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Using statistical assumptions to set reference levels for adult diagnosis using Positron Emission Tomography (PET CT)

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ABSTRACT

Radioprotection of patients is based on the principle of justification and optimization to reduce the doses delivered to patients. Diagnostic Reference Levels (DRLs) are one of the many effective tools for optimizing nuclear medicine examinations, which do not should be exceeded, but should be approached close to an "optimal dose" in order to reduce patient exposure. In this work were collected information on dose, patient demographics, equipment details, and acquisition protocols for Fluoride-18 Fluorideoxyglucose (18F-FDG) PET/CT procedures, to study the administered activities of radiopharmaceuticals and radiation doses from hybrid Computed Tomography (CT) accompanied by Positron Emission Tomography (PET)/CT. We determined the DRLs based on 75th percentile, although DRLs obtained in this work for administered activity (244MBq), and Dose-Length Product (DLP) (453.29mGy.cm) are acceptable compared to the international DRLs. The effective dose of FDG and additional diagnostic CT scans were identified separately, the total effective dose was reported for whole-body 18F-FDG PET/CT. Although the DRLs determined in this study are acceptable compared to European DRLs.

Keywords: nuclear medicine, Diagnostic Reference Levels (DRLs), PET/CT, radiopharmaceutical, radiation exposure

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INTRODUCTION

Oncology field has seen remarkable progress with different types introduction of Positron Emission Tomography (PET/CT), which uses radiotracers like Fluorodeoxyglucose (FDG), Prostate Specific Membrane Antigen (PSMA) and cholinethese radiotracers serve distinct diagnostic purposes, FDG PET-CT is widely used to detect glucose metabolism in various types of glucose-absorbing cancer [1, 2]. PSMA PET-CT has gained importance in the diagnosis and staging of prostate cancer, targeting PSMA receptors on cancer cells [3, 4]. On other hand, Choline PET-CT is valuable for imaging prostate and brain tumors [5, 6]. Tracers help in the diagnosis of other diseases, for example, (Sodium Fluoride) NaF-PET-CT which specializes in bone health assessment, Amyloid PET-CT focuses on detection of brain plaque accumulation in Alzheimer's disease [7]. Cardiac perfusion imaging benefits from thallium or rubidium PET-CT, and F-Dihydroxyphenylalanine (FDOPA) PET-CT facilitates the diagnosis of brain tumors and Parkinson's disease [8, 9]. These radiotracers allow healthcare professionals to tailor PET-CT scans to various medical conditions, improving diagnostic accuracy and patient care.

On the other hand, technological development of PET-CT technology has played a crucial role in reducing the dose of radiation administered to patients. A significant advancement is introduction of Time-of-Flight and Point Spread Function (TOF) and (PSF) in PET-CT, it is a new generation of devices offering additional information, which makes it possible to correct the attenuation, locate lesions and optimize the scanning time, consequently, a reduction in the patient's radiation exposure time, and an improvement in therapeutic procedures [10-12].

This technique is constantly evolving, both from the point of detector view and algorithms, making it possible to reduce radiotracer doses and maintain very good image quality, which facilitates diagnostic accuracy.

All these developments make PET/CT a fully operational tool, which has its place within medical imaging. On the other hand, the radiation doses in PET/CT examination depend not only on the activity administered, but also on the radiation delivered by the scanner which round the radiation load is unusually high for the patient [13, 14]. Carrying out a systematic dosimetric evaluation of imaging devices to evaluate the progress obtained on the basis of daily practice (injected activities, associated CT

constants) is very important. Hence the concept of DRLs which is recognized internationally as an important means of optimizing the dose received by the patient during radiation applications in medical diagnosis [15].

At the international level, in the 1990s, first recommendations concerning medical practices came from the International Commission on Radiological Protection (ICRP), including the implementation of Diagnostic Reference Levels (DRLs) [16]. In 2003 H. Beauvais-March published an article on the new French approach in radiology to define DRLs since the data was insufficient before, a campaign of measuring doses to patients was launched by a steering committee to allow the establishment effective national reference values and prepare their periodic review in a continuous optimization process [17].

Recommended dose levels for PET-CT diagnosis may vary slightly between countries, but they generally follow international standards and guidelines to ensure patient safety and diagnostic accuracy. Reference dose levels have been studied by researchers around the world to ensure appropriate and effective use this type of medical radiological diagnostic technology., for example, Essam Mohammed and all others who reported the reference level for local whole-body PET CT diagnosis of children in Australia, where it is considered extremely important in terms of radiation protection, and Bingsheng Huang et al. evaluated PET-CT doses in the United States and Hong Kong, concluding that the scans should be clinically justified due to the high radiation dose [18, 19]. We also find EM Alkhybari et al. in their work, reported Diagnostic Reference Levels (DRL) for PET CT for the whole of Australia, Queensland, Western Australia, and New Zealand and concluded that it was necessary to improve the radiation doses provided by PET/CT scanning [20].

There are also other studies on dosage reference levels for children, such as study conducted by Saad Alqahtani et al. this study concluded that these levels are higher than those reported internationally, with notable differences [21].

Determination of these reference levels is based on a rigorous statistical analysis, involving the validation of specific hypotheses linked to radioprotection, Ngoneh Jallow who carried out a static study using ANOVA test to check if there is a difference significant differences between doses in years (2010-2014), concluded that there was no significant change in dose between baseline years (repeated measures ANOVA, p=0.985) [22].

In this work, we aim to define and validate the statistical hypotheses essential for good radioprotection in PET-CT imaging in adult patients in Morocco by comparing our value of doses delivered to patients with DRLs in other countries located in different geographical areas. Validation of these statistical assumptions provides the basis for developing robust radiation protection protocols, ensuring that patients receive the diagnostic benefits of PET-CT while keeping radiation exposure as low as reasonably possible. This research not only contributes to the advancement of medical imaging practices but also improves the safety and well-being of patients undergoing PET-CT examinations in Morocco [23].

MATERIAL AND METHODS

Hospital study site

The study carried out at the Chu Ibn Rochd Hospital, located in Casablanca, Morocco. This hospital is equipped with a Positron Emission Tomography coupled to Computed Tomography (PET-CT) system (Siemens Biograph 6 True Point), which used to perform PET-CT examinations on patients.

