional who specializes in nuclear medicine.

Every radiopharmaceutical is designed to travel to a different part of the body. Once it has arrived at its destination, it will release radioactive agents to destroy the tumor cells. To date, researchers have discovered radiopharmaceuticals that can target the following cancers:(Thyroid cancer, Brain cancer, Lymphoma and Cancers that have spread to the bones, radiopharmaceuticals can also be used to diagnose certain cancers, as oncologists can track radioactivity throughout the body after the drugs are administered to determine if cancer is present. This requires the use of a special imaging system, such as a gamma camera or a similar gamma imaging device. When radiopharmaceuticals are used for diagnostic purposes, the drugs are known as "tracers." Diagnostic radiopharmaceuticals contain smaller amounts of radiation than those that are used for treatment, radiopharmaceuticals, as the name suggests, are pharmaceutical formulations consisting of radioactive substances (radioisotopes and molecules labelled with radioisotopes), which are intended for use either in diagnosis or therapy or diagnosis. The use of radioactive material necessitates careful and safe handling of these products by trained and authorized personnel, approved/authorized laboratory facility as per the guide lines(Radiopharmaceuticals | Moffitt, 2001)

2.2.1 Units of Radioactivity:

- In the International System (SI), the unit of radioactivity is one nuclear transmutation per second and is expressed in Becquerel (Bq), named after the scientist Henri Bequerel.
- The old unit of radioactivity was Curie (Ci), named after the scientist's Madame Marie Curie and Pierre Curie, the pioneers who studied the phenomenon of radioactivity.

One Ci is the number of disintegrations emanating from 1 g of Radium-226, and is equal to 3.7 x 1010 Bq. The Becquerel (Bq) is the SI derived unit of radioactivity. One becquerel is defined as the activity of a quantity of radioactive material in which one nucleus decays per second. The activity of a source is measured in bacquerels.

This is a very small unit, and multiples are often used:

1 MBq = 1 mega Bq= 1,000,000 Bq; 1 GBq= 1 giga Bq= 1,000,000,000 Bq

1 TBq = 1 tera Becquerel = 1,000,000,000,000 Bq

The radioactivity of an environment, a material or a foodstuff is given in Becquerel's per kilogram or per liter. The gray (Gy) is defined as the absorbed dose of radiation per unit mass of tissue. One gray is the absorption of one joule of radiation energy per kilogram of matter. The amount of radiation your cells absorb is measured in grays.

1 Gy = 1 joule per kilogram

Sub-multiples are often used:

1 mGy = 1 milligray = 0.001 Gy; 1 μGy = 1 microgray = 0.000001 Gy

1 nGy = 1 nanogray = 0.000000001 Gy

The Sievert (Sv) is a measure of the health effects of low levels of ionizing radiation on the human body. At equal doses, the effects of radioactivity on living tissue depends on the type of radiation (alpha,

beta, gamma, etc.), on the organ concerned and also on the length of exposure.

Contrary to the Becquerel, the sievert is a very large unit, and we often use sub-multiples:

1 mSv = 1 millisievert = 0.001 Sv; 1 μSv = 1 microsievert = 0.000001 Sv

2.2.2 Storage of Radioactive Substances:

Radiopharmaceuticals should be kept in well-closed containers and stored in an area assigned for the purpose. The storage conditions should be such that the maximum radiation dose rate to which persons may be exposed is reduced to an acceptable level. Care should be taken to comply with national regulations for protection against ionizing radiation.

Radiopharmaceutical preparations that are intended for parenteral use should be kept in a glass vial, ampoule or syringe that is sufficiently transparent to permit the visual inspection of the contents. Glass containers may darken under the effect of radiation.(Dr Sumanta et al 2017).

2.3 Gamma Cameras:

The gamma or scintillation camera is an imaging device that is most commonly used in nuclear medicine. It is also called the Anger camera in honor of Hal O. Anger, who invented it in the late 1950s. Gamma cameras detect radiation from the entire field of view simultaneously and therefore are capable of recording dynamic as well as static images of the area of interest in the patient. Various designs of gamma cameras have been proposed and made available, but the Anger camera with a single crystal is by far the most widely used. Although many sophisticated improvements have been made on the gamma cameras over the years, the basic principles of the operation have essentially remained the same.(Saha, 2006)

The original gamma camera invented by H. O. Anger over 50 years ago and its subsequent generations. Its principle of operation consists of a single large crystal (typically 25–50 cm in diameter) in which gamma rays are converted to scintillations of light. Here, a limited number of scintillation detectors view these through a collimator to provide information for an image.(, Joseph A. et al 2012)

Figure 2-1 Planer gamma camera

2.3.1 System Components of gamma camera:

- Collimator
- NaI(Tl) crystal
- Light Guide (optical coupling)
- Photo Multiplier -Tube array
- Pre-amplifier
- Position logic circuits (differential & addition etc.)

- Amplifier (gain control etc)
- Pulse height analyser
- Display (Cathode Ray Tube etc).

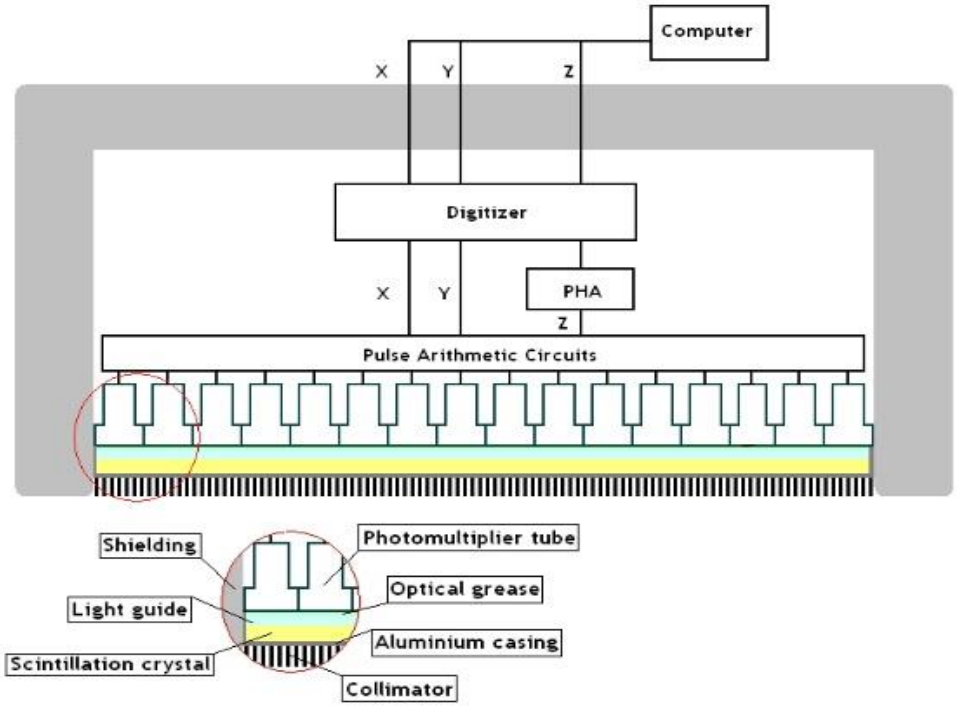


Figure 2-2 System Components of gamma camera.

2.3.2 Types of collimator:

- Pinhole collimators are used in imaging small organs such as thyroid glands.
- Converging collimators are employed when the target organ is smaller than the size of the detector,
- diverging collimators are used in imaging organs such as lungs that are larger than the size of the detector.
- Parallel hole collimators are most commonly used in nuclear medicine procedures.

- Fanbeam collimators They are designed for a rectangular camera head to image smaller organs like the brain and heart
- Slanthole collimators A variation of the Parallel hole is the Slant hole collimator, which has all tunnels slanted at a specific angle.

2.3.3 Quality control of Gamma Camera:

The observation techniques and activities used to fulfill requirements for quality. minimum level of routine QC is required to ensure that nuclear medicine equipment is functioning properly

1. Visual Inspection: may reveal obvious defects which may compromise the safety or the imaging efficacy of the system
2. Background Radiation Levels and Contamination
3. Photopeak And Window Setting: Incorrect photopeak energy window setting(s) can degrade uniformity, reduce sensitivity, or can increase the scatter contribution to the image
4. Uniformity: checks that the response of the detector to a uniform irradiation is uniform within defined limits
5. Resolution: checks is to detect gradual, long-term deterioration of resolution, rather than detecting abrupt changes
6. Whole Body Scan Resolution: the relative physical position between bed and detector has to be accurately synchronized with the electronic offset applied to the image data to form the whole body image
7. Centre of Rotation

2.4 Dose calibrator:

Is a gas-filled ionization chamber in the shape of a well, used to determine the intensity of a radioactive source expressed in Becquerels [Bq]. The radioactivity is measured indirectly: X-ray or gamma photons cause ionization in the gas. A large voltage differential is applied to the

electrodes in the chamber. The electrons released by the ionizations are drawn to the anode, which creates a voltage pulse. Using, an electronic circuit, this voltage pulse is converted into an electric current. For a given radionuclide, there is a proportional relationship (the “yield”) between de activity (Bq) and the strength of the current (μA). For different radionuclides, this relationship depends on the photon energy (keV) and the photon flow (density). The latter is influenced, amongst other things, by the count geometry, such as size and position of the source, and by attenuation. Because of this dependence, the amplification factor of the circuitry must be set separately for each radionuclide. In contrast to gamma cameras, a radionuclide is not measured on a particular peak, but all (X-ray and gamma) photons contribute to the measurement of the activity (and sometimes even the Auger electrons, as with 123I). Most dose calibrators have pre-programmed selection keys for the proper amplification of certain radionuclides. In addition, an arbitrary setting may be selected. The manufacturer provides a list of radionuclides and their associated settings. The calibration has been performed at the factory for a particular source geometry (syringe) in a certain position. Apart from the opening of the well, the ionization chamber is surrounded by lead. This causes ionization by background radiation to be kept to a minimum, but there will nevertheless still be some ionization giving rise to a leakage current. Most dose calibrators have a zero setting which is used to compensate for this leakage current. In older types, the background must first be measured, or first ‘zeroed’ before a preparation can be measured.(Sara H Muller et al 2010)

Figure 2-3: dose calibrator

2.5 Nuclear medicine scans:

2.5.1 Bone Scan:

2.5.1.1 Radionuclide: 99mTC t 1\2: 6 hours ,Energies: 140 Kev, Type: IT. y. generator

2.5.1.2 Radiopharmaceutical: MDP (methylene diphosphonate), HDP (hydraxymethylene diphosphonate)

2.5.1.3 Localization: Chemisorption; chemically bonds on surface of hydroxyapatite crystals. These hydrolyze and bind normally to bone as tin oxide and/or Tc02 and present as prominent focal areas during the process of osteoblastic activity of bone repair.

2.5.1.4 Quality Control: No 0 2 in kit. Chromatography. >95% tagging. Use MDP within 6 hours and HDP within 8 hours.

2.5.1.5 Adult Dose Range : 20-30 mCi (740-1110 MBq). pediatrics by weight .

2.5.1.6 Method of Administration: intravenous: Straight stick, butterfly or existing IV catheter with saline flush. Flow requires fast bolus injection.

2.5.1.7 Indication:

Detection of primary and staging metastatic disease. 'types known to frequently metastasize to bone are neuroblastoma. breast, lung, prostate, and kidney. Evaluation of neoplasm or known lesion(s).

Differentiation of monostotic (single bone) from polyostotic primary bone tumors. Differentiation between osteomyelitis (inflammation of bone and bone marrow) and cellulitis (inflammation of cellular or connective tissues).

A three-phase flow study is indicated. Three-phase studies examine vascular, immediate blood pool. then osseous (osteoblastic) activity distinguishing cellulitis (activity in flow and immediate phases) from osteomyelltis (activity in third or all three phases). A fourth phase includes a 24-hour delay. Evaluation of prosthesis concerning suspected loosening, infections, avascular necrosis, and/or pain. In some institutions, this also indicates a three-phase bone scan. Evaluation of reflex sympathetic dystrophy (RSD) or complex regional pain syndrome [CRPS). In some institutions, this also indicates a three-phase bone scan. Detection of occult (obscure, difficult to find) fractures and known or suspected stress fractures or shin splints.

Some institutions flow fractures and shin splints. Evaluation of bone pain and/ or trauma. Detection and evaluation of metabolic bone diseases such as fibrous dysplasia or Paget disease (bone inflammation and resorption replaced by soft bone), osteoporosis, and osteomalacia [vitamin D deficiency) and other osteopathies. Detection and evaluation of arthritides and degenerative disk and/or joint (osteoarthrosis) disease. One type, ankylosing spondylitis, usually chronic pain involving inflammation of vertebrae, SI joint, shoulders, hips, and ribs. Evaluation of anemia (due to chronic arthritis). Evaluation of limited bone, joint or limb function, heterotopic ossification (abnormal bone growth) and bone afflictions e.g., hypertrophic osteoarthropathy (Bamberger-Marie Syndrome), temporomandibular joint (TMJ) and sickle cell disorders.

Evaluation of bone graft viability, bone viability when blood supply is in question (infarct). Evaluation for bone surgery (e.g.,

vertebroplasty, total knee or hip replacements). Evaluation of abnormal laboratory results (e.g., elevated prostate-specific antigen [PSA], elevated alkaline phosphatase in osteogenic sarcoma and metastatic prostate cancer, elevated Ca2 + in breast, lung, and kidney cancer bone).

Evaluation of abnormal findings on other diagnostic images, e.g., x-ray images, positron emission tomography (PET magnetic resonance imaging (MRI), computed tomography (CT). Evaluation of response to chemotherapy, radiation therapy, antibiotic therapy, and other treatment and osteoblastic distribution before radionuclide therapies and Localization of sites for biopsy.

2.5.1.8 Patient preparation:

Identify the patient. Verify doctor's order. Explain the procedure. For flow of three-phase bone study, remove any attenuating material from region of interest (ROI). Instruct patient to drink lots of fluids (hydrate well) and urinate often before imaging and Instruct patient to return in 2-4 hours (usually 3 hours) after injection for delayed statics, whole-body imaging or single photon emission computed tomography (SPECT).

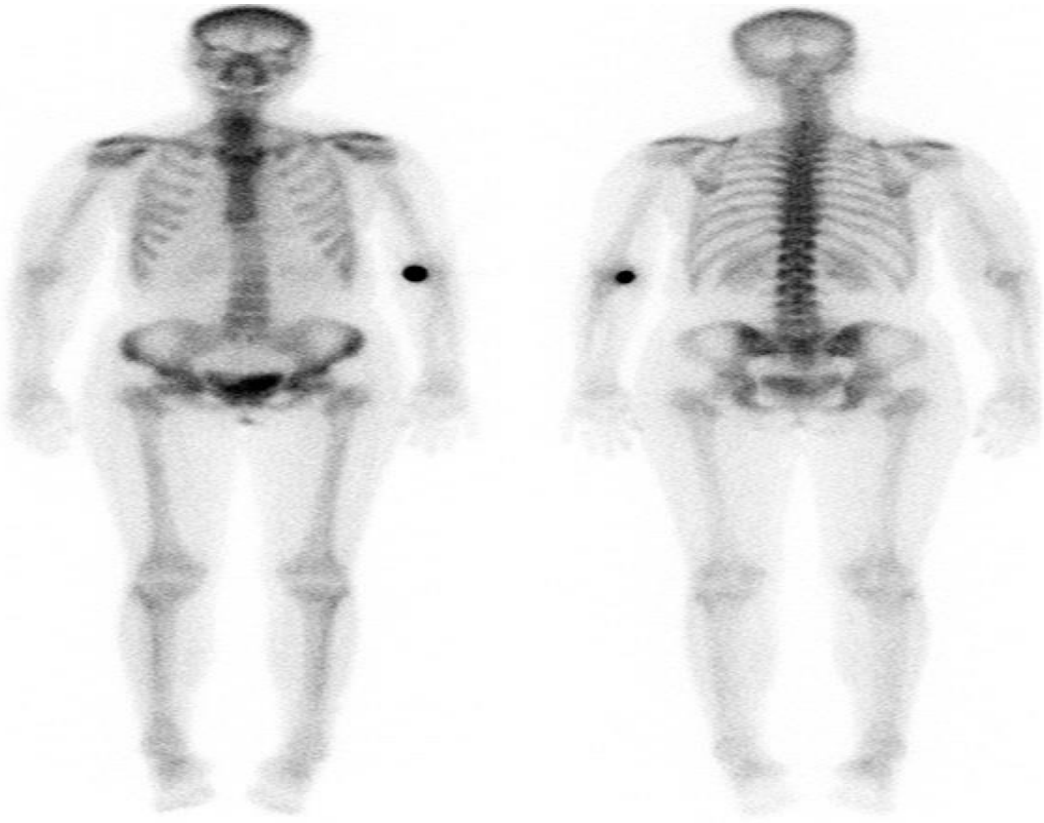


Figure 2-3 Normal Tc-99m MDP whole-body bone scan. A high level of anatomical detail can be visualized. Some areas of increased uptake are normally seen in the adult, including activity in the joints. A small dose infiltration is present in the left antecubital fossa.

