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Reassessment of Effective Doses for Selected Diagnostic Nuclear Medicine Procedures Using ICRP-Based Models and RADAR-2017

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ABSTRACT

This study presents a standardized reassessment of age-dependent effective doses for commonly performed diagnostic nuclear medicine procedures using the current International Commission on Radiological Protection (ICRP) dosimetric framework. Unlike previous investigations that focused on individual radiopharmaceuticals, this work applies a unified methodology to multiple commonly used diagnostic agents, enabling consistent comparisons across adult and pediatric reference phantoms. Effective doses were calculated for ^{99m}Tc-sulfur colloid (liver and spleen imaging), ^{18}F-FDG (whole-body positron emission tomography), ^{99m}Tc-MIBI (myocardial perfusion imaging), and ^{131}I-MIBG (neuroendocrine tumor imaging) using biokinetic models and dose coefficients from ICRP Publications 103, 106, and 128 implemented in the SNMMI Nuclear Medicine Radiation Dose Tool (RADAR-2017). Pediatric-administered activities were estimated by linear body-weight scaling based on ORNL/ICRP reference phantoms.

Adult effective doses were 2.1 mSv for ^{99m}Tc-sulfur colloid, 4.8 mSv for ^{18}F-FDG, 5.8–6.0 mSv for ^{99m}Tc-MIBI myocardial perfusion imaging, and 7.0 mSv for ^{131}I-MIBG. Although pediatric-administered activities were substantially reduced, children exhibited higher effective doses per unit of administered activity due to age-dependent anatomical characteristics, reduced photon attenuation, and increased tissue radiosensitivity. These findings highlight the importance of age-specific dosimetric assessment and standardized activity selection in diagnostic nuclear medicine. While the present study does not evaluate image quality or clinical performance, it provides a robust dosimetric framework that may support protocol optimization, benchmarking against contemporary reference values, radiation protection practices, and future development of patient-specific imaging protocols. Effective dose is presented as a radiation protection quantity for comparing procedures and for supporting optimization strategies, rather than for estimating individual patient risk.

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Introduction

In the field of nuclear medicine, radiation is utilized for diagnostic and therapeutic applications. Because ionizing radiation can cause biological effects, ensuring safety through comprehensive radiation protection programs is critical. International radiation protection guidance issued by the IAEA and ICRP classifies radiation exposure in nuclear medicine into three principal categories: medical exposure, occupational exposure, and public exposure. Each type requires distinct safety measures and regulatory control to ensure compliance with international standards.

Medical exposure involves the deliberate application of ionizing radiation to patients for diagnostic imaging, therapeutic procedures, or biomedical research activities. For example, patients may receive ^{99m}Tc-MDP for bone imaging or ^{131}I for thyroid ablation. Both the IAEA and ICRP highlight the importance of justification, whereby each procedure must provide a clinical benefit that exceeds the associated radiation risk (ICRP, 2007).

Occupational exposure refers to radiation doses incurred by workers because of their professional activities, including nuclear medicine technologists, radio pharmacists, and physicians. Such personnel are subject to continuous monitoring and protection through optimization strategies based on the ALARA (As Low as Reasonably Achievable) concept. ICRP Publication 103(ICRP, 2007) defines an occupational effective dose limit of 20 mSv per year, averaged over five years, with a maximum of 50 mSv permitted in any single year. Safety measures include personal dosimetry, use of shielding, and minimizing time near sources.

Public exposure includes radiation doses received by individuals who are neither occupationally exposed nor undergoing medical procedures, such as visitors or members of the public. Regulatory frameworks impose strict limits on public exposure, restricting the annual effective dose to a maximum of 1 mSv. Control measures include waste management, shielding design, and restricting access to radiation-controlled areas.

The IAEA in 1999 emphasized the importance of comprehensive radiation protection programs in nuclear medicine facilities to ensure safety across all exposure types. Such programs are founded on the three fundamental radiation protection principles: justification, optimization, and dose limitation. They also ensure adherence to local and international safety standards through measures such as facility shielding, worker training, quality assurance, and incident reporting. Implementing such programs promotes both patient safety and occupational and public health. In modern nuclear medicine, radiopharmaceuticals play a vital role in diagnosing and treating many diseases. To use these materials safely and effectively, strong radiation protection programs must be established based on the core principles of justification, optimization, and dose limitation. These measures are crucial to maximize the benefits of nuclear medicine while reducing radiation risks to patients, healthcare workers, and the public.