Collect data

Data relating to patients' PET-CT examinations extracted from hospital archives, including radiological images as well as relevant clinical information. The data necessary collected for calculating the effective dose received by patients, including:

- PET-CT images of each patient.
- Administered activity values of the radiopharmaceutical used for the examination.
- Acquisition parameters of the CT scanner include the values of the X-ray exposure dose.
- Patient information, such as age, gender, and relevant doctors.

Patients classifications

The study cohort included a sample of adult patients who underwent Positron Emission Tomography (PET) examinations coupled with Computed Tomography (CT) as part of medical diagnosis. Patient data collected from the hospital's electronic medical records, and the inclusion criteria were as follows:

- Patients aged (19 years-88 years) old (Figure 1).
- Patients weighing between (34 kg-103 kg) (Figure 2).
- Patients for whom complete data were available for the calculation of the effective dose received.

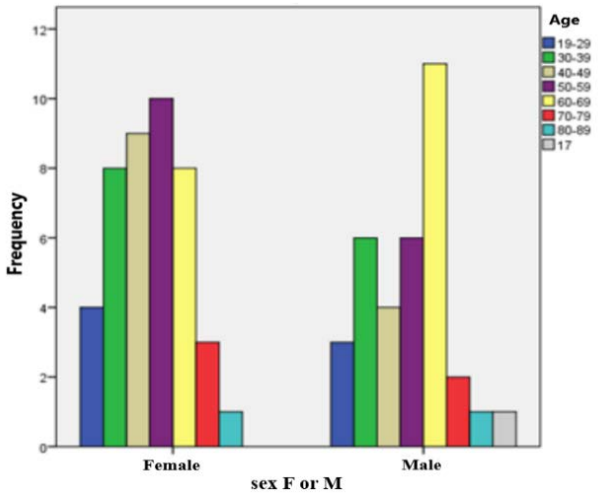

Fig. 1. Patients age

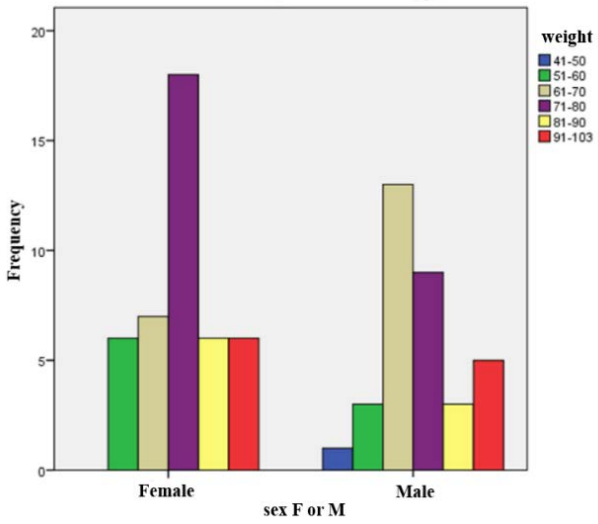

Fig. 2. Patients weight

Choice of dosimetric parameters calculation of the total effective dose for PET-CT examination

In nuclear medicine, The total effective dose received by patient during a PET-CT examination is determined by calculating ef-fective dose sum induced by administered Radiopharmaceutical 18 F-fluorodeoxyglucose (^{18}FDG) $E_{PET,}$ applying conversion factors published by ICRP for major radiopharmaceuticals, as adapted at the national level [24, 25]. These conversion factors, initially computed based on tissue weighting factors of ICRP Pub-lication 60, have adjusted by a mean factor of 0.9 to account for the modifications introduced by ICRP Publication 103 [23, 26, 27]. and delivered by the CT scan E_{CT}, using Dose-Length Product (DLP) method as recommended by International Com-mission on Radiological Protection (ICRP) in publication 102 or Size Specific Dose Estimates (SSDE) method as recommended by American Association of Physicists in Medicine AAPM Report No. 204 [28-30].

In this work, we relied on the DLP method and at the same time measured effective PET dose resulting from radiopharmaceuti-cal injection using the model proposed in ICRP publication 106 [31]. Average effective dose for the entire body. $E_T=E_{PET}+E_{CT}$ [26](1)

With

E_T: Total effective dose in (mSv).
E_{PET}: Effective dose in PET.
E_{CT}: Effective dose in CT.

To calculate the effective dose for a PET-CT examination, should use the value of the Dose Length Product (DLP), for each exami-nation. In addition, the administered activities of ^{18}FDG in MBq.

Effective dose in PET (E_{PET})

The activity is of the order of 3 MBq/kg to 4 MBq/kg of ^{18}FDG depending on the patient's weight.

Dose factor

For each radioactive element ingested there a coefficient called in-gestion dose factor. This dose factor makes it possible to compare the harmfulness of radioactive elements, with equal ingested activ-ity [32].

$$\text{Dose}(\text{Sv or mSv}) = \text{Dose factor}.\text{Administered activity (Bq ou kBq)}$$

$$D=F.A \qquad (2)$$

Where:

D = Effective dose (Sv or mSv).
F = Dose factor.
A = Administered activity (Bq or kBq).

In our case, this coefficient for Fluorine (^{18}F) is equal to 4.9.10-11 according to the ASN (Nuclear Safety Authority).

Effective dose in CT (E_{CT})

Effective dose calculation provided from scanner is determined by multiplying DLP by a conversion factor Fdlp:

$$E = DLP \times F_{dlp} \quad (3)$$

With:

E: Effective dose due to the scanner in (mSv).
DLP: Dose Length Product in (mGy.cm).
F_{dlp}: Conversion factor allowing the transition from DLP (mSv.mGy-1.cm-1) to the effective dose (mSv). It takes into account the age of the patient and the ir-radiated region.

In our case the conversion coefficient for irradiated region (whole body) and according to the reference age (adult) is: 0.0154 (Table 1) [27-33].

Tab. 1. Conversion factor [27-33]

CT Scan in PET/CT protocol	Anatomical area	K=ED/DLP (mS/mGy cm)
Brain	Head	0.0024
H and N	Head/neck	0.009
-	-	0.0204
Dual time	Chest	0.0163
Dual time	Abdomen	0.0143
Dual time	Pelvis	0.0171
Dual time	Abdomen/pelvis	0.0186
Trunk, Torso	Chest/ Abdomen/pelvis	0.0154
H and Torso	Whole body	0.006 male
Limbs	Lower extremities	0.0073 female

To compare the study's results, particularly the effective doses received by patients, with international standards and Diagnostic Reference Levels (DRLs) established in other countries, data consider in the comparative analysis, it's from publications and national and international databases.
In this study, will compared the mean values of DLP and injected activity to DRLs. The objective is to contextualize PLD (Patient Limit Doses) and injected activity values of our study by comparing them to international reference values. DRLs values proposed by the Institute of Radiation Protection and Nuclear Safety (IRSN) for PET and CT presented in Tables 2 and Table 3 [34].

