Guidelines to Optimize Extremity Monitoring and to Reduce Skin Doses in Nuclear Medicine. Results of the ORAMED Project

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Abstract:
ORAMED (www.oramed-fp7.eu) is a European collaborative project developed in 2008-2011 to enhance the safety and efficacy of the use of radiation in medicine, mainly in interventional procedures and in nuclear medicine. This paper focuses on summarising the project guidelines in order to optimize extremity monitoring and to reduce skin doses in nuclear medicine (NM).
NM procedures require handling of radiopharmaceuticals in contact with the extremities. NM radiopharmaceuticals are mostly photon emitters, but mixed photon/beta emitters are used for Positron Emission Tomography (PET) and pure beta emitters for many therapeutic applications. These characteristics lead to difficulties in establishing an appropriate monitoring program. On the one hand, the dosemeter has to be sensitive to a large range of radiation types and, on the other, the dosemeter should be worn close to the most exposed area on the hand. Monitoring of 124 workers from 32 hospitals in Europe highlighted that, in some cases, the maximum skin dose limit is exceeded and that, for the same type of work, there is a wide range of exposures. To complete the experimental observations, a Monte Carlo simulation of some selected typical NM scenarios was undertaken to quantify the influence of different radiation protection means. Based on the results of these studies, it can be concluded that there is a need to perform an appropriate extremity monitoring for NM staff in charge of labeling or injection of radiopharmaceuticals. Guidelines are proposed to correctly estimate hand exposure in NM and to reduce hand doses to an acceptable level.

Key words: extremity dosimetry, nuclear medicine, individual monitoring

Introduction

Nuclear medicine (NM) is a medical speciality based on the use of radioactive substances either for the production of images to diagnose different pathologies or, less frequently, for therapeutic purposes. In recent years the increase of workload at NM departments has called into question whether radiation protection standards for extremities of NM staff has adapted to the current situation. This fact has been reflected on field-related scientific literature.

Published works highlight important common points. Firstly, and especially for therapy procedures, very high finger doses are occasionally found in the literature when radiation protection measures are not optimized. In these cases, finger doses can easily exceed the annual dose limit for extremities (Rimpler *et al.* 2008, Cremonesi *et al.* 2006). Secondly, a wide range of measured doses is observed. Variations on the radiation protection measures, radionuclides and measurement methodologies, among other factors, entail large variability of results, even for similar or equal procedures (Donadille *et al*. 2008). This fact leads to the conclusion that an optimization of the procedures is still possible. The third main point is that the distribution of the dose across the hand is inhomogeneous, with very high ratios between the dose measured in the fingertips - the likeliest position of maximum dose - and the common positions for wearing a routine dosemeter. The range of reported ratios is very wide. Finally, it is clear from the reading of available works, that the use of inappropriate dosimetric material for beta or positron radiation is not rare (Carinou *et al*. 2008). On the other hand, such data diversity makes their analysis difficult to handle, as highlighted by literature reviews, Vanhavere *et al*. (2008), (ICRP 2008).

Aim and outline

The radiation protection of workers in Nuclear Medicine (NM) presents open issues that have not yet been satisfactorily addressed, in spite of growing interest in the subject. As a response to the general problems of radiation protection for medical staff, the ORAMED project (Optimization of RAdiation protection for MEDical staff) (http://www.oramed-fp7.eu/) was founded in 2008 by the European Commission. ORAMED was a collaborative project of the 7th EU Framework Programme, Euratom Programme for Nuclear Research and Training. The project lasted three years and covered the fields of Interventional Radiology and Cardiology and Nuclear Medicine, not only for extremity doses, but also for eye lens doses.

The main results of the ORAMED project can be found in the special issue of Radiation Measurements Journal (Ginjaume *et al*. 2011). The proposed recommendations to optimize radiation protection in interventional radiology and cardiology are presented in Carinou *et al*. (2011) and summarized in Carinou *et al*. (2012).