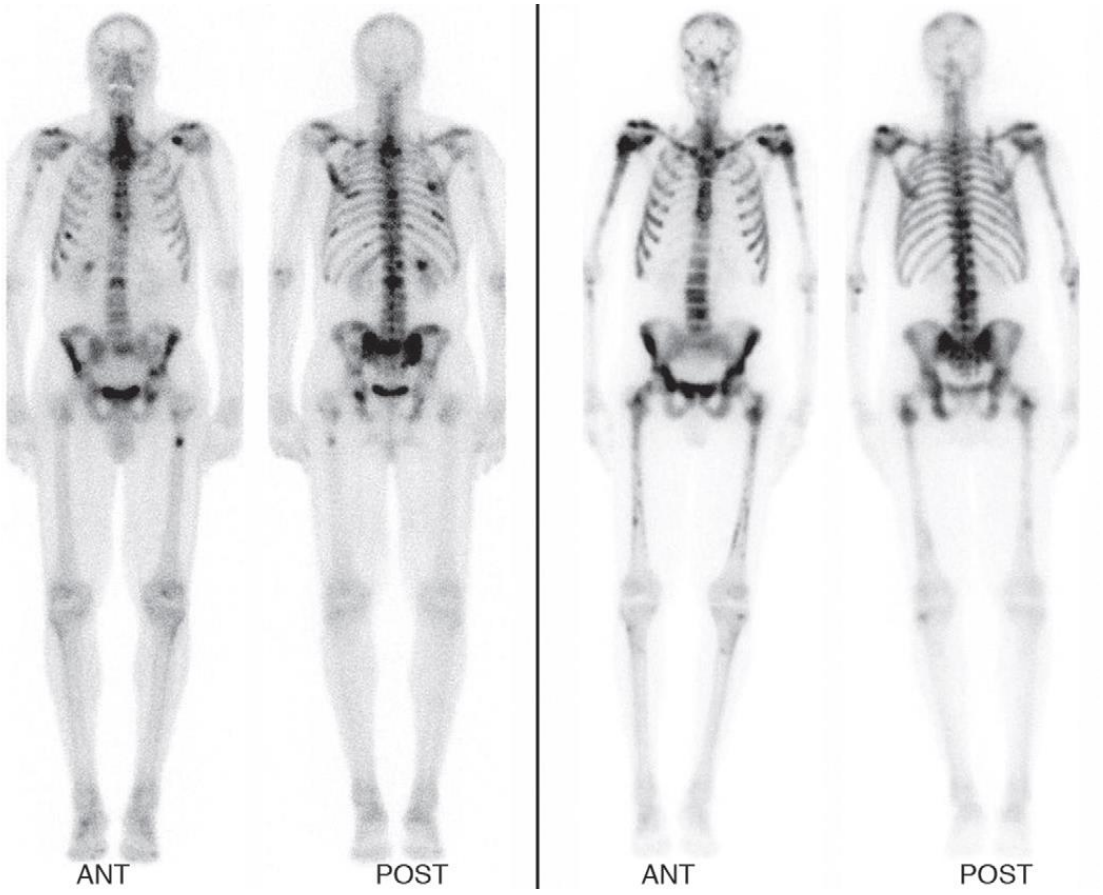


Figure 2-4 Prostate cancer metastatic disease. A, Numerous foci of increased activity, largely in the axial skeleton, are typical as the bones respond to metastases. B, two years later, with disease progression diffuse increased uptake is seen in the spine, pelvis, and ribs, with multiple new lesions in the skull and proximal long bones. In some areas, such as the pelvis, bones appear intense but almost normal.

2.5.2 Renal: Cortical Imaging (99mTc-D M SA):

2.5.2.1 Radionuclide: 99m'TC t 1\2: 6 hours, Energies: 140 keV, Type: IT,y, generator

2.5.2.2 Radiopharmaceutical: 99m'TC-DMSA (dimercaptosuccinic acid), 99m'TC-GH (n-glycero-D-glucoheptonate complex, gluceptate, or glucoheptonate)

2.5.2.3 Localization : Compartmental, blood stream; DMSA: 90% binds to plasma proteins, preventing any significant glomerular filtration, hence slow clearance from renal cortex (proximal convoluted tubules) with 40%-50% of the injected dose localizing in the proximal tubules of the cortex. Only 10% excreted through the urine in the first several hours. GH: a carbohydrate cleared from kidneys by renal tubules and glomerular filtration; 10%-15% of injected dose remains bound to renal tubules

2.5.2.4 Quality Control : Chromatography, >90%. DMSA: Relatively unstable; a more stable form has been recently developed. Draw immediately after mixing into syringe. No O2 introduction. Use within 30 minutes of preparation. GH Use up to 5 hours after preparation.

2.5.2.5 Adult Dose Range: 9Elm'fc-DMSA: 1-6 mCi (37-222 MBq), pediatric; 0.05 mCi/kg (l.85 MBq/kgl), 9Elm'fc-GH: 10-20 mCi (370-740 MBq).

2.5.2.6 Method of Administration: Direct intravenous (IV) injection or IV catheter with saline flush.

2.5.2.7 INDICATIONS: Evaluation of renal cortex. Evaluation and quantitation of regional relative function. Evaluation and quantitation of differential function. Detection and localization of renal mass (space-occupying lesions). Differentiation of hypertrophied renal column (of Bertin) a.k.a. renal pseudotumor from a cystic or solid renal mass. Detection and differentiation of acute and chronic pyelonephrttis and associated edema or scani.ng. Evaluation for renal blood supply obstruction and/or trauma and Evaluation of renal transplant to include acute tubular necrosis, acute and chronic rejection,

cyclosporine/tacrollmus toxicity, lymphoceles, hematomas, injury to renal artery or vein, ureteral obstruction, urine leakage (urinomas).

2.5.2.8 PATIENT PREPARATION: Identify the patient. Verify doctor's order. Explain the procedure, especially the delay between injection and imaging. Patient is to be well hydrated and should void before test begins. Patient may be required to discontinue angiotensin-converting enzyme (ACE) inhibitors or angiotensin II receptor blockers (ARB) and Patient should supply list of all medications including over-the-counter drugs and results of any previous related tests and/ or studies.

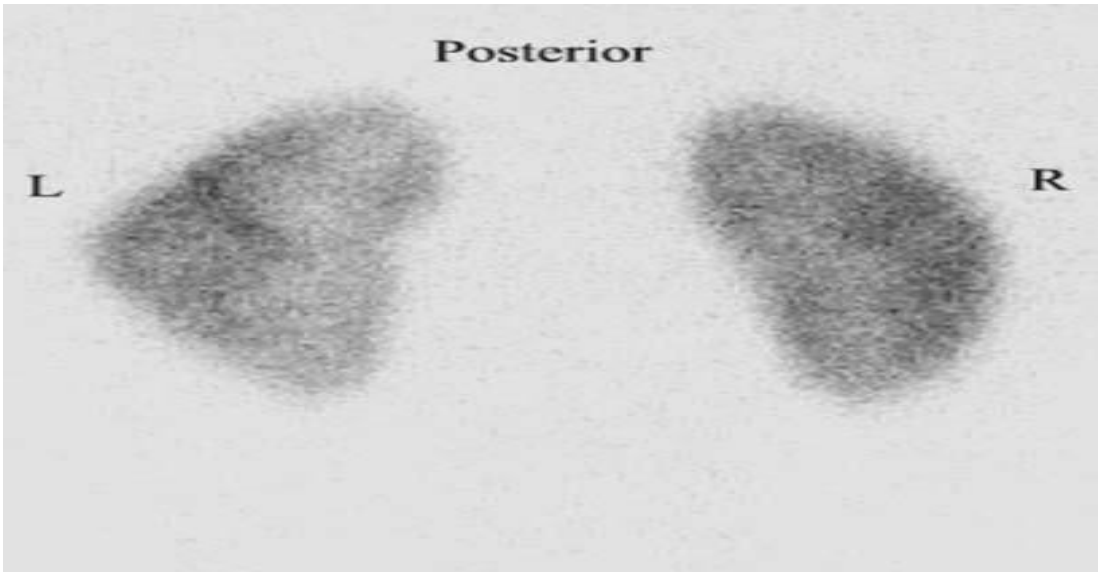


Figure 2-5 Normal DMSA image in an 8-year-old girl with history of UTI. The lateral aspect of the mid pole of the left kidney shows prominent columns of Bertin.

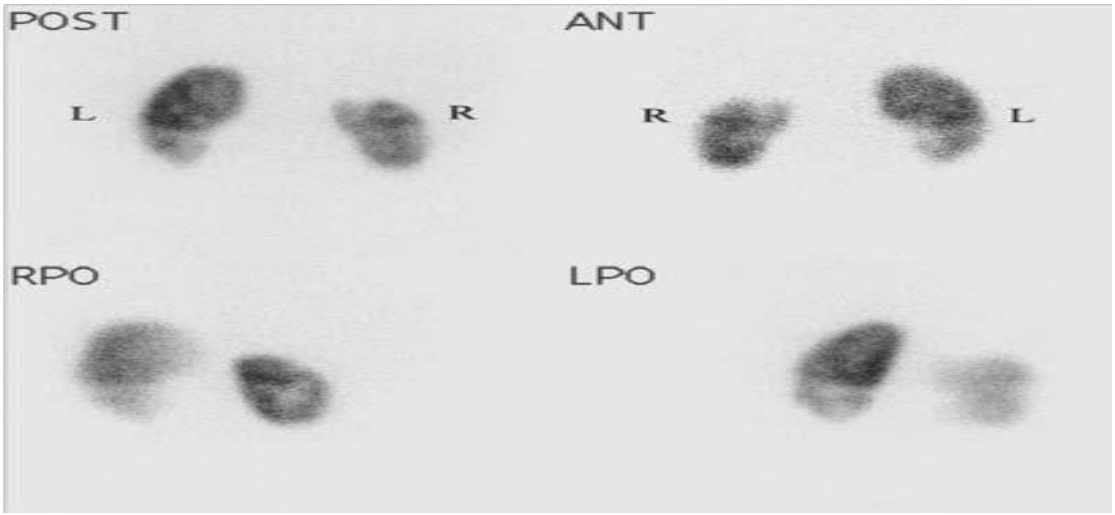


Figure 2-6 Abnormal DMSA scan in a 13-year-old boy with a history of UTIs and bilateral grade 4 reflux. The relatively small right kidney shows a wedge-shaped defect in the upper pole that is typical of renal scarring. There is also an area of significantly reduced uptake in the lower pole of the left kidney–best seen on left posterior oblique (LPO) view – that also represents scarring. Relative renal function was measured as: L=61%, R=39%.

2.5.3 Renal: Renogram (Diuretic, and Captopril, Tubular Function, effective Renal Plasma Flow, and Glomerular Filtration Rate)

2.5.3.1 Radionuclide : 99mTc: t 1\2 : 6 hours - Energies: 140 keV - Type: IT. 'Y' generator. I(123): t 1\2: 13.2 hours - Energies: 159 keV - type: EC, y, accelerator and I(131): t 1\2 : 8.1 days - Energies: 364 keV - type: B ~-, y, fission product

2.5.3.2 Radiopharmaceutical:99TC-DTPA:(diethylenetriaminepentaaceticacid),99TC-MAG3 (mercaptoacecyltrlglyclne),I131-0IH(orthoiodohippurate) sometimes still used in ERPF

2.5.3.3 Localization: Compartmental, blood flow. 9 9mTc-MAG3 highly protein bound, removed from plasma by organic anion transporter 1 in the basolateral membrane of the proximal renal

tubules. It is then transported into the tubular lumen by organic anion transporters on the apical membrane with retained activity dependent on impairment. Uptake 1s by tubular secretion. Clearance Is through the urinary system and bladder with a small amount cleared through the hepatobiliary system and is 90% within 3 hours. 9 9mTcDTPA uptake 1s glomerular filtration and 1s purely filtered by the glomerulus and excreted through the urinary system and bladder. Clearance ls dependent on the amount of impurities In the product, which bind to the protein In the body.

2.5.3.4 Method of Administration: Bolus intravenous (IV) injection, If study includes a diuretic, use butterfly or IV catheter (furosemide 20-40 mg), Angiotensin-converting enzyme (ACE) inhibitor study, Captopril (Capoten171 50 mg) is given by mouth (PO) 1 hour before examination, Enalapril maleate (Vasotec® 0.04 mg/kg IV over 3-5 minutes).

2.5.3.5 Adult Dose Range: 99m'TC: DTPA: 5-10 mCi (185-370 MBq); pediatric :0.05 mCi/kg (1.9 MBq/kg), minimum dose 1 mCi (37 MBq).

2.5.3.6 Indication: Evaluation for renal artery stenosis, obstruction, and/or trauma. Evaluation of renal tubular function and perfusion (glomerular filtration) for blood flow, parenchyma, and excretion. Evaluation of renal vascular flow (effective renal plasma flow). Evaluation of renal obstructive nephropathy and/or hydronephrosis (study with furosemide). Differentiation between obstructive hydronephrosis and nonobstructive dilation of collecting system. Differentiation of renal (renovascular) hypertension (RVH) and renal artery stenosis (captopril/enalaprilat study). Evaluation of RVH therapy.

Evaluation of abdominal or flank bruits, azotemia, pulmonary edema, retinopathy, and unexplained renal dysfunction. Detection of acute tubular necrosis and Evaluation of a kidney transplant to include acute tubular necrosis, acute and chronic rejection, cyclosporine/tacrolimus toxicity, lymphoceles, hematomas, injury to renal artery or vein, ureteral obstruction, urine leakage (urinomas).

2.5.3.7 Patient Preparation: Identify the patient. Verify doctor's order. Explain the procedure. Instruct the patient to hydrate well (water; up to 10 mL/kg) and void just before test. If it is a 1-day two-study test, the hydration should continue between studies. Dehydration causes delayed uptake and clearance. Physician is to instruct the patient to discontinue ACE inhibitors for several days (3-7) before examination depending on the half-life of the drug (e.g., captopril 48 hours, enalapril and lisinopril 1 week). There are cases where the patient cannot discontinue medication. Physician may also choose to discontinue ARBs (4-7 days), diuretics, beta blockers, and calcium channel blockers. Instruct the patient to be NPO (liquids only) for at least 4 hours on morning before captopril study. Preimaglng voiding is a must Post study voiding is recommended to lessen bladder exposure. Catheterization of patients who cannot adequately void may be a consideration particularly if it is a diuretic study. The effect of the diuretic is diminished with increased bladder pressure and Captoprtl renal function: tubular excretion rate ratio is 40:60.