Tab. 2. DRL values in FDG position emission tomography

Exam	Activity injected (MBq)
PET	200–500

Tab. 3. DRL values for DLP

Exam	DRLs (mGy.cm)
Brain	1050
Thorax	500
Abdomen	650
Pelvis	450

Some anatomical regions listed in Table 3, do not always correspond to current clinical practice. In this study, will perform a joint acquisition for the thoracic, abdominal and pelvic regions, this implies a necessary adaptation of reference values. In accordance with 2004 IRSN guidelines, for a TAP acquisition, the reference DLP is modified to reach 1600 mGy.cm, resulting from DLP sum of three anatomical examinations [35].

Statistical analysis

Statistical analysis of data performed using specialized software, IBM SPSS Statistics version 20 (IBM SPSS, Inc., Chicago, IL) [36]. The main analysis carried out on all patient data: The statistical hypotheses relating to effective dose, patient radioprotection, and comparison with DRLs tested, using appropriate methods, such as analysis of deviations, ANOVA (Analysis Of Variance), test student. In addition, to evaluate the independence of clinical

parameters and effective dose, the correlation of each parameter with effective dose studied using a regression analysis, generating a Pearson correlation matrix all tests were bilateral. Statistical significance defined as P <0.05 [37]. Continuous variables are expressed as mean ± Standard Deviation (SD) or medians with range (minimum, maximum), although categorical variables are reported as number and percentages. Details of the statistical tests, models, and specific parameters will be presented in the results section.

Statistical hypotheses

Null Hypothesis (H_0) of compliance with DRLs:

This null hypothesis suggests that testing whether the observed effective doses in study do not differ significantly from the Diagnostic Reference Levels (DRLs) established by international organizations.

- H_0- Effective doses received by adult patients during PET-CT examinations in Morocco comply with Diagnostic Reference Levels (DRLs) established by international organizations.

Alternative Hypothesis (H_1) of non-compliance with DRLs:

This alternative hypothesis indicates that seeking to detect a significant difference between the observed effective doses and the Reference Diagnostic Levels (DRLs).

- H_1- Effective doses received by adult patients in Morocco differ significantly from the Diagnostic Reference Levels (DRLs) established by international organizations.

Hypothesis of correlation between doses and clinical parameters:

These hypotheses examine whether specific clinical variables are significantly associated with effective doses.

- H_0- There is no significant correlation between the effective doses received by adult patients and clinical parameters such as age, gender, clinical diagnosis, or body size.
- H_1: There is a significant correlation between the effective doses received by adult patients and clinical parameters such as age, gender, clinical diagnosis, or body size.

Hypothesis of data normality:

To test if data on effective doses are approximately normally distributed.

- H_0- Data on effective doses follow a normal distribution.
- H_1- Data on effective doses do not follow a normal distribution.

Hypothesis of homogeneity of variances:

This hypothesis verifies if the variances of effective doses are similar among patient subgroups, for example, based on diagnosis.

- H_0- Effective doses variances are homogeneous among patient subgroups.
- H_1- Effective doses variances differ significantly among patient subgroups.

RESULT AND ANALYSES

Comparison of mean injected activity and DLP values to diagnostic reference levels

In this study, will compared the mean values of DLP and injected activity with the values of Diagnostic Reference Levels (DRLs) for adults in CT and nuclear medicine proposed by the Institute of Radioprotection and Nuclear Safety (IRSN) [34]. We compared DLP values for TAP examinations and injected activity values for PET examinations to DRLs. Figure 3 and Figure 4 present these results respectively for DLP and the injected activity. Results analysis obtained shows good agreement with the DRLs diagnostic reference levels recommended by the IRSN. This sug-gests that the practice of PET CT diagnosis in Morocco appears to respect the IRSN radiation protection recommendations.

The results highlight the safety of PET-CT diagnostic procedures in Morocco, ensuring that patients exposed to acceptable levels of radiation. This is positive from view point of patient safety and radiation protection. These results are also consistent with inter-national standards for radiation protection, helping to ensure that medical practices are in line with global radiation safety recom-mendations (Table 4).

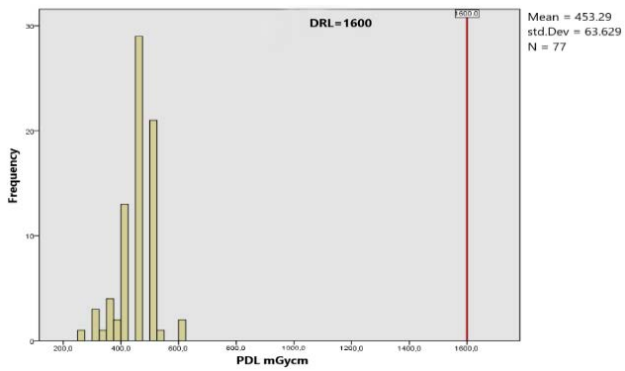

Fig. 3. Comparison of the mean of DLP values and DRL

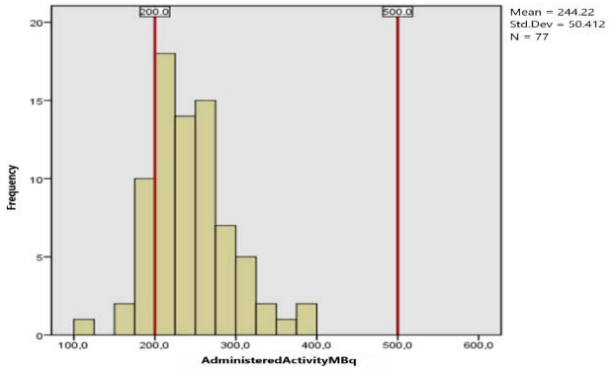

Fig. 4. Comparison of administrated activity mean values and DRL

Tab. 4. Descriptive statistics result for the effective dose

Statistics				
Descriptions		**Effective Dose CT(mSv)**	**Effective Dose FDG (mSv)**	**Effective Dose Total (mSv)**
N	Valid	76	77	77
	Missing	1	0	0
Mean		6.9814	11.9677	18.9477
Std. Error of Mean		0.11330	0.28150	0.32282
Median		7.0100	11.7600	18.5500
Std. Deviation		0.98777	2.47015	2.83280
Variance		0.976	6.102	8.025
Minimum		4.20	6.03	12.30
Maximum		9.49	18.82	28.30
Percentiles	25	6.3100	10.1200	17.0000
	50	7.0100	11.7600	18.5500
	75	7.9200	13.3050	20.2350

Average effective dose exposure values for an ^{18}FDG injection are 11.97 mSv, with the median dose being 11.77 mSv. The standard deviation is quite low, 2.47mSv, which can be explained by the homogeneity of the patient population in terms of weight (Figure 5 and Figure 6).