Diagnostic nuclear medicine procedures involve the administration of radiopharmaceuticals that deposit ionizing radiation energy in patient organs. These internal exposures contribute to stochastic risk and are quantified using the effective dose (E), which represents the weighted sum of equivalent doses to individual organs based on tissue radiosensitivity (Alnaaimi *et al*., 2022). ICRP recommends using E to compare and optimize medical exposures. Patient radiation dose depends on administered activity, isotope physical half-life, and biokinetics in the body. International guidance emphasizes justification of each imaging study and optimization of activity (ALARA) (Alnaaimi *et al*., 2022). Recent compendia (ICRP 128, 2015) provide updated dose coefficients for diagnostic radiopharmaceuticals (Cherry *et al*., 2012).

In clinical practice, administered activities are adjusted according to patient age and body size, with pediatric protocols commonly scaling activity by body weight or body surface area. Reference values exist for typical adult and pediatric administered activities. However, it is important to verify that these protocols yield effective doses consistent with expectations.

Commonly used radiopharmaceuticals such as Technetium-99m (^{99m}Tc), Iodine-131 (^{131}I), and Fluorine-18 (^{18}F-FDG) exhibit relatively short physical half-lives (6 hours, 8 days, and 110 minutes, respectively). Each radiopharmaceutical has specific diagnostic and therapeutic applications: ^{99m}Tc-sulfur colloid is employed for liver, spleen, and bone marrow imaging; ^{99m}Tc-MIBI is used in cardiac, neuroendocrine tumors, and breast imaging; ^{131}I is applied in the treatment of thyroid-related disorders and certain cancers; and ^{131}I-MIBG serves as a targeted radiotherapy agent for neuroendocrine tumors. Additionally, ^{18}F-FDG PET offers essential insights into tumor metabolism, complementing traditional methods. Diagnostic benchmarks have been set for various cancer-related uses (Elhaie *et al*., 2024). Although technical improvements continue, ^{18}F-FDG PET increasingly integrates into multimodal cancer diagnosis protocols as recommended by guidelines.

Several studies, including those by Cherry *et al*. (2012); Ali *et al*. (2021) and Shin *et al*. (2025), have focused on dose assessment methodologies, age-specific biokinetics, and occupational exposures during diagnostic and therapeutic procedures. These investigations highlight the ongoing need to refine dosimetric techniques and enhance the accuracy of radiation dose estimation for both patients and medical personnel.

This study recalculates age-dependent and comparison

with published reference values of effective doses for representative nuclear medicine diagnostic procedures using updated ICRP-103/106/128-based dosimetric methodology integrated within RADAR-2017 simulations. Effective doses were estimated for adult and pediatric reference phantoms for four commonly used radiopharmaceuticals: ^{99m}Tc-sulfur colloid, ^{18}F-FDG, ^{99m}Tc-MIBI, and ^{131}I-MIBG. The objectives were to quantify age-related dose variations, compare recalculated values with published benchmarks, and evaluate optimization strategies for improving radiation protection and dose management in routine clinical nuclear medicine practice.

Unlike previous studies that typically evaluate individual radiopharmaceuticals or specific imaging procedures, the present work provides a unified reassessment of effective doses across multiple diagnostic nuclear medicine examinations using current ICRP-based dosimetric methodology. By combining standardized phantom calculations, contemporary biokinetic models, systematic benchmarking against published reference values, and age-dependent comparisons, the study offers an updated dosimetric framework that supports radiation protection assessments, protocol benchmarking, and future development of patient-specific optimization strategies.

Material and Method

This study was designed as a computational dosimetric reassessment of effective doses associated with commonly performed diagnostic nuclear medicine procedures. No patient-specific imaging data or clinical measurements were collected. Instead, effective doses were calculated using standardized anthropomorphic reference phantoms, published biokinetic models, and internationally recommended dose coefficients. The objective was to provide a consistent comparison of age-dependent effective doses across multiple diagnostic radiopharmaceuticals using a unified dosimetric methodology based on current International Commission on Radiological Protection (ICRP) recommendations.