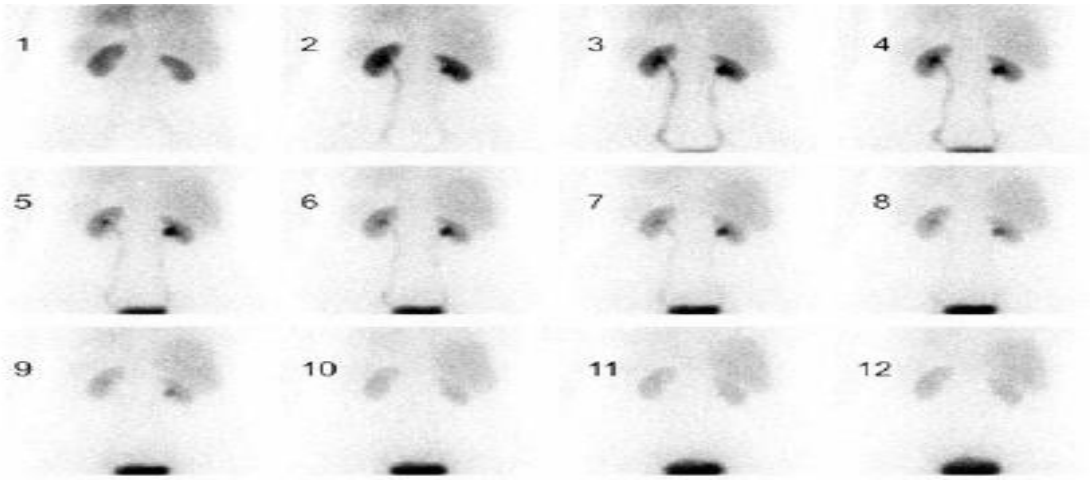


Figure 2.7 Normal anterior perfusion images A, acquired at 7 days post-transplant showing aortic bifurcation, iliac arteries, and renal

2.5.4 Thyroid scan:

2.5.4.1 Radionuclide: 123I - t 1\2: 13.2 hours Energies: 159 keV type: EC, y, accelerator, 131I - t1\2: 8.1 days Energies: 364 Kev (y), 606 keV (B-) \ type: B-, y, fission product, 99mTC- t 1\2: 6 how-s Energies: 140 keV type :IT: .y. generator

2.5.4.2 Radiopharmaceutical: 123I and 131I as capsules, Na 99mTCO4: Sodium perteclmetate

2.5.4.3 Localization: Active transport. 99mTC04 - trapped but not organified, 123I and 131I: Active transport; trapped in follicular cells by a high-energy sodium iodide symporter (iodine pump), organified by the thyroid, and held in cells or follicular lumen.

2.5.4.4 Quality Control:

- 99mTC: Chromatography >90%, moly and Al breakthrough
- 123I and 131I : Assay capsule(s) in the dose calibrator to confirm amount of radioactivity.

2.5.4.5 Adult Dose Range: 131I: 1µ-ci - 10 m Ci (0.037-370 MBq) depending on patient and reason for scan Usually 5-30 µ-Ci

(0.185-1.110 MBq) for uptake and scan, 2-5 mCi (74-185 MBq) for whole body imaging and/or treatment of patients, 1231: 100-600 µCi (3.7-25 MBq), pediatrtcs; 3-10 µCi/kg (0.1-0.3 MBq/, 99m'TC04-: 2-10 mCi (74-370 MBq)

2.5.4.6 Method of Administration: 123I and 131I capsule PO (per os meaning b mouth or oral), 99m'TC by intravenous injection

2.5.4.7 INDICATIONS: Evaluation of thyroid function and anatomy, e.g., position, goiter (enlarged gland due to inadequate iodine supply), surgery, and cold or hot nodule(s). Detection and evaluation of hyperthyroidism and hypothyroidism (including congenital). Detection and localization of metastases from thyroid cancer. Differentiation of benign from malignant nodules. Detection, localization, and evaluation of independent functioning nodule(s). Differentiation and evaluation of heterogeneity of function within the hyperthyroid gland, e.g., Graves' disease or toxic nodular goiter from subacute, silent, postpartum, or factitious hyperthyroidism. Detection and localization of benign or malignant ectopic thyroid tissue. Evaluation of unidentified neck or substernal mass. Evaluation of abnormal thyroid serum laboratory results. Evaluation of subclinical (before appearance of typical symptoms of disease) and subacute (between acute and chronic) disease processes, e.g., toxic goiter, thyroiditis and Evaluation of thyroid because of palpation and/or abnormal findings on previous examination, e.g., x-ray images, magnetic resonance imaging (MRI), computed tomography (CT) ultrasonography (US), nuclear medicine (NM), and/or positron emission tomography (PET).

2.5.4.8 PATIENT PREPARATION: Identify the patient. Verify doctor's order. Explain the procedure. Patient should bring recent lab reports and all previous results from related studies, e.g., US, CT, MRI, NM, and x-ray. 99m'fc: None other. Patient to discontinue thyroid medications and avoid contrast material, Betadine or amiodarone. Please refer to the list in thyroid uptake chapter or in reference section. Prolonged periods of time of discontinuation of certain medications may be detrimental to some patients. Instruct the patient to refrain from eating foods containing iodine such as cabbage, turnips, green leafy vegetables, seafood, shellfish, sushi, kelp, soy products, milk, cheese products, eggs, multivitamins, chocolate, or large amounts of iodized table salt. Some require this as a 3- to 10-day protocol before administration of the capsule(s) and 1231and 131I: Patient will be returning at 4-6 hours and/or 24 hours for scan. 1311: Patient will usually be returning at 24 hours and beyond for imaging. 1bis iodine is not routinely used for uptake and scans. See appropriate thyroid chapters. (Ziessman et al., 2004)

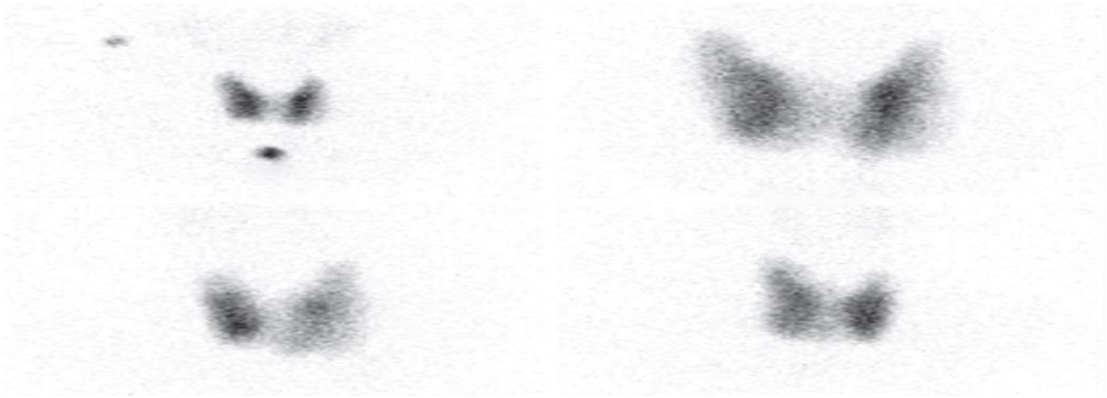
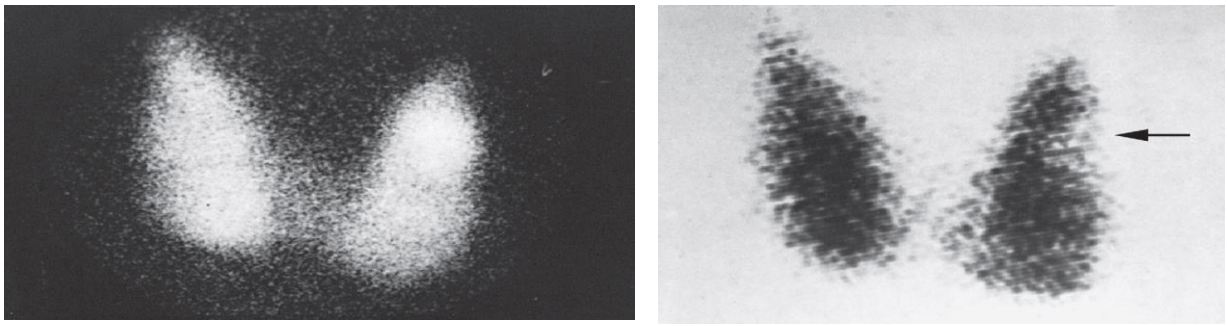


Figure 2-8 Normal I-123 thyroid scan. The *left upper* image is acquired with the collimator distanced further from the neck than the other three images, permitting a larger field of view and clear view of the suprasternal notch *(SSN)* and the right side *(RT)* hot markers. The anterior *(ANT),* left anterior oblique *(LAO),* and right anterior oblique *(RAO)* views are acquired with the pinhole close enough to the patient's neck that the image fills two thirds of the field of view. The right lobe is best viewed on the RAO view and the left lobe on the LAO image because those lobes are closest to the collimator and best magnified.



A B

Figure 2-9 Discordant nodule. A, Tc-99m pertechnetate scan shows relatively increased uptake in a palpable nodule in the *left upper* pole. B, In the corresponding radioiodine scan the nodule *(arrow)* is cold. Thus, the nodule can trap but not organify iodine. This discordance requires further workup to exclude malignancy.

2.6 Nuclear medicine dosimetry:

Radionuclides are administered to patients in nuclear medicine procedures in a variety of diagnostic and therapeutic applications. A key consideration in such studies is the absorbed dose to different organs of

the patient, where a significant absorbed dose may be received by other organs and in particular by radiosensitive organs. The purpose of this parts is to review the methods and models used in internal dosimetry in nuclear medicine and discuss some current trends and challenges in this Field. It is not our intention to catalog radiation dose for many nuclear medicine procedures; such dose estimate compendia may be found in various reference(Stabin 1999)

In 1976, the Medical Internal Radiation Dose (MIRD) Committee of the Society of Nuclear Medicine issued MIRD Pamphlet No. 1, Revised, as a supplement to The Journal of Nuclear Medicine. The purpose of that document was to update the original MIRD schema issued in 1968 , The MIRD schema, with examples, was published in didactic format in 1988 and later in 1991 as the MIRD Primer , Since that time, the MIRD schema has provided a broad framework for the assessment of absorbed dose to whole organs, tissue subregions, voxelized tissue structures, and individual cellular compartments from internally deposited radionuclides(Bolch et al., 2009)

At the same time, the International Commission on Radiological Protection (ICRP), whose mission is to establish guidelines regarding accidental, occupational, and patient exposures, formulated an almost identical dosimetry schema that includes physical quantities such as absorbed dose. In addition, the ICRP defined the radiation protection quantities equivalent dose and effective dose to address the relative biological effectiveness (RBE) of all emitted radiations and the differential radiosensitivity of organs to radiation-induced stochastic effects (cancer induction due to mutation of somatic cells or heritable effects due to mutations of germ cells) (Bolch 2009)

Fundamentally, the computation of absorbed dose in both the MIRD and the ICRP systems is similar, as each uses the concepts of absorbed fraction, specific absorbed fraction, source and target tissue regions, reference computational phantoms, and compartmental models describing biokinetic distributions of activity in the human body. These dosimetry schema differ more in notation than in substance. The purpose of this MIRD pamphlet is 3-fold. First, the Committee restates the MIRD schema for assessment of absorbed dose in a manner consistent with the needs of both the nuclear medicine and radiation protection communities with the goal of standardizing nomenclature. Second, the Committee adopts the dosimetry quantities, equivalent dose, and effective dose for use in comparative evaluations of potential risks of radiation-induced stochastic effects to patients after nuclear medicine procedures. Finally, the Committee highlights the need for dosimetry quantities to address deterministic effects (due to cell death or impairment of organ function after high absorbed doses and dose rates) associated with targeted radionuclide therapy(Loevinger 1991).

2.7 Dose calculation:

Dosimetry Quantities and Units Quantification of the amount of radiation received by a potentially radiosensitive site is essential to the characterization of the possible risks of the exposure, The principal quantity used to identify and measure the amount of radiation received is the absorbed dose, sometimes called just dose.

The word dose has anumber of meanings in its general use, as a noun, these are the definitions:

1. An amount of some agent applied for a medical purpose:

(a) A specified quantity of a diagnostic and therapeutic agent, such as a drug or medicine, prescribed to be taken at one time or at stated intervals.

(b) The amount of radiation administered as diagnostic agent or therapy to a given site.

2. An ingredient added, especially to wine, to impart flavor or strength.

3. An amount, especially of something unpleasant, to which one is subjected: a dose of hard luck.

4. Slang: A venereal infection. As a verb, these are the definitions:

(a) To give (someone) a dose, as of medicine.

(b) To give or prescribe (medicine) in specified amounts.

In this text, we are interested in the quantity alluded to in part 1(b) above and will very specifically define it. This little diversion was entertained to point out that when one uses the term dose in a medical setting, it is not uncommon for the understanding of that term to vary.

Many times, physicians refer to the dose of a radiopharmaceutical given to a patient, meaning the amount of activity given to the subject (MBq or mCi, for example), not the radiation dose (rad or Gy) received by the tissues of the patient's body. This is a sometimes unfortunate but very understandable mixing of terms, as physicians administer doses of medicine more often than dosimetrists calculate doses of radiation for medical subjects,

One must simply be aware of this possible confusion of terms and be sure that the right quantities are employed in the right circumstances. One solution is to use the term dosage to refer to the quantity of an administered pharmaceutical and reserve the term dose for quantification of radiation dose (i.e., energy/mass). The first quantity that is of interest

to our text is absorbed dose. Absorbed dose is the energy absorbed per unit mass of any material. Absorbed dose (D) is defined as:

$$D = d3/ dm$$

where d3 is the mean energy imparted by ionizing radiation to matter in a volume element of mass dm. The units of absorbed dose are (energy/mass) of any material. One may use, for example, (erg/g, J/kg) or others. Special units are also defined for absorbed dose:

$$1 \text{ rad} = 100 \text{ erg/g}$$

$$1 \text{ gray (Gy)} = 1 \text{ J/kg}$$

$$1 \text{ Gy} = 100 \text{ rad}$$

The word rad was originally an acronym meaning “radiation absorbed dose.” The rad is being replaced by the SI unit value, the gray (Gy), which is equal to 100 rad. Note that rad and gray are collective quantities: one does not need to place an “s” after them to indicate more than one(ICRP, 1990)

2.8 Equivalent dose:

Many biological effects of radiation can be related to an amount of absorbed dose. At very low doses, no effects may be observed. After the dose passes a particular threshold, some effects may be observed and will generally become more severe as more dose is received. However, when different experiments are performed in certain biological systems using perhaps different kinds of radiation or measuring different biological end points, different amounts of absorbed dose may be needed to observe a particular effect.

This is particularly true for high linear energy transfer (LET) radiations like alpha particles and fast protons. The other important

quantity traditionally defined to account for these differences is the equivalent dose. Equivalent dose is the absorbed dose modified by a factor accounting for the effectiveness of the radiation in producing biological damage. Equivalent dose (HTR) is defined as:

$$HTR = wR\ DTR$$

where DTR is the dose delivered by radiation type R averaged over a tissue or organ T, and wR is the radiation weighting factor for radiation type R. The factor wR is really dimensionless; the fundamental units of equivalent dose are the same as those for absorbed dose. Operationally, however, we distinguish using the special units:

$$H\ (rem) = D\ (rad) \times wR$$

$$H\ (Sv) = D\ (Gy) \times wR$$

$$1\ Sv\ (Sievert) = 100\ rem$$

Note that, like rad and gray, rem and sievert are collective terms; one need not speak of “rems” and “sieverts,” although this may sometimes be heard in informal speech and even observed in some publications.

The recommended values of the radiation weighting factor have varied somewhat over the years as evidence from biological experiments has changed. The current values recommended by the International Commission on Radiological Protection (ICRP)1 are given in Table 2.1.(Stabin, 2008)

Table 2.1. Radiation weighting factors recommended by the ICRP.