Effective dose delivered by the CT examination, is generally lower than the dose of PET component, as confirm in Figure 7, average effective dose is around 6.98 mSv, median dose is 7.01 mSv, and standard deviation is around 0.98.

Total effective dose mean is means sum of the doses of ^{18}FDG injection and CT, 18.95 mSv, median dose is 18.94 mSv, and standard deviation 2.83 mSv.

From the results of Figure 8, we conclude that the dose delivered by the administered activity presents more than 60 of the total dose delivered to the patients during the PET/CT examination.

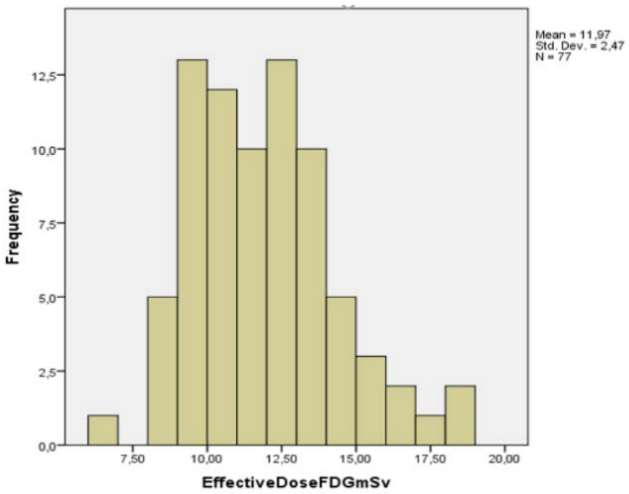

Fig. 5. Effective dose mean of FDG

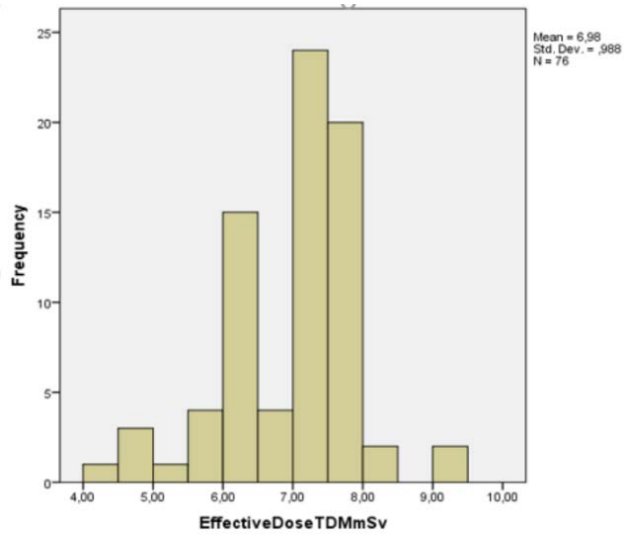

Fig. 6. Effective dose mean of the CT

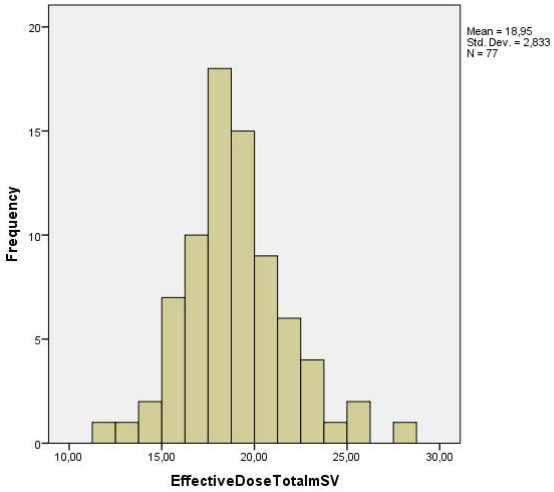

Fig. 7. Total effective dose mean

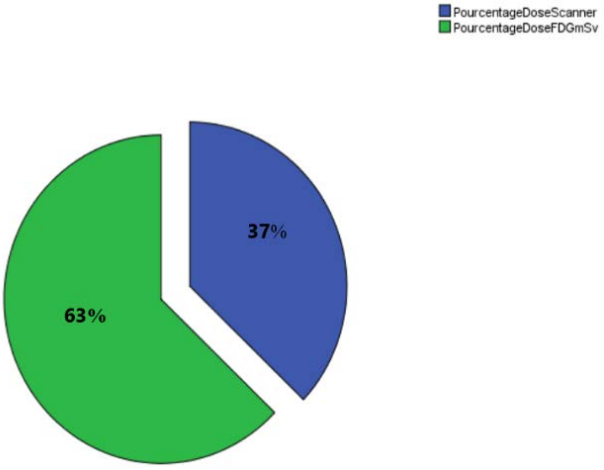

Fig. 8. PET-CT dose contribution

Validation of static hypotheses

Test student:

The student test aims to test the null Hypothesis (H_0) of compliance with the DRLs, which assumes that the effective doses received by adult patients during PET-CT examinations in Morocco comply with Diagnostic Reference Levels (DRLs) established by the international organizations. As well as the alternative Hypothesis (H_1) according to which the effective doses received by adult patients in Morocco differ significantly from DRLs established by international organizations.

Both Tables 5-7 contain the results of the single-sample average t-

test. The difference between the two averages appears under Mean difference column (-1146.7143), and t equal to -158,141for the dose delivered by the DLP scanner Table 5. for the difference between the two averages of the doses received due to the injection of 18FDG and the average of reference value, is order of -255.7792, t equal to -44.522 (Table 7). The t value of both Table 5 and Table 6 is far from zero.