Radiopharmaceuticals and Administration

Four commonly used diagnostic radiopharmaceuticals were included in this study: ^{99m}Tc-sulfur colloid for liver and spleen imaging, ^{18}F-FDG for whole-body PET imaging, ^{99m}Tc-MIBI for myocardial perfusion imaging (rest and stress), and ^{131}I-MIBG for neuroendocrine tumor imaging. Representative adult administered activities were selected from internationally recognized dosimetric references, including ICRP Publication 128, the SNMMI Nuclear Medicine Radiation Dose Tool (RADAR-2017), and standard nuclear medicine literature. These values were chosen to represent typical clinical practice and to enable standardized comparisons rather than to reproduce local institutional protocols or Diagnostic Reference Levels (DRLs).

In this study, we considered the following common diagnostic tracers and protocols:

Technetium-99m (^{99m}Tc) sulfur colloid (liver–spleen scan, intravenous injection); typical adult activity ~185 MBq.

Fluorine-18 (^{18}F-FDG) (whole-body PET scan, intravenous); adult male (73.7 kg) activity ~250 MBq.

(^{99m}Tc-MIBI) (myocardial perfusion, intravenous): rest and stress phases (each ~740 MBq in adult).

^{131}I-MIBG (neuroendocrine tumor imaging, intravenous); adult activity ~44 MBq.

These activities were based on standard adult protocols. Pediatric activities were scaled linearly by body weight (Han *et al*., 2006).

Pediatric Administered Activity Scaling

Pediatric administered activities were estimated using linear body weight scaling according to

$$A_{child} = A_{adult} \times \frac{W_{child}}{W_{adult}}$$

where A_{child} is the administered activity for the pediatric reference phantom, A_{adult} is the corresponding adult activity, and W, represents body weight.

This simplified scaling approach was chosen to ensure consistency with the standardized ICRP reference phantom methodology used throughout the study. It also aims to facilitate direct age-dependent dosimetric comparisons. The authors acknowledge that current clinical practices increasingly align with the European Association of Nuclear Medicine (EANM) Dosage Card and the North American Consensus Guidelines (Gelfand *et al*., 2011 and Fahey *et al*., 2016) both of which utilize nonlinear scaling methods, procedure-specific correction factors, and minimum administered activities. Therefore, the scaling approach presented here should be viewed as a standardized computational method rather than a recommendation for prescribing clinical pediatric dosages.

***Dose Coefficients and Biokinetics*:**

Age-specific effective dose coefficients and radionuclide biokinetic data were obtained from ICRP Publications 106 and 128 (ICRP, 2008 and ICRP, 2015) and implemented using the SNMMI Nuclear Medicine Radiation Dose Tool (RADAR-2017). The calculations incorporated radionuclide-specific organ uptake, biological clearance, and physical decay characteristics described in the corresponding ICRP biokinetic models. Effective doses were calculated using ICRP Publication 103 tissue-weighting factors to ensure consistency throughout the study (Hussin *et al*., 2017).

Dose Coefficients and Effective Dose Calculation:

Effective dose calculations were performed using the SNMMI Nuclear Medicine Radiation Dose Tool (RADAR-2017, Version 2.2). For each radiopharmaceutical and age-specific reference phantom, the corresponding effective dose coefficients (mSv MBq^{-1}) were selected from the datasets implemented within RADAR-2017. These coefficients are based on the age-dependent biokinetic models and dosimetric methodology described in ICRP Publications 106 and 128, with effective doses calculated using the tissue-weighting factors recommended in ICRP Publication 103. The selected datasets incorporate radionuclide-specific organ uptake, biological clearance, physical decay characteristics, and age-dependent anatomical reference phantoms adopted by the ICRP.

Effective dose was calculated according to:

$$E(mSv) = A(MBq) \times DC(mSv/MBq) \quad (1)$$

Where E is the effective dose in mSv, and A is the administered activity in MBq, and DC is the ICRP Dose Coefficient in mSv/MBq obtained from the RADAR-2017 database. The same dosimetric framework and dose coefficient datasets were consistently applied to all radiopharmaceuticals to ensure methodological uniformity and facilitate direct comparisons across age groups and imaging procedures.

This study focused solely on evaluating the effective dose. Organ-specific absorbed doses were not calculated because the goal was to provide a standardized comparison of effective doses across representative diagnostic nuclear medicine procedures rather than to assess patient-specific internal dosimetry. Therefore, the calculated effective doses should be interpreted as radiation protection quantities for comparing imaging procedures and supporting protocol benchmarking, rather than as estimates of individual patient risk.