Type of radiation	**wR**
Photons, all energies	1
Electrons and muons, all energies (except Auger electrons in emitters bound to DNA)	1
Neutrons, energy:	
<10 keV	5
10 keV to 100 keV	10
>100 keV to 2 MeV	20
>2MeV to 20 MeV	10
>20MeV	5
Protons, other than recoil protons, E>2MeV	5
Alpha particles, fission fragments, heavy nuclei	20

Note: Reproduced with permission from International Commission on Radiological Protection. 1990 Recommendations of the International Commission on Radiological Protection. ICRP Publication 60. Pergamon Press, New York, 1991

2.9 Effective dose (E):

It is important to recognize that the potential biological effects from radiation depend not only on the radiation dose to tissue or organ, but also on the biological sensitivity of the tissue or organ irradiated. Effective dose is a dose descriptor that reflects this difference in biologic sensitivity. it is a single dose parameter that reflects the risk of a non-uniform exposure in terms of an equivalent whole-body exposure.

The units of effective dose are sieverts (usually milli sieverts (mSv) are used in diagnostic radiology). The assumed radiosensitivities were derived from the observed rates of expression of these effects in various populations exposed to radiation. Multiplying an organ's dose equivalent by its assigned weighting factor gives a weighted dose

equivalent. The sum of weighted dose equivalents for a given exposure to radiation is the effective dose:(Stabin, 2006)

$$E = H \times Wt$$

Where:

H = equivalent dose

Wt =tissue weighting factor

Here is an example (using ICRP 30 weighting factors):

Organ	tissue weighting factor Wt
Gonads	0.25
Breast	0.12
Lungs	0.15
Red marrow	0.12
Thyroid	0.03
Bone surfaces	0.03
Liver	0.06

2.10 Diagnostic reference level:

2.10.1 Terminology:

In its 1990 Recommendations (ICRP,1991), the Commission described reference levels (when used for applications other than medical exposures of patients) as values of measured quantities above which some specified action or decision should be taken. These include recording levels, above which a result should be recorded, lower values being ignored; investigation levels, above which the cause or the implications of the result should be examined; and intervention levels, above which some remedial action should be considered.

The DRL was introduced in 1996 as the term for a form of investigation level used to identify situations where optimization of protection may be required in the medical exposure of patients (ICRP, 1996). In this publication, the Commission recommends the use of two new terms: ‘DRL quantity’ (a commonly and easily measured or determined radiation metric that assesses the amount of ionizing radiation used to perform a medical imaging task) and ‘DRL value’ (an arbitrary notional value of a DRL quantity, set at the 75th percentile of the distribution of the medians of distributions of the DRL quantity obtained from surveys or other means)(ICRP, 1996)

In its 2007 Recommendations (ICRP, 2007a), the Commission uses the terms ‘dose constraint’ in the context of planned exposure situations and ‘reference level’ for existing and emergency exposure situations. Thus, the term ‘reference level’ should not be used in the context of medical imaging. Also, although the medical exposure of patients is a planned situation, the use of ‘dose constraints’ is not applicable (International Commission on Radiological Protection, 1990).

2.10.2 Definition of DRLs:

“Diagnostic reference levels” (general medical imaging task) means dose levels in medical radio- diagnostic practices or, in the case of radiopharmaceuticals, levels of activity, for typical examinations for groups of standard-sized patients or standard phantoms for broadly defined types of equipment. These levels are expected not to be exceeded for standard procedures when good and normal practice regarding diagnostic and technical performance is applied (ICRP 2002).

The term general medical imaging task refers to an imaging task for a general clinical purpose, with minimum specification of other factors, Examples of quantities and their application to improve a

regional, national or local distribution of observed values for a general medical imaging task are: Entrance surface year kerma (in year, no backscatter) or entrance surface dose (in a specified material, with backscatter) in mGy, for a given radiographic projection (e.g. PA chest); Dose area product (DAP) in mGy cm2 for a given type of fluoroscopic examination that has a well-defined anatomical region of clinical study (e.g. barium enema); and Administered activity (A) in MBq for a given nuclear medicine imaging task using a given radiopharmaceutical (e.g. lung perfusion with Tc-99m MAA).*(*ICRP, 2010)

2.10.3 History:

Wall and Shrimpton (1998) have reviewed the use of measurements of quantities related to patient dose for optimization of protection. Beginning in the 1950s, national surveys of such quantities for diagnostic x-ray examinations were performed 28 ICRP Publication 135 in the USA and the UK. In the 1970s, the Nationwide Evaluation of X-ray Trends surveys began in the USA (FDA, 1984), and in the 1980s, the National Radiological Protection Board (NRPB, now Public Health England) surveys in the UK measured entrance-surface exposure either free-in-year or incident on the patient The results of these and similar surveys were the basis for recommendations for radiographic technique and for levels of the quantities surveyed. These were first developed in the USA (Shrimpton et al., 1986).

A summary of the Commission's guidance on DRLs from Publications 60 and 73 and Supporting Guidance 2 was included in Publication 105 (ICRP, 2007c). (7) In Europe, DRLs were formally introduced in Council Directive 97/43/ EURATOM (EC, 1997), and Member States of the European Union were obligated to promote the establishment and the use of DRLs as a strategy for optimization. This

obligation was reiterated by the European Commission (EC, 2013), with a requirement for the establishment, regular review, and use of DRLs. The 2013 Council Directive also states that appropriate local reviews are undertaken whenever DRLs are consistently exceeded, and that appropriate corrective action, if required, is taken without undue delay.

Several research programmers were launched by the European Commission, beginning in 1990, to collect data on patient doses and image quality, produce guidance on image quality criteria for adult and pediatric radiology and CT, and promote the use of DRLs (EC, 1996a,b, 1999a,b). Between 1995 and 2005, additional programmers (SENTINEL, 2007; DIMOND, 2006) on digital and interventional radiology established initial DRL values for newer imaging modalities(ICRP, 1990)

2.10.4 Uses for a Diagnostic Reference Level:

A diagnostic reference level can be used:

(a) To improve a regional, national, or local distribution of observed results for a general medical imaging task, by reducing the frequency of unjustified high or low values.

(b) To promote attainment of a narrower range of values that represent good practice for a more specific medical imaging task

(c) To promote attainment of an optimum range of values for a specified medical imaging protocol.

Uses (13) (a), (b) and (c) are differentiated by the degree of specification for the clinical and technical conditions selected by the authorized body for a given medical imaging task(ICRP - PubMed, 2001)

2.10.5 Issues with the current use of DRLs:

There are several issues with the application of the DRL process in current practice: misuse of DRL values for individual patients (or individual examinations) instead of groups of patients or a series of examinations; misuse of DRL values as a limit for individual patients or individual examinations; using phantoms or inappropriate measures of radiation output to set DRL values; establishing DRL values when there are differences in technology among imaging systems and differences in necessary image quality for different clinical indications for the same examination; and characterizing image quality. There are also problems in pediatric radiology with the paucity of studies and data that can be used in setting DRLs, because of the small numbers of patients of any particular size that are examined(Rehani, 2015)

The appropriate and optimized dose for an individual depends on the patient's size and the purpose of the medical imaging task. Once protocols for 'standard' patients are optimized, the equipment's automatic control mechanisms should be able to scale technique factors appropriately for smaller or larger patients. For nuclear medicine, the administered activity is, in some cases, weight-based.(Järvinen 2017)

2.10.6 DRLs values should be based on clinical practice:

For x-ray imaging, DRL values should, in general, be determined using data on values of DRL quantities derived from patient examinations. Phantoms were often used in the past. The Commission now recommends setting DRL values based on surveys of patient examinations, because the DRL value should be tied to defined clinical and technical requirements for the medical imaging task. The data gathered from patient examinations provide a perspective on the distribution of these data that cannot be observed using simple phantoms (McCollough 2011).

2.10.7 Technology and clinical indication affect DRL values:

DRL values are dependent on the state of practice and the available technology at a particular point in time. Technological advances may allow adequate image quality at values of the DRL quantity lower than an arbitrary percentile of the survey distribution. Separate DRLs may be needed were technological advances or changes lead to significant, consistent, identifiable differences in doses. One example is the use of more sensitive digital radiography systems (‘Journal of Radiological Protection Diagnostic reference 2017)

The Commission, in Publication 73, stated, ‘In principle, it might be possible to choose a lower reference below which the doses would be too low to provide a sufficiently good image quality. However, such reference levels are very difficult to set, because factors other than dose also influence image quality’ (ICRP, 1996). Differences in technology between equipment also make setting DRL values for lower bounds problematic(ICRP 73 - PubMed, 1999)

In some cases, different clinical indications for an examination may require different image qualities, and therefore different amounts of radiation. Therefore, the DRL values for these indications should ideally be different. The same is true for certain screening examinations. For some examinations, the setting of a DRL without an indication of clinical indication is of little value. The compilation of more information on dose and image quality requirements linked to clinical tasks is an area that requires more attention. Note that the European Society of Radiology uses the terms ‘clinical indication’ or ‘clinical DRL’ which are equivalent to the ICRP term ‘clinical task’(Damilakis 2018)

For interventional procedures, the amount of radiation applied to the patient depends largely on the type of procedure and on procedure complexity. Procedure complexity may vary for different clinical indications for the same procedure. For example, a nephrostomy performed for ureteric obstruction, where the renal collecting system is dilated, requires less radiation exposure to the patient than the same procedure performed for a ureteric leak or for access for stone removal (a more complex and difficult procedure because the collecting system is not dilated)(Miller, Kwon and Bonavia, 2009)

2.10.8 Local Flexibility in Setting Diagnostic Reference Levels:

Diagnostic reference levels should be used by authorized bodies to help manage the radiation dose to patients so that the dose is commensurate with the clinical purpose.

The concept of a diagnostic reference level permits flexibility in the choice of quantities, numerical values, and technical or clinical specifications, in order to allow authorized bodies to meet the objectives relevant to their circumstances. The guiding principles for setting a diagnostic reference level (DRL) are:

(a) The regional, national or local objective is clearly defined, including the degree of specification of clinical and technical conditions for the medical imaging task;

(b) The selected value of the DRL is based on relevant regional, national or local data.

(c) The quantity used for the DRL can be obtained in a practical way;

(d) The quantity used for the DRL is a suitable measure of the relative change in patient tissue doses and, therefore, of the relative change in patient risk for the given medical imaging task; and

(e) The manner in which the DRL is to be applied in practice is clearly illustrated. (23) Committee 3 encourages authorized bodies to set diagnostic reference levels that best meet their specific needs and that are consistent for the regional, national or local area to which they apply. (ICRP, 2010)

2.11 previous studies:

Reference levels are primarily intended to offer benchmark values as a rough guideline for appropriate practice. There are numbers of studies carried out to Establish National Diagnostic Reference Level for nuclear medicine examinations Reference levels provides a rough guideline for appropriate practice (Ali et al., 2016).

In this study, a national survey for establishment of Nuclear Medicine (NM) Dose Reference Levels (DRLs) for adult patients was carried out. The Administrated Activity (AAs) (MBq) was collected from six nuclear medicine departments. Factors influencing the image quality were also observed. The established Sudan National DRLs represent the AA value corresponding to 75th percentile of the AA frequency distribution. Generally, Sudan National DRLs and average AAs are comparable with the papers published in the international literature. All Sudanese DRLs values were found within the international range. While it is noted that the Sudanese DRLs is higher than the values of ARSA except for the MIBI pharmaceuticals that used in both parathyroid and myocardial perfusion scan and for 99mTcDTPA that used for Dynamic Renal scan study the DRLs values were decreased. In compared with UNSCEAR 2008 data, the average dose (MBq) for Sudanese we note that

the bone scan falls within the average values while it's lower in all other scans except for parathyroid scan in which the AAAs increase more than twice. When compared to BSS 1996, it showed variation in increased and decreased AAAs. There may be potential for reducing the higher values of AAs, in co-operation with Nuclear Medicine staff.

Song *et al* 2019, conducted a study on 32 nuclear medicine imaging studies. They mentioned that DRLs enable the optimization of radiation protection in the field of nuclear medicine imaging. They tested DRLs for diverse protocols of the brain and myocardial perfusion SPECT and respectively. They found out that Q3 values tended to be higher than mode values in six studies in bone scan, leukocyte scan, thyroid scan, dynamic renal scan, dynamic renal scan, gastric emptying scan, and gated cardiac blood pool scan, while were equal to the mode values in the remaining studies. They also compared between the confirmed DRLs in Korea and values of many countries including Japan, Australia, UK, Brazil, USA (NCRP), and EU "Austria, Finland, France, Germany, Greece, Bulgaria, Czech Republic, Spain, Norway, Italy, Sweden, and Switzerland" The Korean DRL values tended to be lower for 10 of 16 studies (62.5%), higher for five, and identical for one study. Also, their DRLs were of similar or lower values than those of other countries, except leukocyte scan and hepatobiliary scan) which showed the highest DRL values.

(Vogiatzi, Kipouros and Chobis, 2018), in few studies he benefited from Greek Atomic Energy Commission's Department of Licensing and Inspections conducted a national survey for the establishment of nuclear medicine (NM) dose reference levels (DRLs) for adult patients, in Greece. The administered activities (AAs) (MBq) were collected from 120 NM departments (88 % of total), during on-site inspections for

licensing purposes. Factors influencing the image quality were also investigated. The established national DRLs represent the AA value corresponding to the 75th percentile of the AA frequency distributions. found that the Greek DRLs and AAAs have lower than values found in the literature, but the majority were higher. He added that the DRLs is in line with the Greek NM protocol. He mentioned that established Greek DRLs are to be regarded as guidelines and should be exceeded only in individual patients whenever necessary and that meeting the DRLs does not automatically mean that good practice is performed. So the Greek DRL to the most extend go along with the Basic Safety Standards (BSS) values, and the Administration of Substances Advisory Committee (ARSAC) values are lower compared with Greek DRLs.

(H et al., 2016) Objective of this study The optimization of medical exposure is one of the major issues regarding radiation protection in the world, and The International Committee of Radiological Protection and the International Atomic Energy Agency recommend establishing diagnostic reference levels

(DRLs) as tools for dose optimization. Therefore, the development of DRLs based on the latest survey has been required for nuclear medicine-related societies and organizations. This prompted us to conduct a nationwide survey on the actual administered radioactivity to adults for the purpose of developing DRLs in nuclear medicine. Methods A nationwide survey was conducted from November 25, 2014 to January 16, 2015. The questionnaire was sent to all of the 1249 nuclear medicine facilities in Japan, and the responses were collected on a website using an answered form.

This study demonstrated that the administered radioactivity in diagnostic nuclear medicine in Japan has been in the convergence zone. Nuclear medicine facilities in Japan show a strong tendency to adhere to

the package insert, texts and guidelines. Furthermore, the Japan administered radioactivities were within the range of variation of the EU and the SNMMI administration radioactivities. Whether nuclear facilities can optimize the dose, or whether this is required, depends on the role of the academic societies and experts.

(J et al., 2016) A screening was carried out in all Brazilian Nuclear Medicine Service (NMS) establishments to support this study by collecting the average activities administered during adult diagnostic procedures and the rules applied to adjust these according to the patient's age and body mass.

Percentile 75 was used in all the activities administered as a means of establishing DRL for adult patients, with additional correction factors for pediatric patients. Radiation doses from nuclear medicine procedures on the basis of average administered activity were calculated for all diagnostic exams.

The result a total of 107 NMSs in Brazil agreed to participate in the project. From the 64 nuclear medicine procedures studied, bone, kidney, and parathyroid scans were found to be used in more than 85% of all the NMSs analyzed. There was a large disparity among the activities administered, when applying the same procedures, this reaching, in some cases, more than 20 times between the lowest and the highest. Diagnostic exams based on 67Ga, 201Tl, and 131I radioisotopes proved to be the major exams administering radiation doses to patients. On introducing the DRL concept into clinical routine, the minimum reduction in radiation doses received.

