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EDITORIAL

Extremity doses of nuclear medicine personnel: a concern

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Introduction

Nearly one in five workers in nuclear medicine is likely to receive more than the legal dose limit for the skin of 500 mSv per year according to a recently completed ORAMED study [1, 2]. ORAMED (Optimization of RAdiation protection of MEDical staff) was a European FP7 project which aimed to develop methodologies for better assessing and reducing the exposure to radiation of personnel working in interventional radiology and cardiology and nuclear medicine. One of the goals of the project was to determine extremity doses of workers in nuclear medicine during the preparation and administration of radiopharmaceuticals. Six countries participated in the study, and large numbers of procedures using ^{99m}Tc (n=335), ^{18}F (n=306) and ^{90}Y (n=127) were monitored.

In stark contrast with the finding of too high extremity doses is the general lack of attention in nuclear medicine paid to extremity dosimetry. The main purpose of this contribution is therefore to emphasize that extremity exposure is a real concern needing the attention of the professional societies and the technical and medical staff. In addition, some guidance is provided in measuring and lowering the extremity dose.

Risks of commonly used radionuclides

The ORAMED project [1, 2] considered ^{99m}Tc, ^{18}F and ^{90}Y, but did not include ^{68}Ga and ^{124}I. The latter two nuclides are increasingly used in PET and they have relatively unfavourable risk profiles. Here we consider all five radionuclides. Their basic physical characteristics are summarized in Tables 1 and 2 [3–5]; some of these are briefly discussed to illustrate the relative radiation hazards of the nuclides.

According to Table 1, the 511 keV annihilation radiation of ^{18}F and ^{68}Ga causes a nearly eightfold higher whole-body dose than the 141 keV gamma photons from ^{99m}Tc [3]. This is a result of the higher energy of the annihilation radiation (511 keV versus 141 keV) and the formation of two 511 keV photons per decay of these positron emitters, whereas ^{99m}Tc emits only one photon per decay. Beta-minus, positron and electron particles emitted by the commonly used nuclides do not directly contribute to the body dose as this is measured at a depth of 10 mm which is too deep for these particles to reach.

When positrons are not completely stopped, e.g. by the liquid in which they are present or the material surrounding the activity, they contribute to the skin dose. In the case of

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Table 1 Exposure parameters of some radionuclides [3, 4]

Nuclide	Body dose[a] due to point source in air [mSv.m^2/(GBq.h)]	Skin dose[b] due to contact with 5-ml syringe [mSv/(MBq.h)]	Skin dose[b] due to contamination with 50 μl on 1 cm^2 [mSv/(kBq.h)]	Lead shielding (mm) To lower transmission to one-half	Lead shielding (mm) To lower transmission to one-tenth
^{99m}Tc	0.02168	0.354	0.00877	0.3	1
^{18}F	0.1655	2.88	0.788	6	17
^{68}Ga	0.1580	31.4	1.25	6	17
^{124}I	0.1745	10.7	0.36	8	31
^{90}Y	0	43.5	1.35	Total β-absorption in 9.2 mm plastic	

[a] Strictly ambient dose equivalent, H*(10), effectively due to gamma radiation.

[b] Personal dose equivalent, Hp(0.07), in principle due to electrons, beta and gamma radiation

point sources of ^{18}F, ^{68}Ga and ^{124}I in air, at a distance of 30 cm, the positron contribution to the skin dose is about 66, 60 an 13 times the contribution of gamma radiation, respectively [4]. This shows that radiation protection of the skin against PET nuclides should in the first place be directed at stopping the positrons.

For bare 5-ml syringes held with the fingers, the skin doses for ^{18}F, ^{68}Ga and ^{124}I are 8, 89 and 30 times higher than for ^{99m}Tc, respectively [4]. Note that positrons from ^{18}F have a lower energy (and range) than those of ^{68}Ga and ^{124}I, and many more of them are therefore stopped in the syringe and do not contribute to the skin dose. A 5-ml syringe with 1 GBq of ^{68}Ga causes a skin dose rate of 8.7 mSv/s, which means that the annual dose limit of 500 mSv would be reached in less than 1 min of contact. For such high-energy positron emitters in a syringe or vial the contribution of positrons to the skin dose is dominant, and protection against these positrons should again be the first goal.