In the field of nuclear medicine the main objectives were:

- To evaluate extremity doses and dose distributions across the hands of medical staff working in NM departments.
- To study the influence of protective devices such as syringe and vial shields and to improve such devices when possible.
- To propose “levels of reference doses” for each standard NM procedure and to use these for risk assessment and optimisation of working methods.
- To propose a methodology to reduce doses to NM workers.

This paper describes the methodology followed to achieve the proposed objectives, summarizes the main results and presents some guidelines to correctly estimate hand exposure in NM and to reduce hand doses to an acceptable level.

Material and methods

To evaluate extremity doses and dose distributions across the hands of NM medical staff, an extensive measurement program was performed including 124 workers from 32 NM departments in 7 European countries, Belgium, France, Germany, Italy, Slovakia, Spain and Switzerland representing the largest number of collected data on extremity dosimetry in NM. All participants followed a common protocol.

Radiopharmaceuticals: The preparation and administration of both diagnostic and therapy procedures were studied. In diagnostics, radiopharmaceuticals labelled with ^{99m}Tc (pure gamma ray source, emitting a photon of 140 keV) and ^{18}F (positron emitter with a maximum energy of 634 keV) were included in the investigations because of their wide use. For therapeutic procedures the studies were focused on ^{90}Y (high-energy beta emitter with a maximum β^- energy of 2.28 MeV) labeled radiopharmaceuticals such as Zevalin® and DOTATOC.

Measurements: For each radionuclide, preparation and administration to the patient of the radiopharmaceutical were separated. Twenty-two TLDs, calibrated to measure the personal dose equivalent $H_p(0.07)$, were used to evaluate the skin dose at 11 positions on each hand (Figure 1). For most of the operators the measurement was repeated 4 to 5 times. In order to compare the exposure of different workers, individual measurements were normalised to the manipulated activity. The manipulated activity was defined as the activity withdrawn from the elution vial for ^{99m}Tc preparation, the activity in the mono- or multi-dose vial for ^{18}F and ^{90}Y preparation and the total activity in the injection syringe for injection.

The TLDs used by the partners were of different types, either LiF:Mg,Ti or LiF:Mg,Cu,P with thickness ranging from 7 to 240 mg.cm^{-2}. For beta and positron radiopharmaceutical only thin detectors (<10 mg.cm^{-2}) were used (Carnicer *et al*. 2011b).

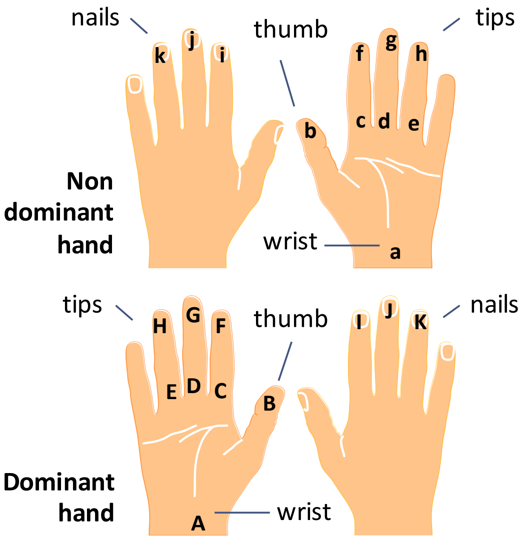

Figure 1: Skin dose measuring positions

***Monte Carlo simulations*:** A set of 6 configurations was defined, representing the most common manipulations carried out during the preparation and injection of radiopharmaceuticals: injecting the radiopharmaceuticals, holding a syringe in hand, by the piston and by the needle, holding a vial in hand and with forceps. Unshielded and shielded (PMMA, Pb, W of different thicknesses) cases were considered for ^{99m}Tc- ^{18}F- and ^{90}Y-labelled radiopharmaceuticals.