(Beveridge, Marks and Thomas, 2019) The Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) published new Australian diagnostic reference levels (DRLs) for nuclear medicine in 2017. The DRLs are based on data collected via a national survey started

in 2014 coordinated by ARPANSA and from two earlier surveys conducted in 1998 and 2008 by the Australian and New Zealand Society of Nuclear Medicine. The Australian nuclear medicine DRLs cover general nuclear medicine, SPECT/CT and PET/CT for adult patients. Where possible, the DRLs have been set using a methodology analogous to that used for setting the Multi-Detector CT DRLs first issued by ARPANSA in 2012.

Australian DRLs have been issued for nuclear medicine, incorporating general nuclear medicine, PET, SPECT/CT and PET/CT. All reference levels have been set based on the response to wide scale surveys, either the NDRLS nuclear medicine survey conducted in 2014/15 or the ANZSNM survey of 2008.

(Fred A. Mettler et al., 2020)The purpose of this study To determine the change in per capita radiation exposure in the United States from 2006 to 2016. The U.S. National Council on Radiation Protection and Measurements conducted a retrospective assessment for 2016 and compared the results to previously published data for the year 2006. Effective dose values for procedures were obtained from the literature, and frequency data were obtained from commercial, governmental, and professional society data. In the United States in 2006, an estimated 377 million diagnostic and interventional radiologic examinations were performed. This value remained essentially the same for 2016 even though the U.S. population had increased by about 24 million people. The number of CT scans performed increased from 67 million to 84 million, but the number of other procedures (eg, diagnostic fluoroscopy) and nuclear medicine procedures decreased from 17 million to 13.5 million.

The number of dental radiographic and dental CT examinations performed was estimated to be about 320 million in 2016. Using the tissue-weighting factors from Publication 60 of the International

Commission on Radiological Protection, the U.S. annual individual (per capita) effective dose from diagnostic and interventional medical procedures was estimated to have been 2.9 mSv in 2006 and 2.3 mSv in 2016, with the collective doses being 885 000 and 755 000 person-sievert, respectively. The trend from 1980 to 2006 of increasing dose from medical radiation has reversed. the result Estimated 2016 total collective effective dose and radiation dose per capita dose are lower than in 2006.

y.Bhg . Tan(‘47Guidelines On DRL In Nuclear Medicine.pdf’, et al 2013) in this study the data were collected from 12 NM center in Malesia involve in the survey of diagnostic examination and threptic procedures for the purpose to develop the drl for NM .the survey was completed with demographic data covering different aspects including the equipment, personnel, and patients information as well as the dosimetry data taking into account types and activities of the radiopharmaceutical used.

This reference administer activity is not based on the 75^{th} percentile from an international or national survey data but on the average administered activity necessary for a good imaging during standard procedure and the proposed DRLs are in good agreement with other national recommendations.

Chapter Three

Material and Methods

3.1 MATERIAL:

3.1.1 Dose Calibrator:

American ATOMLAB 400 Dose Calibrator, Royal Care Hospital. American ATOMLAB 400 Dose Calibrator 2.1-086-250, Shandi Hospital and Radioisotope Dose Calibrator, CRC-25R, CAPINTEC RAMSEY, N-3-07446, 2.0AL 250V, 50/60Hz, 245mA,made in Al-Nileen Center.

3.1.2 Gamma Camera:

Hungarian Mediso SPECT system, Nucline Spirit (DHV), S/N DH-004167-V0 with double head at Royal Care Hospital. Hungarian Mediso SPECT system, Nucline Spirit (DHV), S/N DH-V-single V2.01 with (high, low) collimator at Shandi Hospital. SPECT Gamma Camera, Type: Orbiter 37 with Single Head 37 PMTS/387mm] - Al-Nileen Diagnostic Center.

3.2 Design of the study:

This study adapts a analytical cross sectional design.

3.3 Area of study:

The study was conducted at Radiation and Isotope Center in sudan in tht follwing hospital :

Radiation and Isotope Center of Khartoum, Royal Care International Hospital, Al nilain Diagnostic Center, National Cancer Institute, Shandi Hospital.

3.4 Duration of study:

The study will be conducted during the September 2017- July 2021

3.5 Study Population:

This includes all patients referred to these centers for Nuclear Medicine Exams during the study period with diggrent age but with constant range of weight 60 to 80 Kg.

3.6 Study variables:

The demographic information will be Record. (Age, Gender, Weight, High, BMI, and clinical indications). The Dose will be measure by use certain Equation.

3.7 Methods:

The study was conducted at Radiation and Isotope Center in Sudan in the following hospital: Radiation and Isotope Center of Khartoum, Royal Care International Hospital, Al Nilain Diagnostic Center, National Cancer Institute, Shandi Hospital, in period from Feb 2018- Aug 2021, where the study includes all patients referred to these centers for Nuclear Medicine Exams during the study period. (i.e., diagnostic and therapeutic procedures) with different age but with constant range of weight 60 to 80 Kg.

3.7.1 Gamma Camera:

Hungarian Mediso SPECT system, Nucline Spirit (DHV), S/N DH-004167-V0 with double head at Royal Care Hospital. Hungarian Mediso SPECT system, Nucline Spirit (DHV), S/N DH-V-single V2.01 with (high, low) collimator at Shandi Hospital. SPECT Gamma Camera, Type: Orbiter 37 with Single Head 37 PMTS/387mm] - Al-Nileen Diagnostic Center.

3.7.2 Dose Calibrator:

American ATOMLAB 400 Dose Calibrator, Royal Care Hospital. American ATOMLAB 400 Dose Calibrator 2.1-086-250, Shandi Hospital

and Radioisotope Dose Calibrator, CRC-25R, CAPINTEC RAMSEY, N-3-07446, T 2.0AL 250V, 100-240n, 50/60Hz, 245mA, made in U.S.A– Al-Nileen Diagnostic Center.

3.7.3 Renal:

Renogram (Diuretic, and Captopril, Tubular Function, ffective Renal Plasma Flow, and Glomerular Filtration Rate)

Radionuclide: 99DTc: t 1\2: 6 hours - Energies: 140 keV - Type: IT. 'Y' generator

I(123): t 1\2: 13.2 hours - Energies: 159 keV - type: EC, y, accelerator

(131): t 1\2: 8.1 days - Energies: 364 keV - type: B ~-, y, fission product

Radiopharmaceutical: 99TC-DTPA :(diethylenetriaminepentaacetic acid), 99TC-MAG3: (mercaptoacecyltrlglyclne)

Please note: The iodine compounds are no longer coxmnerdally available in the United States and will only be mentioned in passing as a histortc note.

I123-0IH (orthoiodohippurate) sometimes still used in effective renal plasma flow (ERPF)

I131-0IH (orthoiodohippurate) sometimes still used in ERPF

Localization: Compartmental, blood flow. 9 9m'fc-MAG8o.1. highly protein bound, removed from plasma by organic anion transporter 1 in the basolateral membrane of the proximal renal tubules. It is then transported into the tubular lumen by organic anion transporters on the apical membrane with retained activity dependent on impyearment. Uptake 1s by tubular secretion. Clearance Is through the urinary system and bladder with a small amount cleared through the hepatobiliary system and is 90% within 3 hours. 9 9mTcDTPA uptake 1s glomerular filtration and 1s purely filtered by the glomerulus and excreted through the urinary system

and bladder. Clearance ls dependent on the amount of impurities In the product, which bind to the protein In the body.

Method of Administration: Bolus intravenous (IV) injection, If study includes a diuretic, use butterfly or IV catheter (furosemide 20-40 mg), Angiotensin-converting enzyme (ACE) inhibitor study: Captopril (Capoten171 50 mg) is given by mouth (PO) 1 hour before examination, Enalapril maleate (0.04 mg/kg IV over 3-5 minutes).

Adult Dose Range: 99m'TC: DTPA: 5-10 mCi (185-370 MBq); pediatric :0.05 mCi/kg (1.9 MBq/kg), minimum dose 1 mCi (37 MBq).

Place patient in supine position, camera under table, except for kidney transplant patients for whom camera is placed above the abdomen. Prone for pinhole collimator, kidneys in field of view (FOV).

3.7.4 Thyroid scan :

Radionuclide: 123I - t 1\2: 13.2 hours Energies: 159 keV type: EC, y, accelerator 131I - t1\2: 8.1 days Energies: 364 Kev (y), 606 keV (B-) \ type: B-, y, fission product 99mTC- t 1\2: 6 how-s Energies: 140 keV type: IT: .y. generator.

Radiopharmaceutical: 123I and 131I as capsules, Na 99mTCO4: Sodium perteclmetate

Localization: Active transport. 99mTC04 - trapped but not organified, 123I and 131I: Active transport; trapped in follicular cells by a high-energy sodium iodide symporter (iodine pump), organified by the thyroid, and held in cells or follicular lumen.

Quality Control: 99mTC: Chromatography >90%, moly and Al breakthrough, 123I and 131I: Assay capsule(s) in the dose calibrator to confirm amount of radioactivity.

Adult Dose Range: 131I: 1μ-ci - 10 m Ci (0.037-370 MBq) depending on patient and reason for scan Usually 5-30 μ-Ci (0.185-1.110 MBq) for

uptake and scan, 2-5 mCi (74-185 MBq) for whole body imaging and/or treatment of patients, 1231: 100-600 μCi (3.7-25 MBq), pediatrics; 3-10 μCi/kg (0.1-0.3 MBq/ 99m'TC04-: 2-10 mCi (74-370 MBq)

Method of Administration: 123I and 131I capsule PO (per os meaning mouth or oral) 99m'TC by intravenous injection

The patient lies supine, with hyper - extended neck and the camera anterior to the neck, Fixed Distance Between Camera and neck (20 cm).

3.7.5 Bone Scan:

Radionuclide: 99mTC t 1\2: 6 hours, Energies: 140 Kev, Type: IT. y. generator

Radiopharmaceutical: MDP (methylene diphosphonate), HDP (hydraxymethylene diphosphonate)

Localization: Chemisorption; chemically bonds on surface of hydroxyapatite crystals. These hydrolyze and bind normally to bone as tin oxide and/or Tc02 and present as prominent focal areas during the process of osteoblastic activity of bone repyear. Quality Control: No 0 2 in kit. Chromatography. >95% tagging. Use MDP within 6 hours and HDP within 8 hours. Adult Dose Range: 20-30 mCi (740-1110 MBq). pediatrics by weight.

Method of Administration: intravenous: Straight stick, butterfly or existing IV catheter with saline flush. Flow requires fast bolus injection.

Position the patient in supine position on the table (prone if supine is uncomfortable)

Place the collimator as close to the patient as possible to improve image quality.

3.8 RADAR Medical Procedure Radiation Dose Calculator:

For effective doses under 3 mSv (300 mrem), the risk is considered to be "minimal" and the consent language is rather brief. The doses are related to the equivalent number of days of exposure to natural background. For effective doses between 3 mSv (300 mrem) and 50 mSv (5000 mrem, or 5 rem), the risk is still termed "minimal", but slightly more consent form language is recommended. Doses are still related to the equivalent number of days of exposure to natural background, but information about individual organ doses should be given to the subject.'

3.9 Analysis of data:

All dose parameters will be registered from Data collection sheet , and they will be used as input to the Microsoft excel and SPSS software for analysis, the 3rd quartile of median values will be taken for each group and the correlation will be tested between the activity and (age, weight, gender, BMI and clinical indication) .

Chapter Four

4.1 **Results**:

Estimation of radiation dose for patient underwent nuclear medicine exam for thyroid and kidneys and bone scan in Sudan, where the number of patients was 322 patient's male and females and the data of this study presented as tables and figures:

Table 4.1 Descriptive Statistics for patients from all scans:

Variables	Mean	Std. DeV	Min	Max
Age	47.429	17.7201	6.0	97.0
Height	162.22	12.2050	50.0	190.0
Weight	66.984	11.6487	6.0	105.0
BMI	25.506	4.91290	2.86	45.23
Dose	9.424	6.9897	2.5	26.0
ED	2.6352	1.37233	.45	5.49

Table 4.2 Frequency distribution for patients per exam:

Scan	Frequency	Percent
Renal Scan	112	34.8
Thyroid Scan	108	33.5
Bone Scan	102	31.7
Total	322	100.0

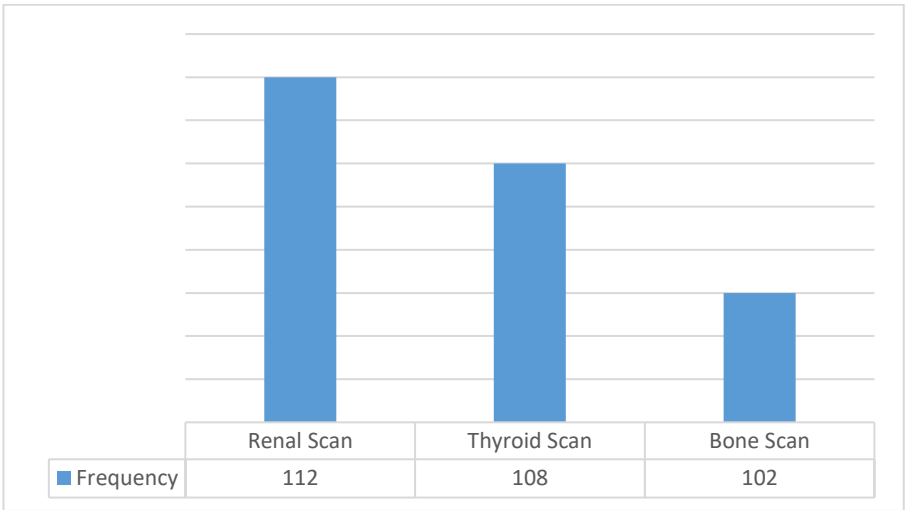


Figure 4.1 Frequency distribution for patients per exam

Table 4.3 Gender frequency for all patients:

Gender	Frequency	Percent
Female	183	56.8
Male	139	43.2
Total	322	100.0

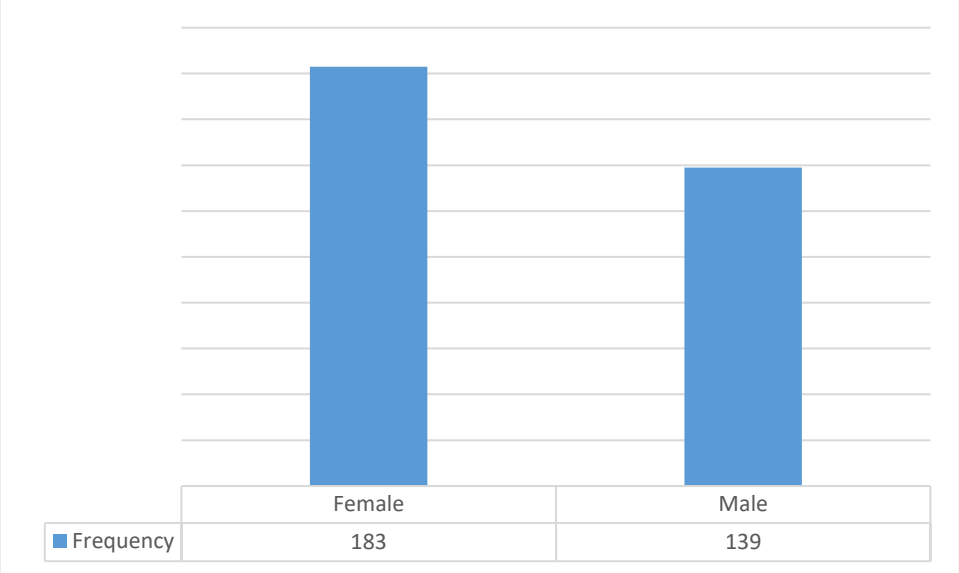


Figure 4.2 Gender frequency for all patients

Table 4.4 Clinical indication distribution for all patients:

Clinical Indication	Frequency	Percent
Obstruction	19	5.9
Urinary Pain	25	7.8
Renal Stone	47	14.6
Fatigue	31	9.6
Joint Pain	64	19.9
CA	110	34.2
Lion Pain	11	3.4
Goiter	15	4.7
Total	322	100.0

Table 4.5 Frequency distribution for scan among all hospitals:

Hospital	Frequency	Percent
NMDC	81	25.2
Shandi Hospital	60	18.6
NCI	70	21.7
RICK	64	19.9
RCIH	47	14.6
Total	322	100.0

Table 4.6 Descriptive statistic for patients from renal scan:

	Mean	Std. Dev	Minimum	Maximum
Age	43.063	16.4926	6.0	80.0
Height	162.929	14.5042	50.0	190.0
Weight	66.179	11.8673	6.0	89.0
BMI	25.3525	4.34087	14.27	36.11
Dose	5.170	1.0729	2.5	10.0
ED	0.9421	0.19773	0.45	1.81

Table 4.7 Correlation between Clinical Indication with Hospitals:

Clinical Indication	Hospital					Total
	NMDC	Shandi Hospital	NCI	RICK	RCIH	
Obstruction	2	2	4	3	6	17
Urinary Pain	3	5	4	5	8	25
Renal Stone	17	12	10	8	0	47
CA	6	1	0	3	2	12
Lion Pain	0	0	10	1	0	11
Total	28	20	28	20	16	112

Table 4.8 Group statistic for patients from renal scan:

	Gender	N	Mean	Std. Deviation	Std. Error Mean
Age	Female	45	41.089	15.0889	2.2493
	Male	67	44.388	17.3563	2.1204
Height	Female	45	156.333	18.2109	2.7147
	Male	67	167.358	9.1182	1.1140
Weight	Female	45	63.956	13.1632	1.9623
	Male	67	67.672	10.7568	1.3142
Dose	Female	45	5.078	0.7609	0.1134
	Male	67	5.231	1.2411	0.1516
Effective Dose	Female	45	0.9254	0.16128	0.02404
	Male	67	0.9533	0.21931	0.02679

Table 4.9 Descriptive statistic for patients from thyroid scan:

	Mean	Std. Dev	Minimum	Maximum
Age	42.694	17.8940	16.0	88.0
Height	162.667	10.5183	132.0	189.0
Weight	67.454	10.7019	39.0	105.0
BMI	25.2991	5.48553	2.86	41.42
Dose	4.523	0.5816	3.5	5.0
ED	2.9952	0.38513	2.32	3.31

Table 4.10 Group statistic for patients from thyroid scan:

	Gender	N	Mean	Std. Deviation	Std. Error Mean
Age	Female	78	41.641	17.3632	1.9660
	Male	30	45.433	19.2402	3.5128
Height	Female	78	161.282	10.0310	1.1358
	Male	30	166.267	11.0670	2.0205
Weight	Female	78	66.333	11.1024	1.2571
	Male	30	70.367	9.1179	1.6647
Dose	Female	78	4.481	0.5946	0.0673
	Male	30	4.633	0.5403	0.0986
Effective Dose	Female	78	2.9672	0.39373	0.04458
	Male	30	3.0682	0.35781	0.06533

Table 4.11 Correlation between Clinical Indication with Hospitals for thyroid scan:

Clinical Indication	Hospital					Total
	NMDC	Shandi Hospital	NCI	RICK	RCIH	
Obstruction	0	1	0	0	1	2
Fatigue	16	5	9	0	0	30
Joint Pain	12	15	12	3	13	55
CA	0	0	0	5	1	6
Goiter	0	0	0	15	0	15
Total	28	21	21	23	15	108

Table 4.12 Descriptive statistic for patients from bone scan:

	Mean	Std. Dev	Minimum	Maximum
Age	57.235	14.7509	9.0	97.0
Height	160.990	11.0780	130.0	183.0
Weight	67.373	12.4112	18.0	91.0
BMI	25.8945	4.88871	16.33	45.23
Dose	19.284	3.1162	5.0	26.0
ED	4.1132	.51170	3.17	5.49

Table 4.13 Group statistic for patients from bone scan:

	Gender	N	Mean	Std. Deviation	Std. Error Mean
Age	Female	60	52.767	13.9349	1.7990
	Male	42	63.619	13.6238	2.1022
Height	Female	60	157.583	10.2035	1.3173
	Male	42	165.857	10.5474	1.6275
Weight	Female	60	67.583	12.9632	1.6735
	Male	42	67.071	11.7253	1.8093
Dose	Female	60	18.783	2.7745	0.3582
	Male	42	20.000	3.4571	0.5334
Effective Dose	Female	60	4.0009	0.45292	0.05847
	Male	42	4.2737	0.55223	0.08521

Table 4.14 Correlation between Clinical Indication with Hospitals for bone scan:

`	Hospital					Total
	NMDC	Shandi Hospital	NCI	RICK	RCIH	
Fatigue	0	1	0	0	0	1
Joint Pain	4	3	0	2	0	9
CA	21	15	21	19	16	92
Total	25	19	21	21	16	102

Table 4.15 Analysis of variance between the effective dose with other variables from renal scan:

		Sum of Squares	df	Mean Square	F	p.value
Age	Between Groups	5474.387	10	547.439	2.237	0.021
	Within Groups	24718.176	101	244.734		
	Total	30192.563	111			
BMI	Between Groups	388.866	10	38.887	2.307	0.017
	Within Groups	1702.726	101	16.859		
	Total	2091.592	111			
Dose	Between Groups	123.824	10	12.382	316.37	0.000
	Within Groups	3.953	101	0.039		
	Total	127.777	111			

Table 4.16 Analysis of variance between the effective dose with other variables from thyroid scan:

		Sum of Squares	df	Mean Square	F	p.value
Age	Between Groups	343.498	3	114.499	0.351	0.788
	Within Groups	33917.418	104	326.129		
	Total	34260.917	107			
BMI	Between Groups	85.217	3	28.406	0.942	0.423
	Within Groups	3134.523	104	30.140		
	Total	3219.740	107			
Dose	Between Groups	36.192	3	12.064	0.000	0.000
	Within Groups	.000	104	.000		
	Total	36.192	107			

Table 4.17 Analysis of variance between the effective dose with other variables from renal scan:

		Sum of Squares	df	Mean Square	F	p.value
Age	Between Groups	3713.376	11	337.580	1.664	0.095
	Within Groups	18262.977	90	202.922		
	Total	21976.353	101			
BMI	Between Groups	376.217	11	34.202	1.511	0.141
	Within Groups	2037.636	90	22.640		
	Total	2413.853	101			
Dose	Between Groups	980.755	11	89.160	0.000	0.000
	Within Groups	0.000	90	0.000		
	Total	980.755	101			

Table 4.18 Comparison between the activity of present study with internationals studies:

Studies	Thyroid (Mci)	Renal (Mci)	Bone (Mci)
Present study 2021	4.52	5.17	19.28
Malaysia 2013	9.4	9.8	22.4
Greek 2011	10	15	25
Korea 2019	5.9	15	25
Japan 2015	9.9	10.8	25.6
UNSCEAR 2008	9.9	9.9	20

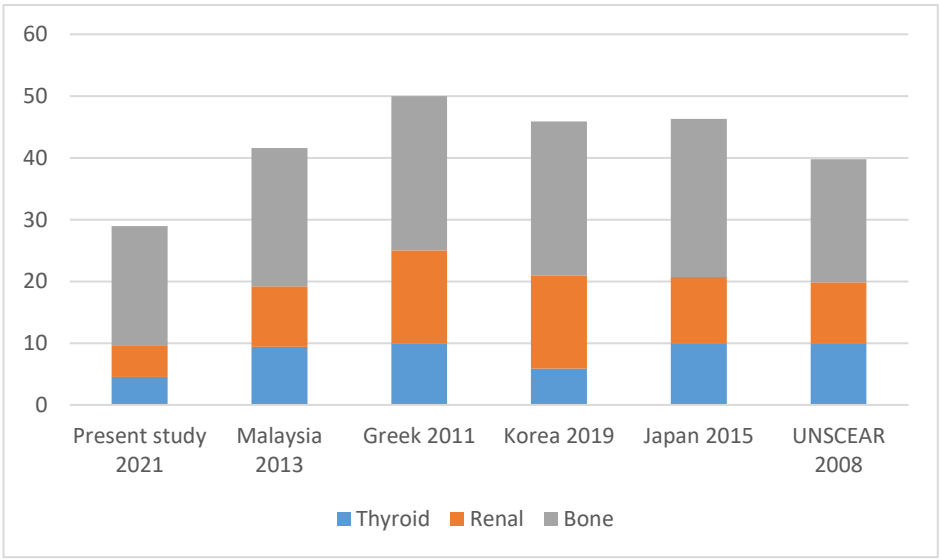


Figure 4.3 Comparison between the activity of present study with internationals studies

Table 4.19 Comparison between the effective doses of present study with internationals studies:

Studies	Thyroid(msv)	Renal(msv)	Bone(msv)
Present study 2021	4.52	1.9	5.91
Brazil 2016	5.33	9.8	22.4
Fred A. Mettler (IAEA)2008	4.8	1.8	6.3
USA 2006-2016	9.9	10.8	25.6
Malesia	7.62	1.9	3.91

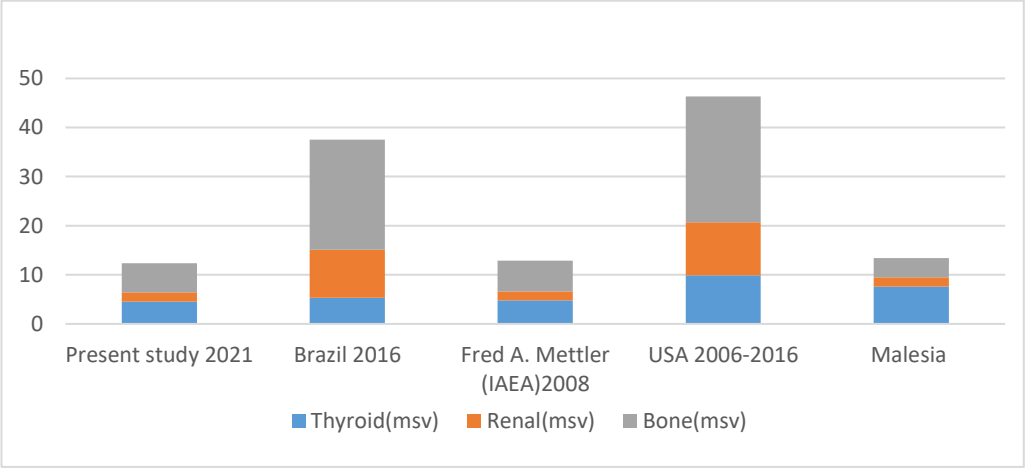


Figure 4.4 Comparison between the effective doses of present study with internationals studies.

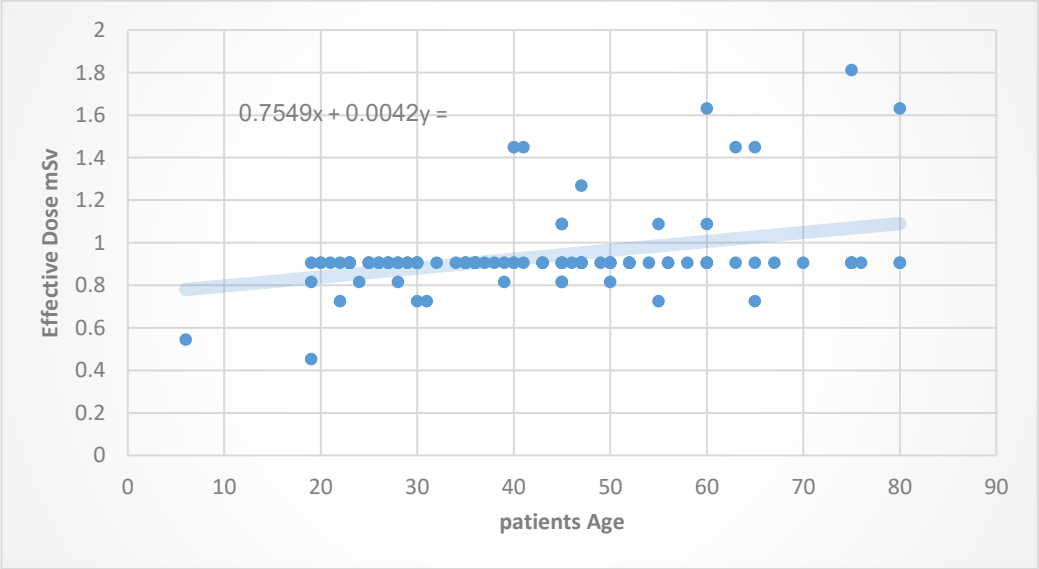


Figure 4.5 Correlation between the effective dose with patients age for renal scan.

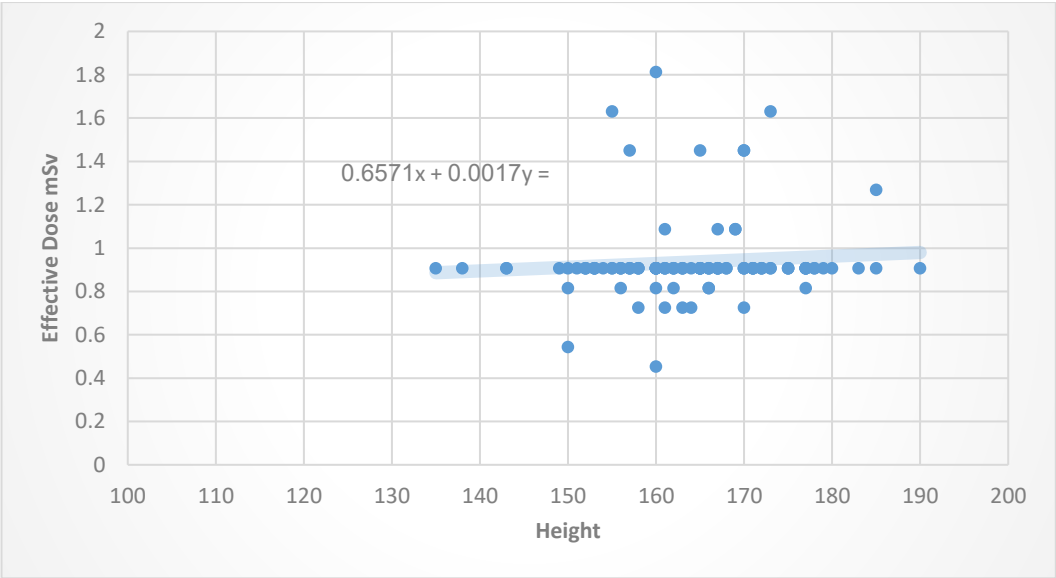


Figure 4.6 Correlation between the effective dose with patient's height for renal scan.

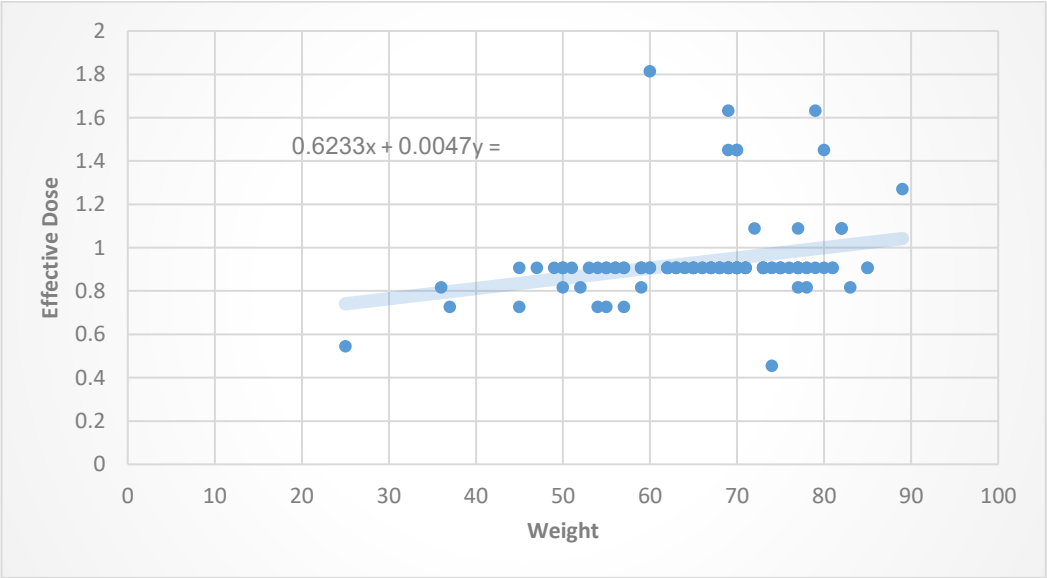


Figure 4.7 Correlation between the effective dose with patients weight for renal scan.