In the case of skin contamination, the ratios of the skin doses with respect to ^{99m}Tc are 90, 143 and 41 (Table 1). In this situation also for ^{18}F only a few positrons are stopped in the very thin source forming the contamination.

Table 2 Some radionuclides and their decay properties relevant to occupational exposure [5]

Nuclide	Energy gamma (intensity) [keV, (per decay)]	Maximum energy beta particle (intensity) [keV, (per decay)]
^{99m}Tc	141 (89%)	–
^{18}F	511 (193%)	634 (97%)
^{68}Ga	511 (178%)	1,899 (88%)
^{124}I	511 (45%), 603 (63%), 723 (10%)	1,535 (12%), 2,138 (11%)
^{90}Y	-	2,284 (100%)

The 511 keV gammas originate from positron annihilation; their intensity is taken as two times the positron intensity, assuming local annihilation

The beta-minus emitter ^{90}Y is extensively used in therapy. It has a high maximum beta energy (Table 2) causing many beta particles to escape from a vial or syringe, resulting in a high skin dose from holding a bare container (12 mSv/s for a 5-ml syringe containing 1 GBq). Note that this is only slightly higher than for ^{68}Ga (8.7 mSv/s per GBq, a value dominated by the contribution of positrons). In other words, a high-energy positron emitter such as ^{68}Ga combines the risks of ^{18}F as far as annihilation radiation is concerned and (nearly) the risk of ^{90}Y as far as positrons are concerned.

In conclusion, these considerations show that the risk of an elevated skin dose is much higher for the beta (beta-minus and positron) emitters considered here than for ^{99m}Tc, the nuclide many workers in nuclear medicine first encountered.

Data on extremity dose

When handling unsealed radiopharmaceuticals, the skin of the hands of nuclear medicine personnel is the organ most at risk. The ICRP has recommended that the personal dose equivalent Hp(0.07), the dose at a depth of 0.07 mm, be used as a measurable proxy for the equivalent skin dose [6]. The annual dose limit of 500 mSv applies to the average over the single square centimetre with the highest exposure [6].

Assessment of compliance with the skin dose limit of 500 mSv/year is difficult in practice as the area with the highest exposure has to be monitored. This location is not known in advance, and it can vary from procedure to procedure, but most often it is the tip of one of the fingers or the thumb [1, 2]. Unfortunately, it is not practical to put a dosimeter at the tip of a digit, as this would affect the digit's use, and also because the fragile dosimeter would easily fracture. Furthermore, the dose must be measured at the tissue depth equivalent to 0.07 mm. This is not trivial for beta particles and positrons, because it requires very thin detectors with thin covers. So far extremity dosimetry has mostly been performed using ring finger or wrist dosimeters, which has been found to result in severe underestimation of the extremity dose [1, 2]. Even worse, in most hospitals extremity dosimetry is not being performed at all.

We only mention the most relevant findings from the ORAMED study; for the complete results we refer to the website [1] and publications [2]. In the study, detailed doses were measured on the fingers, thumb and wrist using thin LiF:Mg,Cu,P thermoluminescence dosimeters. The measurements were complemented by Monte Carlo simulations. For all procedures, in diagnostics as well as in therapy, the difference between minimum and maximum extremity doses was huge, as is illustrated by Table 3. Evidently bad practices were also observed, e.g. holding bare vials and syringes with the fingers. The authors estimated that between 15% and 20% of those working with both ^{99m}Tc and ^{18}F may exceed the annual skin dose limit of 500 mSv. Similar finger doses have been reported by Covens et al. [7] in a review and by Rimpler and Barth [8].

For ^{124}I, the highest skin dose (on the thumb) measured for preparation was 9.5, 3.1 and 1.0 mSv/GBq, depending on the degree of optimization of the procedure [9]. However, the first method was already rather well optimized, and much higher skin doses will be incurred if protection is poor. For ^{68}Ga no experimental data are available as far as we know.