Reference Patient Models:

Calculations were performed using standardized adult and pediatric anthropomorphic reference phantoms developed by ORNL and subsequently adopted within the ICRP dosimetric framework. The reference adult male body mass was 73.7 kg, while pediatric reference body masses were 56.8 kg (15 years), 33.2 kg (10 years), 19.8 kg (5 years), and 9.7 kg (1 year) (Bailey et al., 2014). These reference phantoms represent average anatomical characteristics and were used solely for standardized dosimetric calculations rather than individualized patient assessment.

The methodology was based on standardized reference phantoms and published biokinetic models and therefore does not account for patient-specific anatomy, organ function, disease-related tracer kinetics, or imaging system characteristics. Consequently, the calculated effective doses should be interpreted as reference values suitable for comparative radiation protection assessments rather than individualized effective dose estimates.

Results and Discussion

The effective dose has been calculated based on the administered activity per body weight for various age groups: adults (73.7 kg), 15-year-olds (56.8 kg), 10-year-olds (33.2 kg), 5-year-olds (19.8 kg), and infants (1 year, 9.7 kg) (Han *et al.*, 2006). Equation (2) describes pediatric activity scaling based on linear body-mass proportionality, whereby the administered activity for a child is calculated as the product of the standard adult activity and the ratio of child-to-adult body weight. This approach assumes approximate proportionality between patient mass and radiopharmaceutical distribution volume and is widely used for practical optimization of pediatric administered activities. Although this method reduces injected activity in smaller patients, the resulting effective dose does not decrease proportionally because pediatric dose coefficients are generally higher due to smaller organ size, reduced photon attenuation, and increased tissue radiosensitivity (Verganelakis and Lyra-Georgosopoulou, 2022; Fahey et al., 2017).

$$Administered\ Activity_{child}(MBq) = \frac{Adult\ Activity\ (MBq) \times Child\ Weight(Kg)}{70} \quad (2)$$

^{99m}Tc-sulfur colloid (liver–spleen scan): The effective dose from intravenous injection administration of ^{99m}Tc sulfur colloid to varies age group patients shown in Table (1). The effective doses from ^{99m}Tc-sulfur colloid decrease from 2.1 mSv in adults to 1.1 mSv in 1-year-old patients due to reduced administered activity. RADAR-2017 estimates agree closely with ICRP-128 reference values, confirming methodological validity. Despite lower absolute doses in children, dose per MBq remains higher due to smaller body mass.

^{18}F-FDG PET scan: The effective dose resulting from the intravenous administration of ^{18}F-FDG was assessed across various patients age groups (Table 2). Adult effective dose was 4.8 mSv, while pediatric doses reached up to 4.5 mSv despite lower administered activity. For pediatric patients, the administered activity was reduced proportionally according to body-weight scaling, decreasing from 203 MBq in 15-year-olds to 71 MBq in 5-year-olds. Despite this substantial reduction in injected activity, the effective dose decreased only modestly, from 4.5 mSv in 15-year-olds to 3.4 mSv in 5-year-olds. This relatively limited reduction indicates that decreasing administered activity does not produce a directly proportional reduction in radiation burden. Pediatric patients exhibit higher absorbed fractions because of smaller organ dimensions, shorter photon path lengths, and reduced self-attenuation, which increase energy deposition in radiosensitive tissues. Age-dependent anatomical scaling and biokinetic differences incorporated into ICRP pediatric phantoms collectively increase absorbed dose per unit administered activity (ICRP, 2015; Fahey *et al.*, 2017; Hussin *et al.*, 2017). Results are consistent with published literature (Cherry *et al.*, 2012; Hussin, *et al.*, 2017) and emphasize pediatric dose optimization.

Table 1. The RADAR estimated effective dose due to intravenous injection administration of ^{99m}Tc sulfur colloid to various age groups.

Age	Average Activity MBq	Estimated effective dose, RADAR-2017	Published dose, ICRP-128, (ICRP, 2015)
		mSv	mSv
Adult	185	2.1	2.6
15 yrs.	150	1.9	2.7
10 yrs.	88	1.6	2.5
5 yrs.	52	1.3	2.1
1 yr.	26	1.1	1.9

- *Route of Intake: Intravenous.*
- *Radiopharmaceuticals: ^{99m}Tc sulfur collide.*
- *Scan type: (liver- spleen scan).*

Table 2. *The estimated effective dose due to intravenous injection of ^{18}F-FDG to patients calculated for adults, 15, 10, and 5, respectively*.