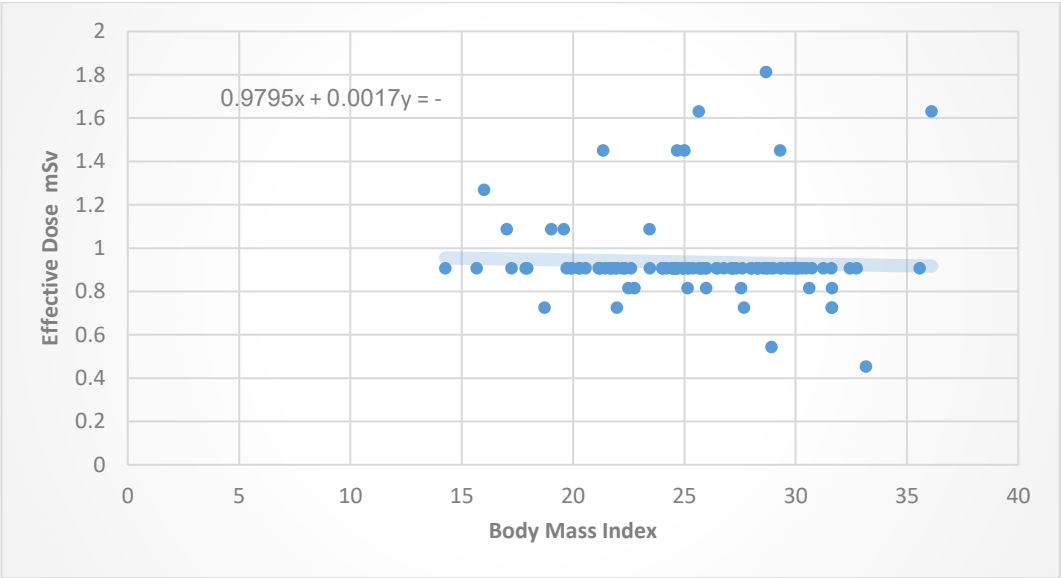


Figure 4.8 Correlation between the effective dose with patients body mass index for renal scan.

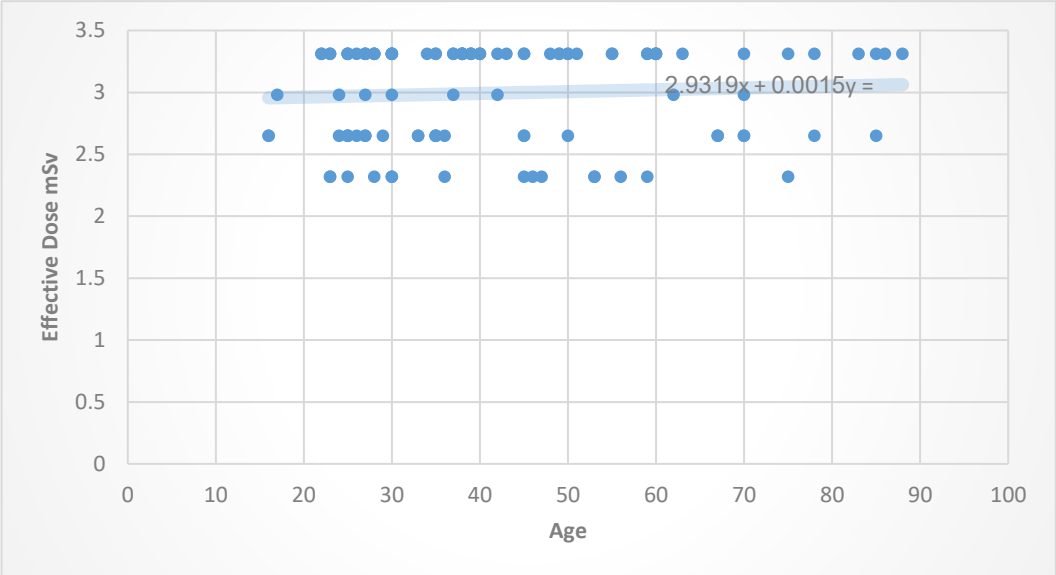


Figure 4.9 Correlation between the effective dose with patients age for thyroid scan.

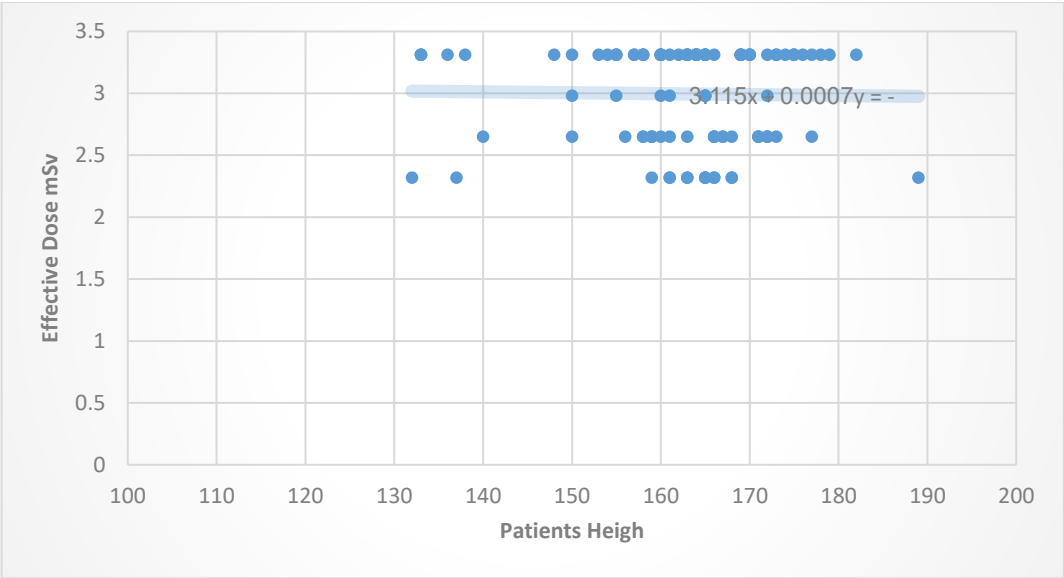


Figure 4.10 Correlation between the effective dose with patients' height for thyroid scan.

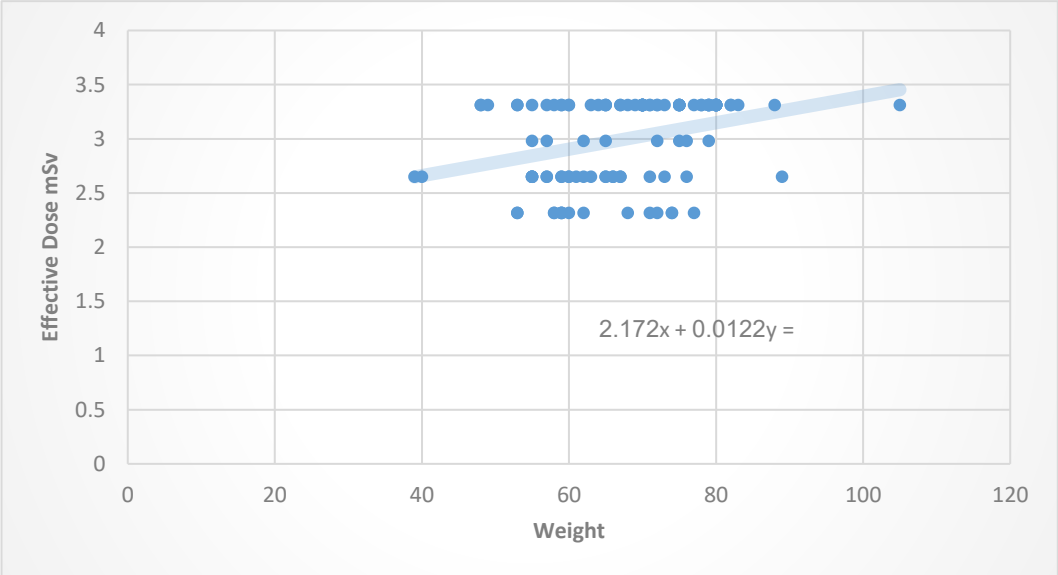


Figure 4.11 Correlation between the effective dose with patients' weight for thyroid scan.

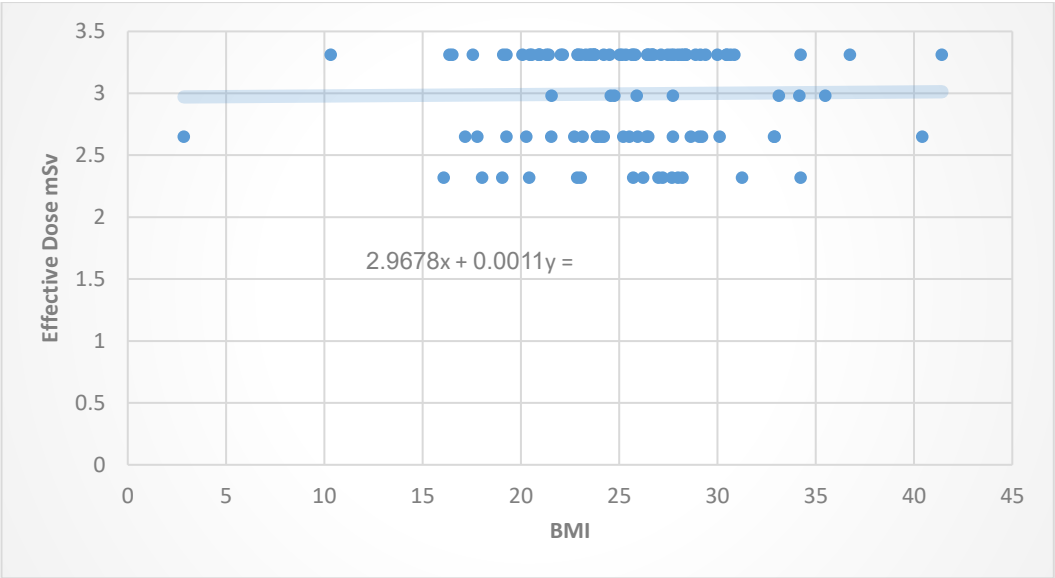


Figure 4.12 Correlation between the effective dose with patients' body mass index for thyroid scan.

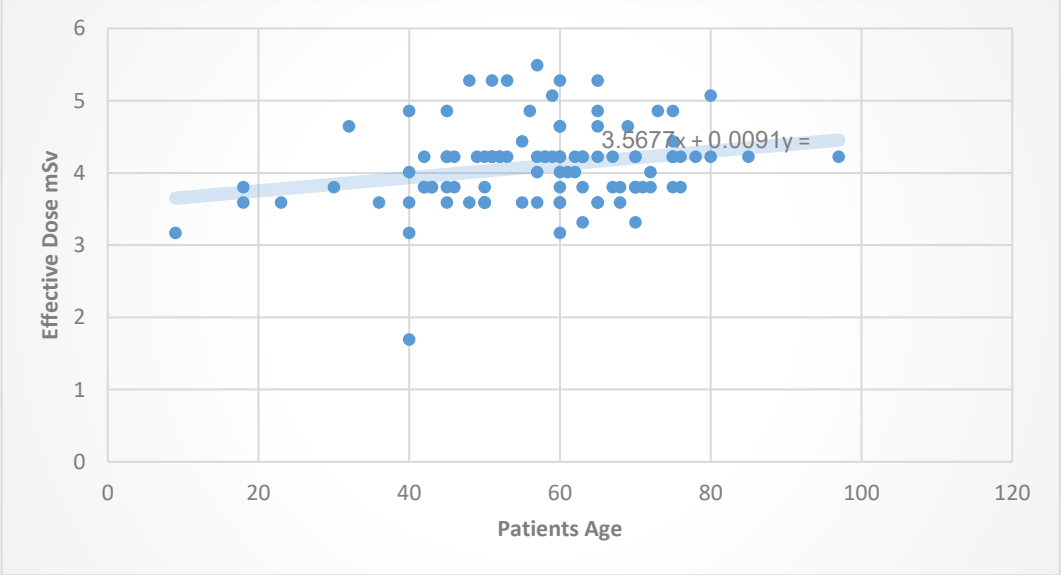


Figure 4.13 Correlation between the effective dose with patients age for bone scan.

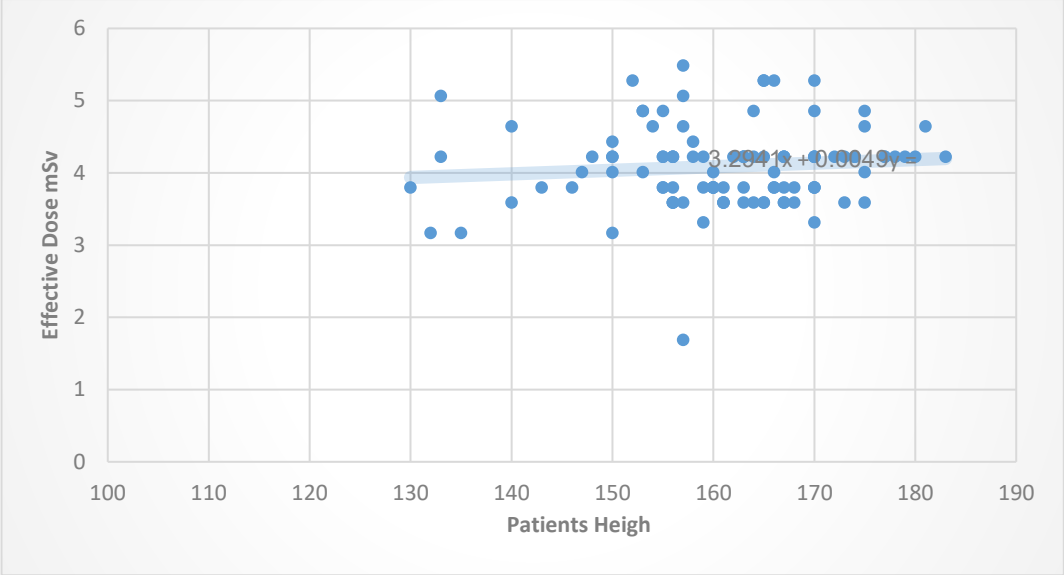


Figure 4.14 Correlation between the effective dose with patients' height for bone scan.