Hands were modelled as voxelized phantoms built from paraffin moulding of real hands (Figure 2). As function of the considered radionuclide and configuration, the calculations involved either the transport of photons only or a coupled photon-electron transport. The MCNPX code was used (Pelowitz 2008). These simulation were validated in selected configurations by comparing $H_p(0.07)$ values measured with TLDs on the original hand moulding with those determined by simulation.

MC calculations aimed at better determining the main parameters that influence extremity exposure, the effectiveness of different radiation protection measures, such as the design of shielding, and the degree of variability that could be "intrinsically related" to each monitored procedure.

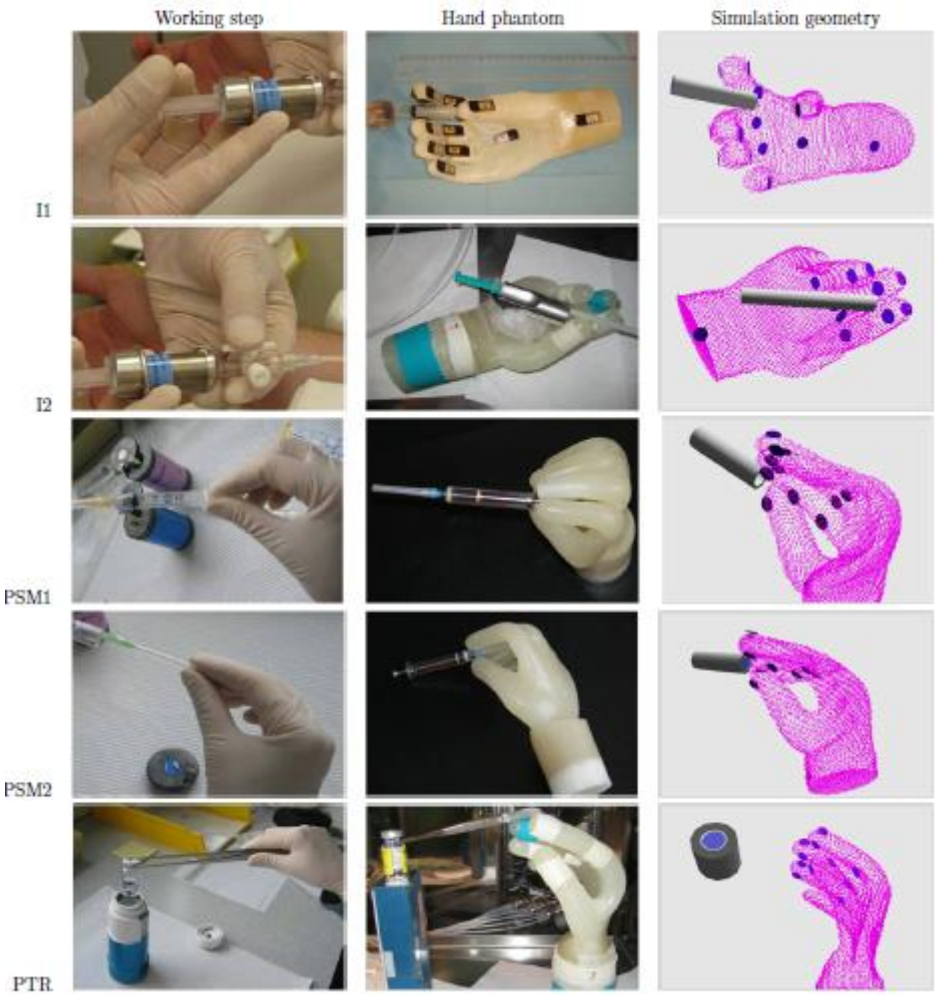

Figure 2: MC Configurations. Left: photographs of selected working steps, middle: paraffin hand phantoms, right: geometry of the simulated hand phantom

Results and discussion

Extremity doses and dose distributions across the hands of NM medical staff

Figure 3 and 4 show the maximum dose for each monitored worker (the worker is represented by a bar) for diagnostics and therapy with ^{90}Y Zevalin® procedures respectively. The first coloured values correspond to the 1st quartile (green), then (in different colours), the 2nd (blue), 3rd (yellow) and 4th (red) quartiles.