Significance level indicated in the Sig column. (Bilateral). Reading 0.000 does not mean that the probability is zero, but that it is less than 0.05 (or 0.5%). The two-sided designation (2 queues) means that take into consideration that the doses received by patients could have been higher or lower than the NRD diagnostic reference level. Both alternatives are possible and interesting. Must therefore reject the null hypothesis and accept H_1 (alternative hypothesis) here.

Tab. 5. Student test for DLP mean

	Test Value = 1600					
	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
DLP (mGycm)	-158.141	76	0.000	-1146.7143	-1161.156	-1132.272

Tab. 6. Student test for activity administrated mean

	Test Value = 500					
	t	Df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
Administered Activity (MBq)	-44.522	76	0.000	-255.7792	-267.221	-244.337

Tab. 7. Test of homogeneity of variances for the effective dose total of patients according to their ages

	Sum of Squares	Df	Mean Square	F	Sig.
Between Groups	135.954	6	22.659	3.347	0.06
Within Groups	473.929	70	6.770	-	-
Total	609.883	76	-	-	-

ANOVA test

ANOVA stands for Analysis of Variance. Uses variance to determine means if they are different or equal. For this case, will used the factor ANOVA test to compare the means of total effective dose between different groups of patients according to weight groups and age during the examination of PET scan. Also, will compare the value of significance at our significance level to assess the null hypothesis, which states that total effective dose variances are homogeneous between patient subgroups. In general, a significance level (denoted alpha or α) of 0.05 works well. A significance level of 0.05 indicates a 5% probability of incorrectly concluding that a difference exists.

In these results, the significance value being less than the significance threshold of 0.05, it can reject the null hypothesis and conclude that the variances of total effective dose differ significantly between the subgroups of patients according to their ages (Table 8).

Tab. 8. Homogeneity test of variances for total effective dose of patients according to their weight

	Sum of Squares	Df	Mean Square	F	Sig.
Between Groups	305.321	5	61.064	14.235	0.05
Within Groups	304.562	71	4.290	-	-
Total	609.883	76	-	-	-

In these results, the significance value being lower than the significance threshold of 0.05 for the total effective dose variance, this means that it can reject the null hypothesis and conclude that the total effective dose variances are significantly differed between subgroups of patients based on their weight.

Pearson correlation test

Correlation is a quantification of the linear relationship between continuous variables. In this study, examined whether specific clinical variables (age, weight, sex) are significantly associated with effective doses or not. The correlation coefficient, which ultimately presents the standardized covariance, varies between –1 and 1. A coefficient of 1 indicates a perfect positive correlation between the two variables. Conversely, a coefficient of –1 indicate a perfect negative correlation (Table 9).

Tab. 9. Test of pearson correlations for total effective dose and age

Descriptions		Effective Dose Total (mSv)	l'age
Effective Dose Total (mSv)	Pearson Correlation	1	0.037
	Sig. (2-tailed)	-	0.747
	N	77	77
l'age	Pearson Correlation	0.037	1
	Sig. (2-tailed)	0.747	-
	N	77	77

According to the results obtained, observing that there is no significant correlation between the effective doses received by adult patients and age (the significance value is 0.747 greater than 0.05), it can accept the null hypothesis and reject hypothesis H_1 (Table 10).

Tab. 10. Test of pearson correlations for total effective dose and weight

Descriptions		Effective Dose Total (mSv)	Person's weight
Effective Dose Total (mSv)	Pearson Correlation	1	0.674**
	Sig. (2-tailed)	-	0.000
	N	77	77
poids du personne	Pearson Correlation	0.674**	1
	Sig. (2-tailed)	0.000	-
	N	77	77

** Correlation is significant at the 0.01 level (2-tailed).

It noted that the significance value is 0.000, this means that the correlation is significant between total effective dose and patient's weight, then we can reject the null hypothesis and accept the alternative hypothesis H_1. Pearson correlation coefficient is of the order of 0.64, so there is a positive linear relationship between total effective dose and patient's weight.

Table 11 shows that the significance value (0.225) above the significance threshold (0.05), it can reject the null hypothesis and accept the alternative hypothesis. It conclude that there is no significant correlation between the total effective dose and the sex of the patients.

Results of Pearson correlation test between the total effective dose and the three parameters (Age, weight, sex) show that there is a positive linear correlation between total effective dose and weight of the patients.

Total effective dose normality test:

To test whether effective dose data are approximately normally distributed. It used a quantile-normal plot, also called QQ plot (Quantile - Quantile plot) (Figure 9).

Tab. 11. Test of pearson correlations for total effective dose and weight

Descriptions		Effective Dose Total (mSv)	sex of the patients
Effective Dose Total (mSv)	Pearson Correlation	1	-0.140
	Sig. (2-tailed)	-	0.225
	N	77	77
Sex of the patients	Pearson Correlation	-0.140	1
	Sig. (2-tailed)	0.225	-
	N	77	77

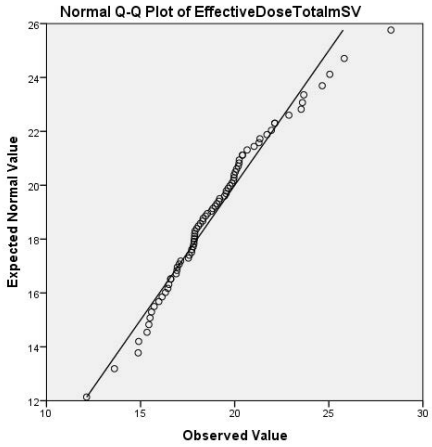

Fig. 9. QQ plot for normality of total effective dose

QQ plot will display a scatterplot that compares the total effective dose quantiles to those of a normal distribution. As shown in the graph these points lie approximately along the diagonal line, this suggests that the total effective dose follows a normal distribution; therefore, it can accept null hypothesis (H_0) and reject alternative hypothesis (H_1).

International comparison

As mentioned previously, similar work has recently been carried out and published by Many advanced countries have carried out and have set up the practice for their DRLs, as the UK, Swiss, France, as part of their strategy to move toward the provision of quality of medicine, With the aim of minimizing the dose of radiation and its impact on patients. The results in Table 12 highlight the international variations in DRLs studies for PET/CT and the results proposed by our study (Figure 10 and Figure 11).