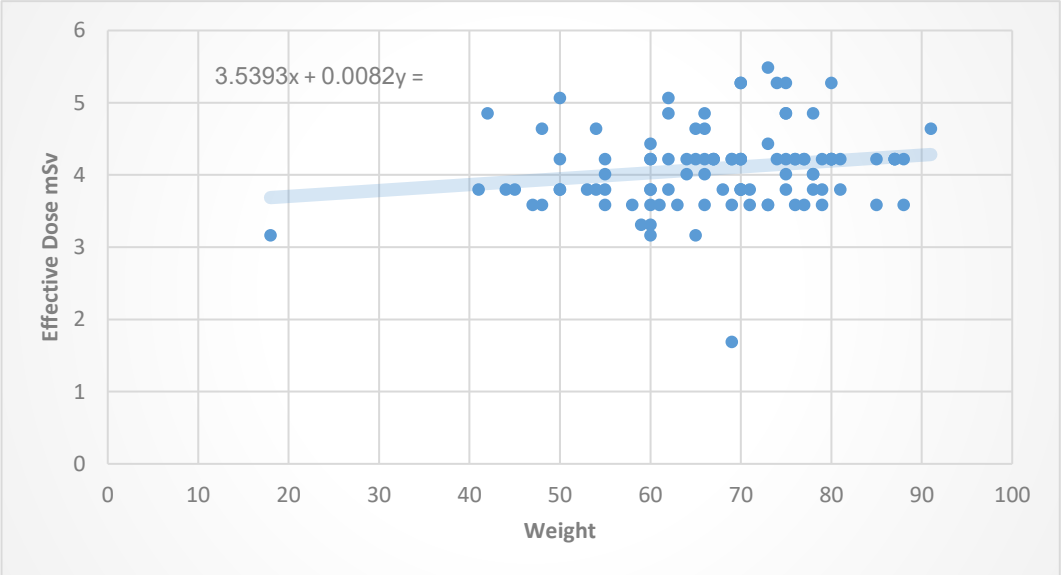


Figure 4.15 Correlation between the effective dose with patients' weight for bone scan.

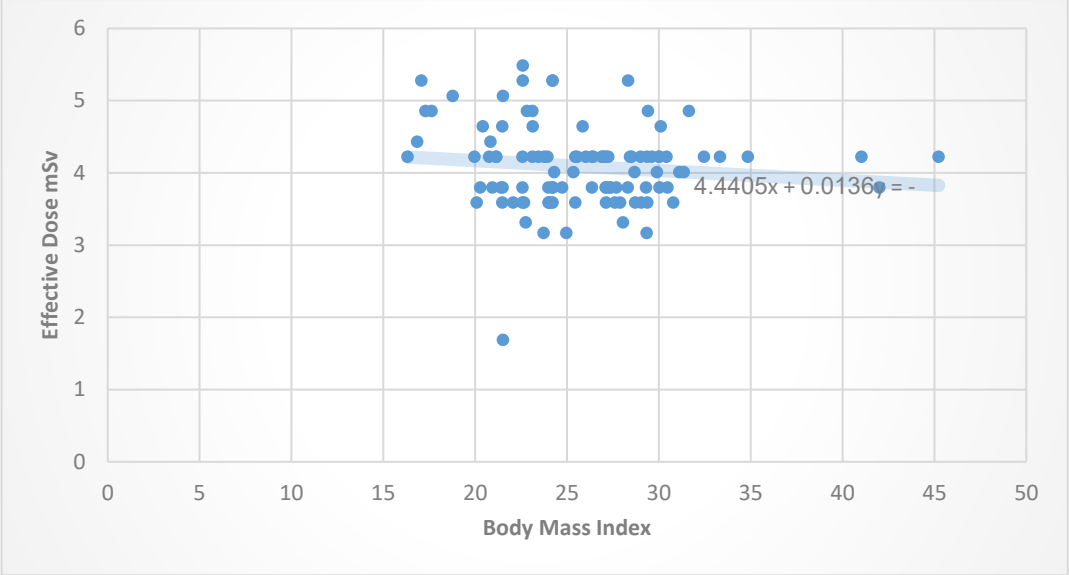


Figure 4.16 Correlation between the effective dose with patients' body mass index for bone scan.

Chapter Five

Discussion, Conclusion & Recommendation

5.1 Discussion:

The study was conducted at Radiation and Isotope Center in Sudan in the following hospital : Radiation and Isotope Center of Khartoum, Royal Care International Hospital, Al nilain Diagnostic Center, National Cancer Institute, Shandi Hospital, in period from Feb 2018- Aug 2021. The aim of this study to estimate of patient's dose for patients are referred to nuclear medicine departments for thyroid and kidneys and bone scan.

Table 4.1 Descriptive statistics for all patients during all scan were the data presented as mean, standard deviation, minimum, and maximum. For age, weight, height, BMI, dose and effective dose. Were the mean ± standard deviation for age was 47.43 ± 17.72 for height, weight and BMI was 162.22 ± 12.20, 66.98± 11.64 and 25.51 ± 4.91 respectively, for dose was 9.42 ± 6.98 and for ED was 2.63 ± 1.37.

Table 4.2 Frequency distribution for patients per exam were the patients that scanned for renal was 112 with percent 34.8% for thyroid scan was 108 with percent 33.5% and for bone scan was 102 with percent 31.7% as presented in Figure 4.1

Table 4.3 Gender frequency foe all patients were the number of female was183 is percent 56.8% and number of male was 139 is percent 43.2% as in shown in Figure 4.2

Table 4.4 Clinical indications distribution for all patients were the number of patients from obstructions was 19 with percent 5.9%, for urinary pain was 25 with percent 7.8%, for Renal Stone 47 with percent 14.6%, for Fatigue 31 with percent 9.6, for joint pain 64 with percent

19.9%, for CA 110 with percent 34.2%, for lion pain 11 with percent 3.4%, for goiter 15 with percent 4.7%.

Table 4.5 Frequency distribution for scan among all hospitals were the number of NMDC was 81 with percent 25.2%, from Shandi Hospital was 60 with percent 18.6%, from NCI 70 with percent 21.7%, from RICK 64 with percent 19.9%, from RCIH 47 with percent 14.6%.

Table 4.6 Descriptive Statistics for all patients during Renal Scan the total number of patients was 112, were the data presented as mean, standard deviation, minimum and maximum. For age the mean ± STD was 43.06 ± 16.49, for patient's height, weight and BMI was 162.93 ± 14.50, 66.18 ± 11.87 and 25.35 ± 4.34 respectively, for dose was 5.17 ± 1.07 and for ED was .9421 ±.19.

Table 4.7 Correlation between Clinical Indication with Hospitals for obstructions the number from NMDC was 2. Shandi hospital was 2, for NCI was 4, for RICK was 3 and for RCIH was 6. For Urinary Pain was for NMDC was 3, for Shandi hospital was 5, for NCI was 4, for RICK was 5, and for RCIH was 8. For Renal Stone was for NMDC was 17, for Shandi hospital was 12, for NCI was 10, for RICK was 8, and for RCIH was 0. For CA was for NMDC was 6, for Shandi hospital was 1, for NCI was 0, for RICK was 3, and for RCIH was 2. For Lion Pain Was for NMDC was 0, for Shandi hospital was 0, for NCI was 10, for RICK was 1, and for RCIH was 0.

Table 4.8 Group statistics for patients during renal scan, for patients age the mean ± standard deviation for female was 41.09 ± 15.09 and for male was 44.39 ± 17.36, for patient's height female was 156.33± 18.21 and for male 167.36 ± 9.12, for weight the female 63.96 ± 13.16 and for male 67.67 ± 10.76, for patient's dose female was 5.08 ± 0.78 and for male 5.23 ± 1.24. for ED female was 0.93 +0.17 and for male was 0.96 ±

0.22. Compared with (Vogiatzi et al 2011) activity for renal was lowest as well as the dose was the activity in our study was 5.17mci, while with (Vogiatzi et al 2011) was 15mci, and for the ED in our study was 0.94msv while with (Mettler *et al.*, 2008) was 1.8msv .

Table 4.9 Descriptive statistics for all patients during thyroid Scan the total number of patients was 108, were the data presented as mean, standard deviation, minimum and maximum. For age the mean ± STD was 42.69 ± 17.89, for patient's height, weight and BMI was 162.66 ± 10.52, 67.45 ± 1070 and 25.29 ± 5.49 respectively, for dose was 4.52 ± 0.58, and for ED was 2.99 ± 0.38.Compared with (Song et al., 2019) activity for thyroid was lowest as well as the dose was the activity in our study was 4.52mci, while with (Song *et al.*, 2019) was 5.9mci, and for the ED in our study was 2.9msv while with(Mettler et al., 2008)was 4.8msv .

Table 4.10 Group statistics for patients during thyroid scan, for patients age the mean ± standard deviation for female was 41.64 ± 17.36 and for male was 45.43 ± 19.24, for patient's height female was 161.28 ± 10.03 and for male 166.26 ± 11.07, for weight the female was 66.33 ± 11.10 and for male 70.37 ± 9.12, for patient's dose female was 4.48 ± 0.59 and for male 4.63 ± 0.54, for ED female was 2.96 ±.39 and for male 3.06 ± .35.

Table 4.11 Correlation between Clinical Indication with Hospitals for thyroid scan for obstructions the number from NMDC was 0,for shandi hospital was 1, for NCI was 0,for RICK was 1 and for RCIH was 2. For fatigue was for NMDC was 16, for shandi hospital was 5, for NCI was 9, for RICK was 0, and for RCIH was 0. For joint pain was for NMDC was 12, for shandi hospital was 15, for NCI was 12, for RICK was 3, and for RCIH was 15. For CA was for NMDC was 0, for shandi hospital was 0, for NCI was 0, for RICK was 5, and for RCIH was 1. For Goiter Was for

NMDC was 0, for shandi hospital was 0, for NCI was 0, for RICK was 15, and for RCIH was 0.

Table 4.12 Descriptive statistic for patients from bone scan the total number of patients was 102, were the data presented as mean, standard deviation, minimum and maximum. For age the mean ± STD was 57.32 ± 14.48, for patient's height, weight and BMI was 160.99 ± 11.08, 67.37 ± 12.41 and 25.89 ± 4.88 respectively, for patients' dose was 19.28 ± 3.12, for ED was 4.11 ± 0.51.

Table 4.13 Group statistic for patients from bone scan for patients age the mean ± standard deviation for female was 52.77 ± 13.93 and for male was 63.62 ± 13.62, for patient's height the female was 157.58 ± 10.20 and for male 165.86 ± 10.55, for weight the female 67.58 ± 12.96 and for male 67.07 ± 11.72, for patient's dose female was 18.78 ± 2.77 and for male 20 ± 3.46, for ED female was 4.1 ± .45 and for male 4.3 ± .55. Compared with (Song *et al.*, 2019) activity for bone scan was lowest as well as the dose was the activity in our study was 19.28mci, while with (Vogiatzi et al 2011) was 25mci, and for the ED in our study was 4.1msv while with(J *et al.*, 2016) was 5.91 ± 1.08msv .

Table 4.14 Correlation between Clinical Indication with Hospitals for bone scan for fatigue was for NMDC was 0, for shandi hospital was 1, for NCI was 0, for RICK was 0, and for RCIH was 0. For joint pain was for NMDC was 4, for shandi hospital was 3, for NCI was 0, for RICK was 2, and for RCIH was 0. For CA was for NMDC was 21, for shandi hospital was 15, for NCI was 21, for RICK was 19, and for RCIH was 16.

Table 4.15 Analysis of variance between the effective dose with other variables from renal scan were the p value showed significant Difference between the dose from renal scan with patients age, BMI and dose were the p value was 0.021, 0.0217 and 0.000.

Table 4.16 Analysis of variance between the effective dose with other variables from thyroid scan were the p value showed there is no significant difference between the patients age, BMI and dose were the p value was 0.788, 0.423 and 0.000.

Table 4.17 Analysis of variance between the effective dose with other variables from bone scan were the p value showed there is no significant difference between the patients age, BMI and dose were the p value was 0.095, 0.141 and 0.000.

Table 4.18 Comparison between the activity of present study with internationals studies our study comparing between the present study with international studies worldwide, were the present study show the lowest value of dose form all others studies for all examination's thyroid, bone and renal scan.

Table 4.19 Comparison between the effective doses of present study with internationals studies our study comparing between the present study with international studies worldwide, were the present study show the lowest value of effective dose form all others studies for all examination's thyroid, bone and renal scan.

Figure 4.4 Comparison between the effective doses of present study with internationals studies our study comparing between the present study with international studies worldwide, were the present study show the lowest value of effective dose form all others studies for all examination's thyroid, bone and renal scan.

Figure 4.5 Correlation between the effective dose with patients age for renal scan were the change of effective dose increase by rate of 0.0042 for each year of the patients.

Figure 4.6 Correlation between the effective dose with patient's height foe renal scan were the change of effective dose increase by rate of 0.0017 for each cm of the patients.

Figure 4.7 Correlation between the effective dose with patients' weight for renal scan were the change of effective dose increase by rate of 0.0047 for each kg of the patients.

Figure 4.8 Correlation between the effective dose with patient's body mass index for renal scan were the change of effective dose decrease by rate of 0.0017 for each kg\cm^2 of the patients.

Figure 4.9 Correlation between the effective dose with patients age for thyroid scan were the change of effective dose increase by rate of 0.0015 for each year of the patients.

Figure 4.10 Correlation between the effective dose with patients height for thyroid scan were the change of effective dose increase by rate of 0.0007 for each cm of the patients.

Figure 4.11 Correlation between the effective dose with patients weight for thyroid scan were the change of effective dose increase by rate of 0.0122 for each kg of the patients.

Figure 4.12 Correlation between the effective dose with patients body mass index for thyroid were the change of effective dose increase by rate of 0.0011 for each kg\cm^2 of the patients.

Figure 4.13 Correlation between the effective dose with patients age for bone scan were the change of effective dose increase by rate of 0.0091 for each year of the patients.

Figure 4.14 Correlation between the effective dose with patients height for bone scan were the change of effective dose increase by rate of 0.0049 for each cm of the patients.

Figure 4.15 Correlation between the effective dose with patients weight for bone scan were the change of effective dose increase by rate of 0.0082 for each kg of the patients.

Figure 4.16 Correlation between the effective dose with patients body mass index for bone scan were the change of effective dose decrease by rate of 0.0136 for kg\cm^2 of the patients.

The estimation of patient's dose using linear regression equation presented for all scan as shown below:

For renal:

- Effective Dose = 0.0042(age) + 0.7549
- Effective Dose = 0.0017(height) + 0.6571
- Effective Dose = 0.0047(weight) + 0.6233
- Effective Dose = -0.0017(BMI) + 0.9795

For thyroid:

- Effective Dose = 0.0015(age) + 0.9319
- Effective Dose = 0.0007(height) + 3.115
- Effective Dose = 0.0122(weight) + 2.172
- Effective Dose = 0.0011(BMI) + 2.9678

For bone:

- Effective Dose = 0.0091(age) + 3.5677
- Effective Dose = 0.0049(height) + 3.2941
- Effective Dose = 0.0082(weight) + 3.2941
- Effective Dose = -0.0136(BMI) + 4.4405

5.2 Conclusion:

The aim of this study to estimate of patient's dose for patients are referred to nuclear medicine departments for thyroid and kidneys and bone scan. The number of patients was 322 patients.

Correlation between the effective dose with patients' height for thyroid scan were the change of effective dose increase by rate of 0.0007 for each cm of the patients also, the effective dose with patients' weight for thyroid scan were the change of effective dose increase by rate of 0.0122 for each kg of the patients, correlate between the effective dose with patients' body mass index for thyroid were the change of effective dose increase by rate of 0.0011 for each kg\cm^2 of the patients.

Correlation between the effective dose with patients age for bone scan were the change of effective dose increase by rate of 0.0091 for each year of the patients, correlate between the effective dose with patients height for bone scan were the change of effective dose increase by rate of 0.0049 for each cm of the patients and the effective dose with patients weight for bone scan were the change of effective dose increase by rate of 0.0082 for each kg of the patients, correlate between the effective dose with patients body mass index for bone scan were the change of effective dose decrease by rate of 0.0136 for kg\cm^2 of the patients.

Comparing between the present study with international studies worldwide, were the present study show the lowest value of dose and effective dose form all other studies for all examination's thyroid, bone and renal scan.

5.3 Recommendations:

- The quality control of the devices must be taken to make the studies more accurate
- The studies should cover all nuclear medicine examinations so that the study is a true diagnostic reference level of nuclear medicine activitys in Sudan
- Increase number of patients to get more accurate result.
- Involve more scans will be better when compare it with other studies.

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