Age	Activity MBq	Estimated effective dose, RADAR-2017	Author
		mSv	
Adult	250	4.8	5.8 (Cherry *et al*., 2012)
15 yrs.	203	4.5	5.78 (Hussin *et al*., 2017)
10 yrs.	119	3.8	6.59 (Hussin *et al*., 2017)
5 yrs.	71	3.4	6.37 (Hussin et al., 2017)

- *Route of Intake: Intravenous.*
- *Radiopharmaceuticals: ^{18}F-FDG.*
- *Scan type: (Total body scan).*

^{99m}Tc-MIBI (myocardial perfusion): The effective dose from the intravenous injection of ^{99m}Tc-MIBI (myocardial perfusion) was calculated for various age groups using the ICRP-128 biokinetic models, as shown in **Table 3**. For adult patients, the calculated effective doses were 5.8 mSv for resting studies and 6.0 mSv for stress studies, consistent with published diagnostic reference values (ICRP, 2015; Alnaaimi *et al*., 2022) and confirming the reliability of the RADAR- 2017 implementation.

In pediatric patients, the effective dose generally decreases with lower administered activity, and this decrease is proportional to body mass. However, this does not imply a lower radiation burden per unit of administered activity. In fact, pediatric patients exhibit higher dose coefficients than adults when normalized (mSv/MBq) due to smaller anatomical structures and reduced photon attenuation.

This is especially true for younger children, were smaller organ masses result in greater local energy deposition from emitted photons. Children's physiological characteristics can also lead to prolonged tracer retention in critical organs, thereby increasing the absorbed dose per unit of administered activity. Thus, despite lower administered activity, children' s effective dose efficiency is higher. A 1-year-old phantom received an effective dose of 3.2 mSv during myocardial imaging, using only about 13% of the activity typically administered to adults. This example illustrates that reducing the administered activity does not lead to a proportional decrease in the effective dose. A similar trend was observed during stress imaging, emphasizing the need for stringent weight-based protocol optimization in pediatric cases to maintain diagnostic quality while minimizing radiation exposure.

The consistency of these findings with ICRP 128 reference data reinforces the validity of using standardized phantom models for age- dependent dosimetry. This underscores the necessity for individualized pediatric activity scaling rather than simple proportional reductions from adult protocols, aligning with current radiation protection principles.

Table 3. ***The effective dose from the intravenous injection of ^{99m}Tc-MIBI (myocardial perfusion) was calculated for various age groups using the ICRP-128 biokinetic models.***

Myocardial resting			
Age	**Activity MBq**	**Estimated dose, mSv. RADAR-2017**	**Published estimated dose, mSv.**
Adult	740	5.8	7.4, (Alnaaimi *et al*., 2022)
15 yrs.	600	6.5	6.7, (ICRP, 2015)
10 yrs.	350	4.8	4.8, (ICRP, 2015)
5 yrs.	209	3.7	3.5, (ICRP, 2015)
1 yr.	103	3.5	3.2, (ICRP, 2015)
Myocardial exercise			
Adult	740	6	6, (Alnaaimi *et al*., 2022)
15 yrs.	600	5.7	5.3, (ICRP, 2015)
10 yrs.	350	4.9	4.9, (ICRP, 2015)
5 yrs.	209	4.2	3.9, (ICRP, 2015)
1 yr.	103	3.1	2.9, (ICRP, 2015)

- *Route of Intake: Intravenous.*
- *Radiopharmaceuticals: 99mTc - MIBI.*
- *Scan type: Myocardial scan.*

^{131}I-MIBG (neuroendocrine tumor imaging): The effective dose associated with intravenous administration of ^{131}I-MIBG for tumor imaging has been evaluated across various age demographics, as illustrated in Table (4). Adult effective dose reached 7.0 mSv, decreasing to 4.4 mSv in infants. The higher doses of iodine-131 are due to its long physical half-life, extended biological retention, and higher emitted radiation energy.

The analysis presented in Table (4) underscores significant age-related trends in radiation exposure associated with various radiopharmaceuticals. Pediatric patients receive a higher effective dose per administered MBq than adults because of their smaller organ masses, reduced photon attenuation, and increased tissue radiosensitivity. This age-dependent increase in dose coefficients necessitates rigorous justification of nuclear medicine procedures and careful optimization of administered activity in accordance with established pediatric dosage guidelines to maintain diagnostic efficacy while minimizing radiation risk (Fahey *et al*., 2017). The ranges of effective dose (a few mSv) are consistent with published effective dose compendia for diagnostic nuclear medicine (Cherry *et al*., 2012; SNMMI.org, 2018).

