Investigation of impact of using the ICRP 110 adult reference phantoms and ICRP 103 tissue weighting factors on the radiopharmaceutical's effective dose

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Abstract
In this study, the effective dose per unit activity administered was calculated for some of the ^{99m}Tc based radiopharmaceuticals by the MIRD method using ICRP biokinetic data, the ICRP 110 adult reference phantoms, and the ICRP 103 tissue weighting factors. The results show that with some exceptions, the calculated effective dose using new phantoms and tissue weighting factors are lower than the ICRP published data. This reduction is significant in some cases and can significantly reduce the collective effective dose of patients.
Keywords: Radiopharmaceutical, MIRD method, Time integrated activity, S-value, Effective dose

Introduction
The effective dose indicates the potential risk from stochastic effects of radiation. It is intended for use as a protection quantity for planning and optimization in radiological protection, and demonstration of compliance with dose limits for regulatory purposes [1]. It allows one to compare different nuclear medicine procedures [2, 3].
The application of radiopharmaceuticals in nuclear medicine for therapy and diagnosis has increased in recent years. This leads to an increase in the number of individuals that receive a radiation dose. The calculation of effective dose can be used to compare the risk associated with the application of different radiopharmaceuticals and if possible choose the radiopharmaceuticals with lower effective doses. This can help to optimize the collective effective dose to the patients.
The ICRP published several documents about radiation dose to patients from radiopharmaceuticals in publications 53 [4], 80 [5], 106 [6] and then published a compendium of biokinetic data for frequently used radiopharmaceuticals in the ICRP 128 [7]. These documents include the biokinetic data for important radiopharmaceuticals. Also, absorbed and effective dose per unit activity administered was calculated. The ICRP revised its formalism for the calculation of effective dose in ICRP 103. Also, the ICRP developed more realistic voxelized phantoms as reference adult in publication 110 [8]. However, in all of its publications about radiation dose to patients, it used ICRP 60 or ICRP 26 formalism for effective dose calculation and stylized phantoms of Cristy and Eckerman [9]. Therefore recalculation of effective dose using new reference phantoms and new calculation method is necessary. The purpose of this study is to investigate the effects of new phantoms and new calculation methods on the effective dose of radiopharmaceuticals. ^{99m}Tc is the most important radioisotope used in nuclear medicine. Thus calculation was made for some of ^{99m}Tc based radiopharmaceuticals.

Materials and methods
Phantoms
ICRP adult reference male and female voxel phantoms are based on the medical images of two individuals that are consistent with the data given in the ICRP 89. These phantoms accommodate all organs and tissues that are relevant to the assessment of effective dose based on the recommendations in the ICRP 103. A detailed description of the phantoms (organs ID numbers, elemental composition, etc) can be found in the ICRP 110.

MIRD method
In this method, the mean absorbed dose $D(r_T,T_D)$ to the target tissue r_T over a defined dose-integration period T_D after administration of the radioactive material to the subject is given as:

$$D(r_T,T_D)=\sum_{r_S}\tilde{A}(r_S,T_D)\,S(r_T \leftarrow r_S) \qquad (1)$$

where $\tilde{A}(r_S,T_D)$ is the time-integrated activity or the total number of nuclear transformations in the source tissue, r_S. The time-integrated activities for radiopharmaceuticals were taken from ICRP publications 128 and 53. The quantity S is the mean absorbed dose in the target tissue, r_T, per nuclear transformation in the source tissue, r_S. The S-values of ^{99m}Tc for source organs of interest were calculated using the GATE Monte Carlo package (version 8.2). The DoseActor was used to calculate the deposited energy in the target organs of interest. Based on these values, the S-values were calculated. For each source organ, the S-values were calculated for 27 target organs and tissues. The uncertainty of the calculated S-values is below 5%. The absorbed dose was calculated using equation (1) for eight different ^{99m}Tc based radiopharmaceuticals (10 biokinetic models) and then the effective dose was calculated using the ICRP 103 tissue weighting factors based on the following formula [1]:

$$E = \sum_T w_T \sum_R w_R \frac{D(r_T, T_D)^{Male} + H(r_T, T_D)^{Female}}{2} \quad (2)$$

Where w_T and w_R are the tissue and radiation weighting factors, respectively. w_R is equal to 1 for beta and gamma radiations.

Results and discussion

Table 1 shows the calculated effective dose for radiopharmaceuticals of interest in this study and compares the results with the data published by the ICRP.

Table 1. Comparison of calculated effective dose (mSv/Bq) in this study (based on the ICRP 103) with the data published by the ICRP.

Radiopharmaceuticals	This study	ICRP	RD %[b]
Tc-99m DMSA[c]	7.55E-03	8.8E-03	-14.22
Tc-99m DTPA (Normal[a])	3.36E-03	4.90E-03	-31.40
Tc-99m DTPA (Abnormal[a])	4.49E-03	4.60E-03	-2.35
Tc-99m MAA	1.35E-02	1.10E-02	22.31
Tc-99m Q12 (Resting subject)	7.20E-03	1.00E-02	-28.04
Tc-99m Q12 (Exercise)	6.80E-03	8.90E-03	-23.55
Tc-99m Citrate complex	5.01E-03	8.30E-03	-39.63
Tc-99m Gluconate	4.71E-03	9.00E-03	-47.66
Tc-99m Penicillamine	6.98E-03	1.30E-02	-46.30
Tc-99m Albumin Microspheres	1.15E-02	1.10E-02	4.63

[a] Normal and abnormal represent normal and abnormal renal function, respectively.

[b] $RD\% = (E_{This\ study} - E_{ICRP})/E_{ICRP} \times 100$

[c] For the first six radiopharmaceuticals (up to Q12 Exercise), the biokinetic data was given from the ICRP 128, and for the rest of the radiopharmaceuticals, the biokinetic data was given from the ICRP 53.

The results show that the effective doses calculated using the ICRP 110 adult reference phantoms and the ICRP 103 tissue weighting factors are generally lower than the ICRP published data except for two radiopharmaceuticals, namely ^{99m}Tc (MAA and Albumin microspheres). The difference between the results is, on average (-20.62±23.06)%. The effective doses for ^{99m}Tc-(Gluconate and Penicillamine) are 47% and 46% lower than ICRP published data, respectively. On the other hand, the effective dose for ^{99m}Tc-MAA is 22% higher than ICRP published data. These differences can be due to the following reasons:

- Anatomical differences in the ICRP 110 phantoms and the Cristy-Eckerman phantoms.
- The calculation method: The ICRP assumes that all electrons absorb in the source organ but in this study, the electron transport was taken into account.
- The differences in the formalism and the tissue weighting factors used for effective dose calculation.

Another set of calculations was made using the same method as ICRP publications. In this case, a separate effective dose was calculated for adult male and female phantoms (based on ICRP 60 formalism). Comparison of results shows that even with the same calculation method, the calculated effective doses for the ICRP adult reference phantoms are generally lower than the corresponding published data except for ^{99m}Tc (MAA and Albumin microspheres). For adult male phantom, also the effective dose of ^{99m}Tc-DMSA is about 1 % higher than the ICRP published data.

Conclusion

According to the results, the application of ICRP 110 adult reference phantoms and the ICRP 103 tissue weighting factors, generally leads to a reduction in the calculated effective dose except for some radiopharmaceuticals. This can lead to a reduction in the collective effective dose of patients undergoing different diagnostic nuclear medicine procedures. This reduction is significant in some cases.

مراجع

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