Tab. 11. Test of pearson correlations for total effective dose and weight

Countries	DLP (mGy.cm)	Administrated activity (MBq)
France	1600	500
Australia	985	310
Newzlend (NZ)	1319	333
Korea	560	370
United kingdom (UK)	310	400
Jordanian	660	303
Japan	600	240
Suisse	760	350
Saudi Arabian	1169	280
Our study	453	244

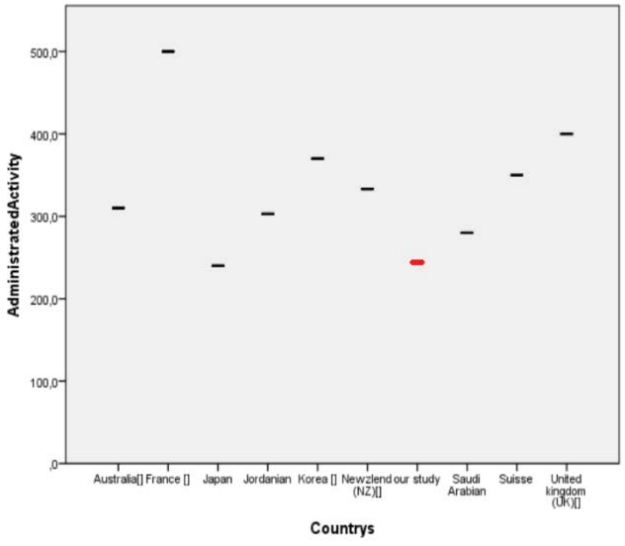

Fig. 10. International data comparison for administrate activity

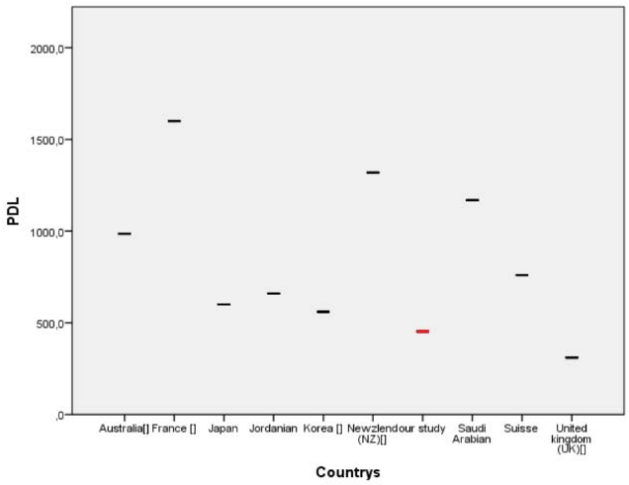

Fig. 11. International data comparison for DLP

DISCUSSION

The number of nuclear medicine services in permanent evolution, Diagnostic Reference Levels (DRLs), have been recognized as a practical tool to study and understand the variation of PET/CT dose, which constitute a tool for dose optimization. Note that the dose delivered to patients is linked to weight, medical equipment technology and diagnostic quality control via quality control protocols and the differents radiopharmaceuticals used. Currently, the number of Positron Emission Tomography (PET/CT) machines is increasing in developed countries, where ^{18}F-FDG is used in more than 1.5 million examinations per year, and the most produced radiopharmaceuticals in the world.

The results presented in this study concern patients who underwent the ^{18}F-FDG PET/CT ex-amination, we started by calculating the additional dose delivered by the scanner, and used the FPDL conversion factor which takes into account two parameters which are the age of the patient and the anatomical region explored, then the effective dose induced by the administration of the pharmaceutical radio ^{18}FDG, where used the DPUI co-efficient (Dose Per Incorporation Unit) to calculate the dose received by each patient, and used the results of calculating effective doses to determine the dose contribution of each PET-CT components. The analysis of these results shows that the average value of DLP (Dose Length Product) is 453.29 mGy.cm, and the average value of the administered activity of FDG (Fluorodeoxyglucose) 244.22 MBq, which are systematically lower than the DRLs (Levels of Reference Diagnostics) recommended by the IRSN (the Institute of Radioprotection and Nuclear Safety), which are defined as tools for optimizations and that they should not be exceeded without justification, indicating a compliance with current radiation standards.

DRLs present a high variability from one country to another. Some protocols are common between countries and the DRLs can therefore be directly compared. These results are visible in Table 6. The results obtained in this study are low compared to other countries, because the number of patients in sample was not large, the measurements taken were insufficient to extrapolate the results to the entire country and to establish the national DRLs. In general, average activities stability noted for the majority of examinations allows to have a faithful image of national practices.

A statistical analysis was performed on the data collected for each protocol, in relation to the Dose-Length Product (DLP) and administered activity of ^{18}FDG for each of these parameters, the mean, standard deviation, median, minimum and maximum values were calculated, it used the SPSS software. Once the data was analyzed, the DRLs representing the 75th% of the percentile distribution of the data were proposed, 7.9200 mSv for the effective dose of scanner, 13.3050 mSv for the effective dose of FDG, and 20 .2350 mSv for the total effective dose of PET/CT. Thus, it carry out static tests to validate the static hypotheses of this study. to validate the null Hypothesis (H_0) or the alternative hypothesis H_1 to verify whether the DRLs doses linked to the DLP and the administered activity observed in our study do not differ significantly from the international DRLs s or there is a significant difference, study used the student test which consists of comparing the average values of DLP or activity administered to a reference DRLs , the results show that the p value is less than 0.05 this means that DRLs of this study can be lower or greater than the reference DRLs value.

After used the 1-way ANOVA test to compare total effective dose means between different groups of patients according to weight groups and age during the PET/CT examination, the results showed that the Effective dose variances differ significantly between patient subgroups based on their ages and weights. Then the Pearson correlation test between the total effective dose and the three parameters (Age, weight, sex), the results show that there is a positive linear correlation between the total effective dose and the weight of the patients. Finally, the linearity test of the total effective dose, the QQ plot, shows that the data on effective doses follow a normal distribution. These results reinforce the reliability of our analysis.

Alongside this observation, it appeared that the irradiation induced by PET represents more than 60% of the total irradiation received by the patient undergoing the PET/CT examination, this remains acceptable given the benefits it brings to the patients in terms of imaging optimization.