The ORAMED study paid special attention to the estimation of the maximum skin dose in daily practice. For all three nuclides studied the authors concluded that the dose measured by a ring dosimeter with the detector on the palmar base of the forefinger of the nondominant hand gave an acceptable estimate of the maximum skin dose, provided a correction factor of about 6 was applied.

Covens et al. also investigated skin contamination (this work is also presented in reference [1]). Of the 300 procedures monitored, 9% revealed a contamination, while all workers were unaware of it. Skin doses up to 30 mSv due to a single contamination were estimated.

Table 3 Maximum skin doses of both hands in nuclear medicine procedures measured within the ORAMED project [1, 2]

Procedure	Skin dose (μSv/GBq)		
	Mean	Minimum	Maximum
^{99m}Tc preparation	432	33	2,062
^{99m}Tc administration	233	12	951
^{18}F preparation	1,205	97	4,433
^{18}F administration	933	139	4,113
^{90}Y DOTATOC preparation	2,100	100	7,400
^{90}Y DOTATOC administration	1,900	400	4,900
^{90}Y Zevalin preparation	11,000	700	63,700
^{90}Y Zevalin administration	4,800	700	24,600

Shielding

The differences in gamma radiation emitted by ^{99m}Tc, ^{18}F, ^{68}Ga and ^{124}I also affect shielding requirements, as is illustrated in Table 1. Shielding should be used whenever possible and it should be adapted to the radionuclide that is being handled. The ORAMED study assessed the benefit of shielding using Monte Carlo simulations. For ^{99m}Tc, shielding with 2 mm tungsten or lead should usually be sufficient. For ^{18}F, syringe shields of tungsten (or lead) of 5 mm or preferably 8 mm thickness should be used. For ^{90}Y, shielding with tungsten is best, as a shield of 5 mm tungsten has been shown to give better protection than 10 mm acrylic in recent studies [10–12]. For syringes with less than 200–300 MBq ^{90}Y the cheaper acrylic is satisfactory, however. The studies [10–12] also indicate that a shield of just tungsten is the best choice for the high-energy positron emitters ^{68}Ga and ^{124}I, as it both stops the positrons and attenuates the gamma radiation and bremsstrahlung. However, syringe shields do not provide protection near the syringe bottom.

Conclusions

Radiation exposure of the hands of personnel in nuclear medicine is a real concern and needs to be addressed urgently. The high doses, and the large spread of doses, are most likely due to lack of radiation awareness and optimization. Some recommendations can be formulated:

1. Professional societies should address extremity dosimetry at their meetings to disseminate information on radiation risks and how these risks can be countered.
2. Technical and medical staff have to take responsibility for their personnel by improving awareness of the existing risks, and by providing education and training. Educational material developed as part of the ORAMED project [1], or available at the IAEA [13], may be helpful.
3. Extremity doses should routinely be measured with a ring dosimeter suitable for beta and gamma radiation, worn on the palmar side of the proximal phalanx of the forefinger of the nondominant hand. A correction factor of 6 should be applied to obtain an estimate of the actual maximum skin dose. The use of dosimeters worn on the ring finger or on the wrist should be discontinued.
4. Performing a study within the workers' own department, aiming at the optimization of a procedure used in

the preparation and administration of activity for imaging or therapy, is an excellent way to achieve radiation awareness, to educate and train workers, and to show compliance with dose limits.

5. Working with positron emitters, especially with high-energy ones, should only be initiated after adequate education and training of workers.
6. Frequent checks for contamination should be performed during all handling of radioactivity.
7. Sufficient shielding materials should be provided for all stages of handling activity where skin exposure is possible. In addition, suitable forceps, pincers, tweezers and possibly other equipment should be available to keep activity at a distance while handling it. Using automated systems may also help.
8. Direct contact of the fingers with unshielded vials, syringes, tubing or valves containing radionuclides must be avoided. This should become a basic principle when handling beta emitters.

Finally, an important and reassuring conclusion from the ORAMED project and the ^{124}I study [9] is that acceptable levels of radiation exposure can be achieved when workers are trained and procedures have been optimized.

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