Figures 3 and 4 highlight wide ranges of maximum doses measured for identical procedures, which indicate that some workers could potentially optimize their working procedures or habits. Three main factors are associated with workers receiving high doses: working without shielded syringe and/or vial, direct contact with the source container. Some workers associated with very low exposure were found to be related to well-optimized procedures or with the use of advanced techniques, including semi-automatic dispensing tools. From these data and considering the monitored workers workload, it was estimated that 19 % of workers could exceed the maximum skin dose limit of 500 mSv, averaged over 1 cm^2 (ICRP, 2007) and almost 51% of them present estimated annual doses above 3/10th of the dose limit. The most critical situation was found for preparation of ^{18}F, in which 40% of the workers could exceed the dose limit, and 47% could receive a dose higher than 3/10th of the dose limit. In the case of ^{90}Y-Zevalin® procedures, the dose limit is not exceeded because in general the frequency of the procedure is low, but the potential risk of these procedures must not be underestimated, since doses for a single measurement can be very high whenever the radiation protection means are not appropriately undertaken.

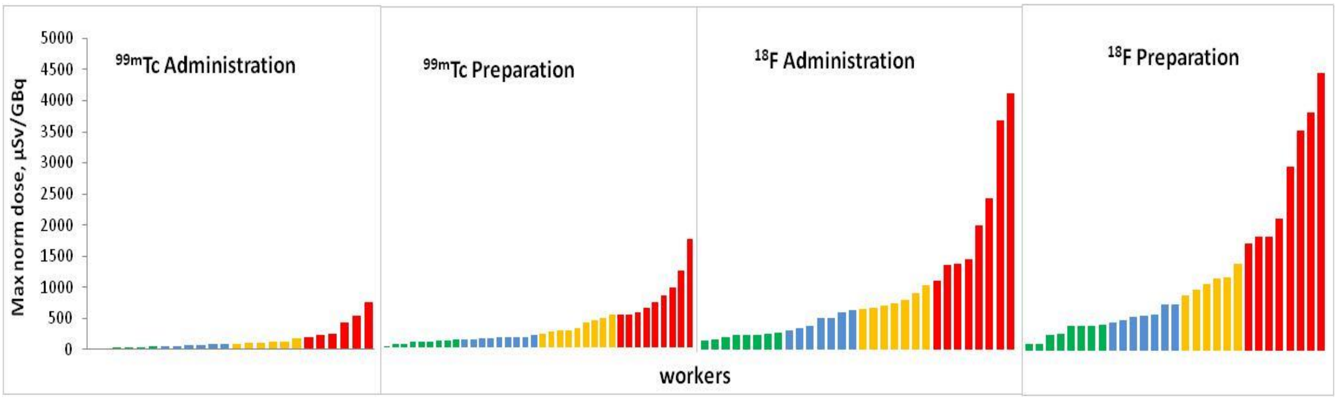

Figure 3: Maximum dose for each worker for diagnostic procedures.