Table 4. ***Effective dose for ^{131}I-MIBG (neuroendocrine tumor imaging) evaluated across various age demographics.***

Age	**Activity MBq**	**Estimated effective dose, RADAR-2017**	**Author**
		mSv	**mSv**
Adult	44	7	10.4, (Alnaaimi *et al*., 2022)
15 yrs.	36	6.7	6.2, (ICRP, 2015)
10 yrs.	21	5.9	5.6, (ICRP, 2015)
5 yrs.	12.5	5.3	5.1, (ICRP, 2015)
1 yr.	6.1	4.4	4.5, (ICRP, 2015)

- *Route of Intake: Intravenous Injection.*
- *Radiopharmaceuticals: 131I-MIBG.*
- *Scan type: Neuroendocrine Tumor Imaging.*

Table (5) provides a detailed overview of effective doses associated with various diagnostic imaging procedures. The table illustrates how radiation exposure varies significantly depending on the radiopharmaceutical used, the administered activity, and the type of diagnostic procedure.

The recalculated effective dose for the ^{99m}Tc-sulfur colloid liver–spleen scan was 2.1 mSv, compared with the published reference value of 2.2 mSv. The observed difference of approximately 4.5% indicates close numerical consistency with the reference dosimetric data. In comparison, the recalculated effective dose for whole-body ^{18}F-FDG PET was 4.8 mSv, which is lower than the published reference value of 5.8 mSv. This difference is likely attributable to variations in dosimetric methodology, including updates to tissue-weighting factors, biokinetic models, and calculation frameworks adopted in recent ICRP recommendations. For myocardial perfusion imaging, the recalculated effective doses were 5.8 mSv for the resting protocol and 6.0 mSv for the stress protocol, values that are consistent with the range reported in the literature for similar administered activities. The relatively higher effective doses observed for these procedures primarily reflect the larger administered activities required to achieve adequate image quality for myocardial perfusion assessment. Among the evaluated radiopharmaceuticals, ^{131}I-MIBG produced the highest effective dose (7.0 mSv). This result is consistent with the radionuclide's longer physical half-life, prolonged biological retention, and higher emitted radiation energy, which collectively increase radiation exposure compared with the technetium-99m– and fluorine-18–based radiopharmaceuticals evaluated in this study. These findings emphasize that differences in effective dose among radiopharmaceuticals are influenced by both radionuclide characteristics and administered activity and should therefore be considered when comparing diagnostic procedures and supporting radiation protection practices.

Table 5. ***Overview of estimated effective doses for different nuclear medicine scan types in adults, alongside corresponding reference values from the literature.***

Scan type. (Adult)	Radiopharmaceuticals	Administered activity (MBq)	RADAR estimated effective dose, (mSv)	Published values
Liver- spleen	^{99m}Tc sulfur colloid	185	2.1	2.2 (ICRP, 2015)
PET scan	^{18}FDG	250*	4.8	5.8 (Cherry *et al*., 2012)
Myocardial resting	^{99m}Tc – MIBI	740	5.8	7.4 (Alnaaimi *et al*., 2022)
Myocardial stress	^{99m}Tc – MIBI	740	6	6 (Alnaaimi *et al*., 2022)
Neuroendocrine tumor imaging	^{131}I-MIBG	44	7	10.4 (Alnaaimi *et al*., 2022)

- *FDG-18 activity within the patient at start scan..*

Dose Optimization

Table (6) compares effective doses for adult patients undergoing ^{18}F-FDG PET imaging using the current study protocol (2.86 MBq/kg) and the Finland protocol (5.3 MBq/kg) (Oliveira *et al*., 2013). The mean effective dose decreased from 8.1 mSv (Finland protocol) to 5.2 mSv (current protocol), corresponding to an approximate dose reduction of 47%. These findings support the adoption of weight-based dosing strategies and modern imaging technologies to minimize radiation exposure, in line with the ALARA principle.

Lower administered activity has the potential to reduce effective dose. However, optimization requires simultaneous maintenance of diagnostic image quality and clinical performance, which were outside the scope of the present dosimetric investigation.