CONCLUSION

This work provides recommendations for national dose reference levels, for CT procedures for whole-body PET/CT examinations in nuclear medicine. suggested for the administered activities of ^{18}F-FDG at 244.22 MBq, and for the Dose Length Product

(DLP) of CT components associated with ^{18}F-FDG PET/CT is 453.29 mGy.cm, only slightly lower than those of the data published identified. Suggested DRLs are based on the administered activity necessary to achieve good image quality required for a given procedure. It should be noted the importance of optimizing CT radiation doses during PET/CT examinations, and it is best to optimize CT acquisition protocols for all whole-body PET/CT protocols, to achieve image quality appropriate while minimizing patient exposure to radiation. These results are comparable to published international whole-body ^{18}F-FDG PET/CT data. It is anticipated that with the reference data determined in this study can help Moroccan PET/CT centers compare their typical median DRLs values to the DRLs values published in this study, it will be possible to optimize patient protection and quality care, and ensure safer and more effective PET/CT practices. It should be noted that DRLs must be continually revised in order to ensure the quality of the procedures, depending on the evolution of the technique whose use is developing in Morocco. Although in this context DRLs concerning patients of standard (average) height, may be exceeded in tall patients, but they must be reduced for children.

LIMITATION AND PERSPECTIVES

In this study, the number of submission centers is insufficient to deduce the Diagnostic Reference Levels (DRLs) in Morocco, DRLs must be based on dose values measured in several hospitals and clinics, well equipped or not, and determined by calculating the third quartile of the distribution of doses evaluated. So the results proposed in this study are an introduction for future research in this area of DRLs in Nuclear Medicine for the examination of PET/CT. Another limitation is that only ^{18}F-FDG tissue weighting factors were obtained from ICRP publications. This study did not take into consideration the date of manufacture of PET/CT used, as well as the development of this technology such as Time-of-Flight point spread function (TOF), the new image reconstruction algorithms used in CT which can reduce patient radiation exposure without deteriorations in image quality, solid-state cameras, combat time, and point spread function technologies. On the other hand the use of new compounds labeled with short-lived positron-emitting radionuclides, a large number of PET radiopharmaceutical products are currently under study, for different regions and different pathologies, such as 68 Ga PET/CT -PSMA which is easily absorbed by the prostate, qF-DOPA-PET for studies of central nervous system, use of these tracers can decrease the activity administered depending on region, and creates considerable potential for metabolic tracers. All these concepts must be used and integrated to Determine Reference Levels (DRLs) in nuclear medicine for the PET/CT examination, in of Morocco with future study's, which are all designed to reduce or limit the exposure of patients to radiation