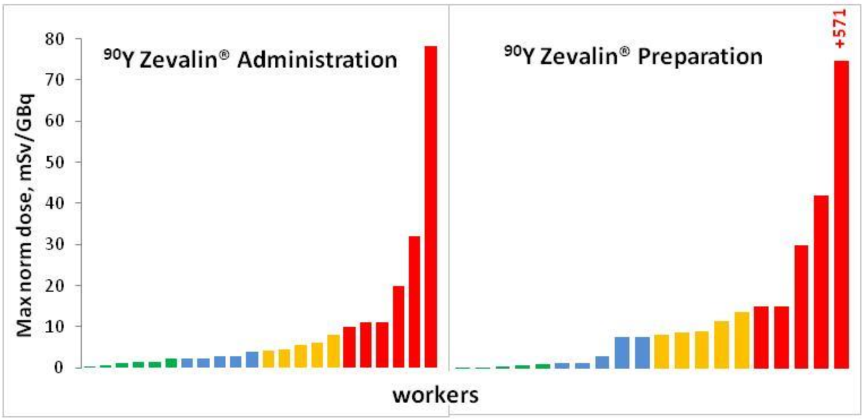

Figure 4: Maximum dose for each worker for ^{90}Y-Zevalin® procedures

Figures 5 and 6 show the frequency of the position where the maximum dose was received for diagnostics and therapy, respectively. For all procedures and when manipulating with shields, the index tip of the non-dominant hand is the position where the maximum dose is most frequently received (from 22% to more than 60%), followed by the thumb of the same hand for almost all procedures (from 7% to 20%). Less frequently, the same positions of the dominant hand were also found to be common positions with maximum dose (up to 10% for most procedures).

There is a general agreement that the fingertips are the most exposed part of the hands (Jankowski *et al*., 2003; Covens *et al*., 2010). However, there is no consensus on which hand and which particular position. From our data, it was observed that the higher exposure of one of the hands is strongly linked to the individual working habits. Nevertheless, this study, based on a large measurement campaign, showed that the fingertips of the non-dominant hand are the most exposed positions, whereas ICRP, based on a thorough literature review, reports that the same fingers of the dominant hand are the most exposed (ICRP, 2008).

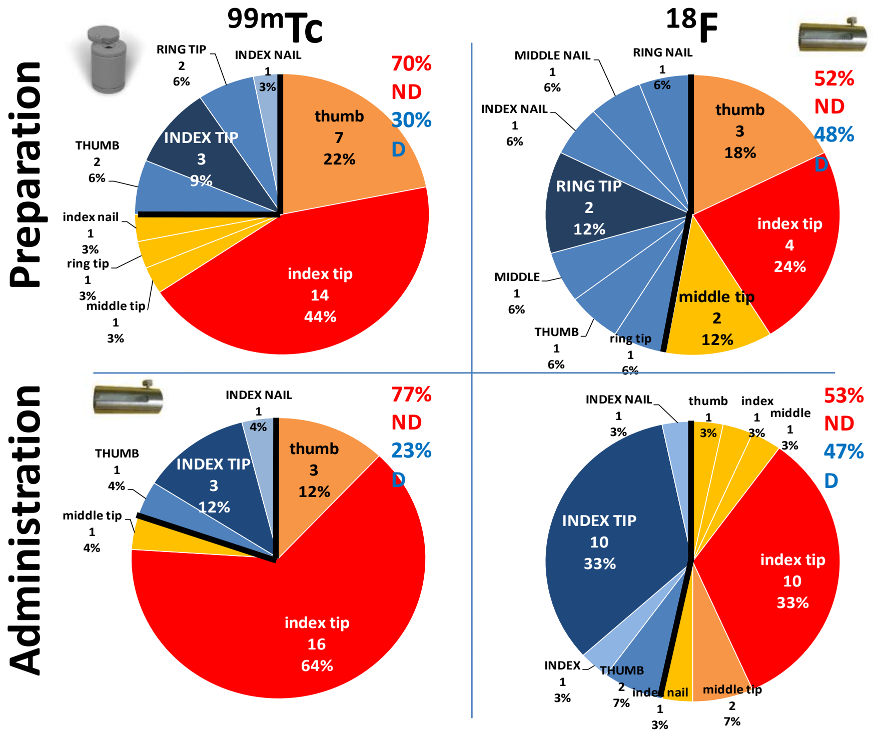

Figure 5: Frequency of the position where the maximum dose was received for each diagnostic procedure when using shielding