Table 6. ***Effective doses for adult patient calculated in the current study compared to the Finland protocol.***

Statistical parameters	Current results			Finland protocol (Oliveira *et al*., 2013).		Estimated reduction in effective dose
	W (kg) adult	Activity(MBq)	E (mSv)	Activity (MBq)	E (mSv)	%
Mean	74	216	5.2	427	8.1	47
Standard deviation	21	50	0.4	125	2.3	15

Interpretation of Effective Dose

Effective dose is a radiation protection quantity developed by the International Commission on Radiological Protection (ICRP) for comparing radiation exposures between imaging procedures and supporting optimization at the population level. It should not be interpreted as an estimate of cancer risk for an individual patient, particularly in pediatric populations, because it is derived from reference phantoms, standardized tissue-weighting factors, and population-averaged risk coefficients rather than patient-specific anatomical or biological characteristics. Consequently, although effective dose provides a useful metric for comparing diagnostic procedures and supporting radiation protection, individualized risk assessment should rely on patient-specific organ absorbed doses together with clinical considerations.

Diagnostic Reference Levels and Clinical Implications

The findings of the present study should also be interpreted in the context of Diagnostic Reference Levels (DRLs), which are widely recognized as practical tools for optimizing patient radiation protection in diagnostic imaging (IAEA, 2014; Treves *et al*., 2014 and ICRP, 2017). In nuclear medicine, DRLs are typically expressed as administered activity rather than patient dose and are intended to help identify unusually high or low activity protocols that may warrant review. They are not regulatory dose limits but serve as benchmarking values that encourage optimization while maintaining adequate diagnostic image quality.

The standardized effective dose estimates presented in this study complement the role of DRLs by providing a consistent dosimetric framework for comparing commonly used diagnostic radiopharmaceuticals across different patient age groups. The observed age-dependent increase in effective dose per unit administered activity emphasizes the importance of carefully selecting administered activities in pediatric patients. Although the present work employed standardized body-weight scaling for comparative dosimetric purposes, the results support the use of established pediatric-administered activity guidelines and institution-specific DRLs to promote consistent practice and minimize unnecessary radiation exposure.

Comparison of administered activities and corresponding effective doses with published reference values also demonstrates the usefulness of standardized dosimetric assessments for benchmarking clinical protocols between institutions. Such comparisons can assist nuclear medicine departments in evaluating whether local protocols are consistent with internationally accepted practice and whether opportunities exist for reducing administered activity while preserving diagnostic performance. However, optimization should always consider image quality, scanner performance, acquisition parameters, reconstruction algorithms, and the specific clinical indication, because radiation protection must be balanced against diagnostic accuracy.

Furthermore, because only effective dose was evaluated, the results should not be interpreted as estimates of individual patient cancer risk, particularly for pediatric patients, where organ-specific absorbed dose provides a more appropriate basis for personalized risk assessment.

Overall, the present study does not establish new DRLs or evaluate clinical image quality. Instead, it provides updated age-dependent effective dose estimates that may support future DRL development, protocol benchmarking, and evidence-based optimization of radiation protection in diagnostic nuclear medicine in accordance with current ICRP and IAEA recommendations.

Conclusions

This study presents a standardized reassessment of age-dependent effective doses for commonly performed diagnostic nuclear medicine procedures using current ICRP biokinetic models and the SNMMI Nuclear Medicine Radiation Dose Tool (RADAR-2017). By applying a unified dosimetric framework across multiple radiopharmaceuticals, the study provides consistent comparisons of effective doses between adult and pediatric reference phantoms based on the latest ICRP recommendations. The results demonstrate that pediatric patients receive higher effective doses per unit administered activity than adults, highlighting the importance of age-specific dosimetric assessment and adherence to standardized pediatric administered activity guidelines.

The findings contribute to radiation protection by providing updated reference effective dose estimates that may support benchmarking of clinical practice, comparison with Diagnostic Reference Levels (DRLs), and periodic review of administered activity protocols. Although this study was limited to effective dose calculations using standardized reference phantoms and did not evaluate image quality, organ-specific absorbed doses, or patient-specific biokinetics, the proposed methodology provides a practical framework for standardized dosimetric assessment. Future studies integrating individualized dosimetry, patient-specific biokinetic modeling, and quantitative image quality evaluation will further support evidence-based optimization of diagnostic nuclear medicine procedures while maintaining appropriate radiation protection principles.

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