REFERENCES

1. Krause BJ, Schwarzenböck S, Souvatzoglou M. Fdg pet and pet/ct. Mol imaging oncol. 2012:351-369.
2. Cohade C, Osman M, Leal J, Wahl RL. Direct comparison of ^{18}F-FDG PET and PET/CT in patients with colorectal carcinoma. J Nucl Med. 2003;44:1797-1803.
3. Awenat S, Piccardo A, Carvoeiras P, Signore G, Giovanella L, et al. Diagnostic role of ^{18}F-PSMA-1007 PET/CT in prostate cancer staging: a systematic review. Diagnostics. 2021;11:552.
4. Ceci F, Fanti S. PSMA-PET/CT imaging in prostate cancer: why and when. Clinical and Translational Imaging. 2019;7:377-379.
5. Giovannini E, Lazzeri P, Milano A, Chiara Gaeta M, Ciarmiello A. Clinical applications of choline PET/CT in brain tumors. Curr Pharm Des. 2015;21:121-127.
6. Evangelista L, Zattoni F, Guttilla A, Saladini G, Zattoni F, et al. Choline PET or PET/CT and biochemical relapse of prostate cancer: a systematic review and meta-analysis. Clin nucl med. 2013;38:305-314.
7. Bastawrous S, Bhargava P, Behnia F, Djang DS, Haseley DR. Newer PET application with an old tracer: role of ^{18}F-NaF skeletal PET/CT in oncologic practice. Radiographics. 2014;34:1295-1316.
8. Hanson MW, Borges-Neto S. PET/CT in Cardiology. InPET/CT: Essentials for Clinical Practice; N Y NY: Springer N Y. 2006; 202-216.
9. Santhanam P, Taïeb D. Role of ^{18}F-FDOPA PET/CT imaging in endocrinology. Clin endocrinol. 2014;81:789-798.
10. Vandenberghe S, Mikhaylova E, D'Hoe E, Mollet P, Karp JS. Recent developments in time-of-flight PET. EJNMMI Phys. 2016;3:1-30.
11. Surti S. Update on time-of-flight PET imaging. J Nucl Med. 2015;56:98-105.
12. Akamatsu G, Ishikawa K, Mitsumoto K, Taniguchi T, Ohya N, et al. Improvement in PET/CT image quality with a combination of point-spread function and time-of-flight in relation to reconstruction parameters. J Nucl Med. 2012;53:1716-1722.
13. De Dreuille O, Maszelin P, Foehrenbach H, Bonardel G, Gaillard JF. Principe et technique de la tomographie par émission de positons (TEP). Emc-Radiol. 2004;1:2-35.
14. Kaushik A, Jaimini A, Tripathi M, D'Souza M, Sharma R, et al. Estimation of radiation dose to patients from ^{18}FDG whole body PET/CT investigations using dynamic PET scan protocol. Indian j med res. 2015;142:721.
15. Talbot A. Analyse des données relatives à la mise à jour des niveaux de référence diagnostiques en radiologie et en médecine nucléaire. Bilan. 2004;2006:2008.
16. Valentin J, Boice Jr JD, Clarke RH, Cousins C, Gonzalez AJ, et al. Published on behalf of the International Commission on Radiological Protection.
17. H. Beauvais-March, Marc Valero, A. Biau, Michel Bourguignon. Diagnostic reference levels for diagnotic radiology. 2003.
18. F. Mcentee, K.P. Willowson, P.C. Brennan, T. Kitsos, P.L. Kench, An australian local diagnostic reference level for paediatric whole-body ^{18}F-FDG PeT/CT, 2019.
19. Huang B, Law MW, Khong PL. Whole-body PET/CT scanning: estimation of radiation dose and cancer risk. Radiology. 2009;251:166-174.
20. Alkhybari EM, McEntee MF, Brennan PC, Willowson KP, Kench PL. Diagnostic reference levels for ^{18}F-FDG whole body PET/CT procedures: Results from a survey of 12 centres in Australia and New Zealand. J Med Imaging Radiat Oncol. 2019;63:291-299.
21. Alqahtani S, Soliman K, Alotaibi S, Alnofaie K, Alahmari A, et al. Analysis of Local Diagnostic Reference Levels for Pediatric Patients Undergoing 18F-FDG PET/CT Imaging for Oncology. J Appl Math Phys. 2023;11:2144-2155.
22. Jallow N, Christian P, Sunderland J, Graham M, Hoffman JM, et al. Diagnostic reference levels of CT radiation dose in whole-body PET/CT. J Nucl Med. 2016;57:238-241.
23. Marti-Climent J, Martin CJ, Demeter S, Holm S, Hosono M, et al. Radiological Protection in PET and PET/CT. ICRP Task Group 117. Eur J of Nucl Med and Mol Imaging. 2022;49.
24. Mattsson S, Johansson L, Leide Svegborn S, Liniecki J, Noßke D, et al. ICRP publication 128: radiation dose to patients from radiopharmaceuticals: a compendium of current information related to frequently used substances. Ann ICRP. 2015;44:7-321.
25. Lee C, Kim KP, Bolch WE, Moroz BE, Folio L. NCICT: a computational solution to estimate organ doses for pediatric and adult patients undergoing CT scans. J Radiol Prot. 2015;35:891.
26. Alkhybari EM, McEntee MF, Willowson KP, Brennan PC, Kitsos T, et al. An Australian local diagnostic reference level for paediatric whole-body ^{18}F-FDG PET/CT. Br J Radiol. 2019;92:20180879.
27. Charles MW. ICRP Publication 103: Recommendations of the ICRP.
28. ICRP, 2007. Managing Patient Dose in Multi-Detector Computed Tomography (MDCT). ICRP Publ 102. Ann. ICRP 37.
29. Christner JA, Kofler JM, McCollough CH. Estimating effective dose for CT using dose–length product compared with using organ doses: consequences of adopting International Commission on Radiological Protection Publication 103 or dual-energy scanning. Am J Roentgenol. 2010;194:881-889.
30. John M. Boone, Keith J. Strauss, Andrew M. Hernandez., Anthony H., Kimberly E. Applegate., et al. Size-Specific Dose Estimate (SSDE) for Head CT. Am Assoc Phys Med (AAPM). 2019.
31. Mattsson S, Johansson L, Liniecki J, Nosske D, Stabin M, et al. Radiation dose to patients from radiopharmaceuticals. InWorld Congr Med Phys Biomed Eng. 2009;25:474-477.
32. Hadid L. Optimization of radiation protection in nuclear medicine: From reference dosimetry to personalized dosimetry Dr diss Paris 7.
33. Huda W, Magill D, He W. CT effective dose per dose length product using ICRP 103 weighting factors. Med phys. 2011;38:1261-1265.
34. Talbot A. Analysis of data relating to the update of diagnostic reference levels in radiology and nuclear medicine. IRSN. 2016-2018:1-137.
35. Coulot J, Magnier F, Chauchat P, Guilabert N, Ricard M, et al. Comparaison de la dose efficace en TEP/TDM et en TDM. Méd Nucl. 2011;35:156-162.
36. Arbuckle JL. IBM SPSS Amos 19 user's guide. Crawfordville, FL: Amos Dev Corp. 2010;635.
37. McCormick K, Salcedo J. SPSS statistics for data analysis and visualization. John Wiley & Sons; 2017.
38. Etard C, Celier D, Roch P, Aubert B. National survey of patient doses from whole-body FDG PET-CT examinations in France in 2011. Radiat Prot Dosim. 2012;152:334-338.
39. Roch P, Célier D, Dessaud C, Etard C. Diagnostic reference levels in France: a contrasting perception of a system that can be improved but is effective. Radiat. prot. 2018;53:13-19.
40. Botros GM, Smart RC, Towson JE. Diagnostic reference activities for nuclear medicine procedures in Australia and New Zealand derived from the 2008 survey. ANZ Nucl Med. 2009;40:2-11.
41. Alkhybari EM, McEntee MF, Brennan PC, Willowson KP, Hogg P, et al. Determining and updating PET/CT and SPECT/CT diagnostic reference levels: a systematic review. Radiat Prot Dosim. 2018;182:532-545.
42. Nam S, Park H, Kwon S, Cho PK, Yoon Y, et al. Updated National Diagnostic Reference Levels and Achievable Doses for CT Protocols: A National Survey of Korean Hospitals. Tomography. 2022;8:2450-2459.
43. Chong A, Park JM, Pak K, Kim YI, Kwon HW, et al. Recent Survey of Effective Doses of F-18 FDG Torso PET/CT in Korea and the Current Recommendations for CT Protocols of PET/CT. Nucl Med Mol Imaging. 2020;54:224-232.
44. Oliveira CM, Sá LV, Alonso TC, Silva TA. Suggestion of a national diagnostic reference level for ^{18}F-FDG/PET scans in adult cancer patients in Brazil. Radiol Bras. 2013;46:284-289.
45. Hart D, Wall BF. UK nuclear medicine survey 2003–2004. Nucl med commun. 2005;26:937-946.
46. Alhorani Q, Alkhybari E, Rawashdeh M, Latiff RA, Sabarudin A, et al. National and Local Diagnostic Reference Levels for ^{18}F-FDG and CT in Jordanian PET/CT Scanning: Findings and Implications in Practice.
47. Abe K, Hosono M, Igarashi T, Iimori T, Ishiguro M, et al. The 2020 national diagnostic reference levels for nuclear medicine in Japan. Ann nucl med. 2020;34:799-806.
48. Lima TV, Gnesin S, Ryckx N, Strobel K, Stritt N, et al. Swiss survey on hybrid imaging CTs doses in Nuclear Medicine and proposed national dose reference levels. Z med Phys. 2018;28:265-275.
49. Alkhybari EM, Alhulail AA, Sulieman A, Faqeeh JM, Albatly AA, et al. Deriving local diagnostic reference levels for four common adult PET/CT procedures in a Saudi Arabian hospital. J Radiat Res Appl Sci. 2022;15:380-385.
50. Alessio AM, Farrell MB, Fahey FH. Role of reference levels in nuclear medicine: a report of the SNMMI dose optimization task force. J Nucl Med. 2015;56:1960-1964.