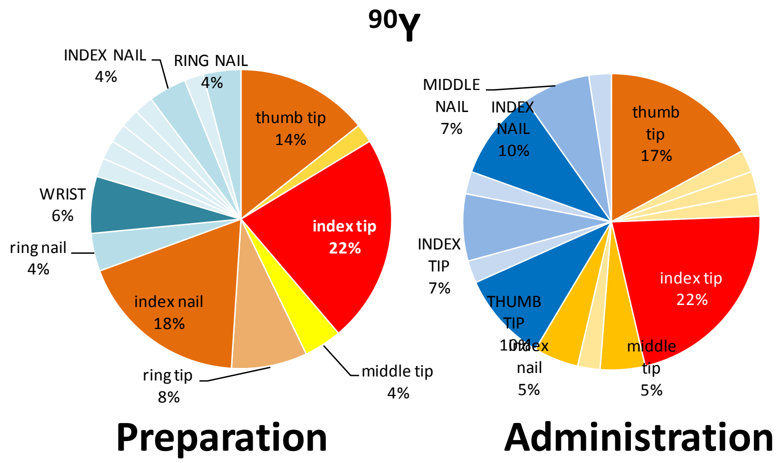

Figure 6: Frequency of the position where the maximum dose was received for ^{90}Y Zevalin® procedures

Tables 1 and 2 show the main results obtained in the ORAMED project compared with previous studies. Comparison of data among different works is a difficult task due to the many variables and parameters involved in this type of measurement, measurement methodologies (detector type, position of the detector/s on the hand...), scope of the measurements (single or multiple radionuclide/s, procedure/s, step/s within the procedure...) and in the expression of the results (how is the dose reported, what other data are given...).

Procedure	Reference	N workers	Measurements per worker	Value (position)	$<H_p(0.07)_{max}/A>$ (µSv/GBq)			
					Min	Median	Mean	Max
^{99m}Tc Administration	Carnicer *et al.* (2011a)	32	4 – 5	Max (tip)	10	120	230	950
	Tandon *et al.* (2007)[a]	54	1 – 2	Mean (ring)	5	46	175	999
	Covens *et al.* (2007)[a,b]	5	n.s.	Max (tip)	40	49	50	60
^{99m}Tc Preparation	Carnicer *et al.* (2011a)	36	4 – 5	Max (tip)	30	250	430	2060
	Tandon *et al.* (2007)[a]	54	1 – 2	Mean (ring)	2	46	113	361
	Wrzesién *et al.* (2008)	13	3-4[a]	Max (tip)	30	-	260	2000
	Covens *et al.* (2007)[a,b]	2	n.s.	Max (tip)	20	65	65	110
	Leide-Svegborn(2011)[b]	3	3-7	Max (tip)	20	29	57	121
^{18}F Administration	Carnicer *et al.* (2011a)	30	4 – 5	Max (tip)	140	640	930	4110
	Tandon *et al.* (2007)[a]	3	1 – 2	Mean (ring)	155	218	232	324
	Covens *et al.* (2007)[a,b]	5	n.s.	Max (tip)	210	320	321	530
	Covens *et al.* (2010)[b]	8	5[a]	Max (tip)	200	280	350	750
	Covens *et al.* (2010)[b,d]	8	2-3[a]	Max (tip)	3.5	10	11	30
^{18}F Preparation	Carnicer *et al.* (2011a)	30	4 – 5	Max (tip)	100	830	1200	4430
	Tandon *et al.* (2007)[a]	3	1 – 2	Mean (ring)	65	87	83	98
	Covens *et al.* (2007)[a,b]	2	n.s.	Max (tip)	290	570	570	850
	Covens *et al.* (2010)[b]	2	25 [a]	Max (tip)	90	320	500	1300
	Covens *et al.* (2010)[b,d]	2	10 [a]	Max (tip)	4.5	9	10	18

n.s. Not specified
[a] Values not directly reported
[b] Approximate values (taken from graphs)
[c] Normalized by the eluted activity plus activity manipulated during radiopharmacy work
[d] Automated dispensing and injection system (Posyjet)

Table 1: Comparison of values of hand skin dose in NM diagnostics in several published works. (Adapted from Carnicer *et al.* 2011a).

Procedure	Reference	N workers	N Measurements	$<H_p(0.07)_{max}/A>$ (mSv/GBq)			
				Min	Median	Mean	Max[c]
^{90} Y-Zevalin® Preparation	Rimpler *et al.* (2011)	15	1-5	0.7	8.0	8.0	32
	Rimpler *et al.* (2011)[a]	20	1-5	0.2	7.6	37	570
	Rimpler *et al* (2008)	11	n.s.	2	5.4	-	13(600)
	Geworski *et al.* (2006)	7	n.s.	1.4	-	4.0	8.1
	Cremonesi *et al.*(2006)[b]	n.s.	15	0.1	1.5	1.9	28
^{90} Y-Zevalin® Administration	Rimpler *et al.* (2011)	19	1-5	0.7	2.9	4.1	11
	Rimpler *et al.* (2011)[a]	22	1-5	0.3	3.2	8.2	78
	Rimpler *et al* (2008)	14	n.s.	0.7	1.0	-	7(27)
	Geworski *et al.* (2006)	8	n.s.	0.4	-	3.3	10.6

n.s. Not specified
[a] Data including outliers
[b] Values not directly reported
[c] Values in parenthesis correspond to outliers and are not considered in the mean and median calculation

Table 2: Comparison of values of hand skin dose in NM therapy in several published works. For all works measurements are taken at the maximum (finger tip). (Adapted from Carnicer 2011c).

Table 1 and 2 highlight a large range of measured skin doses for a given procedure, within a specific study. This trend is higher for studies including larger number of workers (Carnicer 2011c; Wrzesien *et al*. 2008; Lindner *et al*. 2003; Tandon *et al*. 2007(for ^{99m}Tc)). Studies with a smaller number of workers and measurements - (Covens *et al*. 2007; Covens *et al*. 2010; Leide-Svegborn 2011; Tandon *et al*. 2007 (for ^{18}F)) present shorter ranges (without considering isolated outliers indicated in parenthesis) and lie within the ranges found by the largest studies. In addition, it is shown, that preparation of radiopharmaceuticals generally involves higher finger doses per activity than administration. In addition, skin dose per activity is also generally higher for ^{18}F than for ^{99m}Tc.

Parameters of influence on skin dose to the hands

The MC simulation sensitivity study revealed that short source displacements (of up to some few cm) and volume changes (of up to 3 ml) can increase the maximum dose by a factor from 3 to 5 depending on the source (Ferrari *et al.* 2011)

Shielding was found to be, both in the MC study and the measurement data analysis, the most influent parameter to reduce hand dose exposure in nuclear medicine. This is in agreement with the conclusions of the ICRP review (2008) and other authors (Martin and Whitby 2003). Even though the use of shields slows down the procedure and can be uncomfortable for technicians especially for heavy and thick shields, their use provide a protection which cannot be replaced by increasing working speed.

MC simulations provided very valuable information in the study of the influence of shielding. The simulations were used to determine what type of material and which thickness represented the best skin dose reduction. Working with a different radionuclide implies different shielding to be used. The recommended shielding can be summarized as follows:

For the injection (concerning the syringe shielding):

- 2 mm W (or Pb) for ^{99m}Tc give a dose reduction of at least 2 order of magnitudes;
- 5 mm W provides up to a factor of 10 in dose reduction for ^{18}F (8 mm W up to a factor 40).
- For ^{90}Y 10 mm PMMA completely shield beta radiation, nevertheless 5 mm shielding of W provides a slightly better shielding cutting down bremsstrahlung radiation too.

For the preparation (concerning the vial shielding):

- For ^{18}F, 3cm of Pb provides 2 order of magnitude on dose reduction. The same attenuation for ^{99m}Tc is obtained with 2 mm Pb. 3 mm Pb lead provides one order of magnitude of additional attenuation.
- For ^{90}Y an acceptable shielding is obtained with 10 mm PMMA with an external layer of a few mm of lead or alternatively 5 mm of W.

As regards the above mentioned reduction factors, it must be kept in mind that the MC calculations correspond to static scenarios and, in practice, the efficiency of the shielding will be lower.

Extremity dosimetry

Based on the analysis of the position of the maximum hand skin dose, it is recommended to place the extremity dosemeter at the index tip or at the base of the index finger of the non-dominant hand. The detector should face the palm of the hand. Comparing the ratios between dose measurements at the maximum dose position and at the usual monitoring positions, correction factors were derived to estimate the maximum skin hand dose from the monitor readings. A factor of 2-3 should be applied for the indextip, a factor of 6 for the base of the index finger and a factor of 20 for the wrist. The latter position is not recommended for NM (Sans-Merce *et al.* 2011).

Guidelines to optimize extremity monitoring and to reduce skin doses in nuclear medicine

From the analysis and interpretation of the data obtained from the measurement campaign as well as from the simulations, the following guidelines are proposed.

1. Extremity monitoring is essential in nuclear medicine.
2. To determine the position for routine monitoring, the most exposed position on the hand for each worker should be found by individual measurements for a short trial period. If for practical reasons, these measurements are not possible, the base of the index finger of the non-dominant hand with the sensitive part of the dosemeter placed towards the inside of the hand is the recommended position for routine extremity monitoring in nuclear medicine.

3. To estimate the maximum dose, the reading of the dosemeter worn at the base of the index finger of the non-dominant hand should be corrected by a factor of 6.
4. Shielding of vials and syringes is essential. This is a precondition but not a guarantee for low exposure, since not all parts (e. g. bottom of the syringe) are shielded during use.
5. The minimum acceptable thickness of shielding for a syringe is 2 mm of tungsten or lead for ^{99m}Tc and 5 mm of tungsten for ^{18}F. For ^{90}Y, 10 mm of PMMA completely shields beta radiation, but a shielding of 5 mm of tungsten provides better protection, as it cuts down bremsstrahlung radiation.
6. The minimum acceptable shielding required for a vial is 3 mm of lead for ^{99m}Tc and 3 cm of lead for ^{18}F. For ^{90}Y, acceptable shielding is obtained with 10 mm of PMMA with an external layer of a few mm of lead.
7. Any tool increasing the distance (e.g. forceps, automatic injector) between the hands/fingers and the source is very effective for dose reduction.
8. Training and education in good practices (e.g. procedure planning, repeating procedures using non radioactive sources, estimation of doses to be received) are more relevant parameters than the worker's experience level.
9. Working fast is not sufficient, the use of shields or increasing the distance are more effective than working quickly.

Conclusions:

The ORAMED project has contributed to enlarge knowledge on hand skin dose levels and dose distribution across the hand in NM by providing the most comprehensive data on extremity exposure of staff in nuclear medical so far. Based on this information and on a thorough sensitivity analysis by Monte Carlo simulation, guidelines for improving protection standards and reducing staff exposures are proposed. Shielding was clearly found to be the most efficient means for dose reduction. For those steps requiring manipulation of bare syringes (e.g. for the activity check), the use of tweezers or automatic systems is recommended, especially for therapy procedures. Training material related to the optimization of radiation protection in nuclear medicine can be down-loaded for free from http://www.oramed-fp7.eu/. In addition, the website provides the instructions to receive an easy tool to estimate hand dose distribution for typical nuclear medicine procedures upon acceptance of freeware license agreement.

Furthermore, the study highlights the importance of extremity monitoring in nuclear medicine and provides specific recommendation to estimate the maximum skin dose.

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