Extremity Doses of Workers in Nuclear Medicine: Mapping Hand Doses in Function of Manipulation

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Abstract

The increasing number of medical procedures requires proper attention of extremity doses of radiopharmacy staff members in nuclear medicine. In the academic hospital of the University of Brussels (AZ-VUB), hand doses have been monitored for several years by means of wristdosimeters and ringdosimeters (TLDs). Both types are convenient to wear but do not necessarily represent the location on the hand where the highest skin dose is received. The number of manipulations, the amount of handled activity and the results of the routine monitoring emphasise the need of more detailed dosimetry for radiopharmacy workers. Mapping the dose distribution of the hand, in function of the manipulation, can give a notion about the location and the order of magnitude of the highest skin dose.

In this study, two radiopharmacists were monitored during more then 300 manipulations at 18 different locations on each hand. The results are expressed in dose per unit of handled activity during a specific manipulation. They show a good reproducibility for the individual radiopharmacist. Typical values of Hp(0.07) range from 50 to 600 µSv/GBq of handled activity and usually indicate the fingertips as the highest dose location. Particular personal habits in handling the radiopharmaceuticals determine the location and the order of magnitude of the highest skin dose, especially when manipulating radiopharmaceuticals with high exposure rates, such as ¹⁸FDG.

The calculation of the ratio “highest dose / ringdosemeter dose” and the evaluation of the total workload, made it possible to estimate the yearly received highest skin dose. This exercise shows that the annual dose limit of 500mSv can be exceeded without further optimisation but also indicates where specific radiation protection measures are appropriate.

1. Introduction

Besides some therapeutic procedures, a nuclear medicine department can be generally characterised by various diagnostic examinations involving intravenous administration of radiopharmaceuticals. These pharmaceuticals are usually labelled with ⁹⁹mTc and among the more common are also ¹⁸F, ²⁰¹TI, ¹²³I, ⁵¹Cr and ⁶⁷Ga. Current trends in clinical nuclear medicine include an emphasis on radioimmunodiagnosis, single photon emission tomography (SPECT) and positron emission tomography (PET) which mainly involves the use of ¹⁸F-labelled fluorodeoxyglucose (¹⁸FDG).

The distribution of the principal radiopharmaceuticals which contribute to extremity doses in AZ-VUB are 85% ⁹⁹mTc, 10% ¹⁸F and 5% other labelled pharmaceuticals (¹²³I, ²⁰¹TI, ⁵¹Cr,…).

Before imaging the patient with SPECT or PET, the radiopharmaceutical causes radiation exposure during a number of manipulations. Generally one can consider three basic manipulations (FIG. 1):

- During kit preparation multidose kit vials of different radiopharmaceuticals are prepared. The preparation of ¹⁸FDG occurs generally by fully automated modules in heavy shielded ‘hot cells’ and is not considered as a significant source of exposure to the extremities. This is however not the case during ⁹⁹mTc-labelling where the manipulation starts with the elution of the ⁹⁹Mo-⁹⁹mTc generator into an elution vial and ends up with the injection of a typical activity into a multidose kit vial.

- These kit vials have to be dispensed into syringes after which the individual patient activity is checked in the dose (activity) calibrator and the syringe is transferred with a shielded transport box to the administration room.

- The third manipulation is the administration to the patient. The insertion of a butterfly cannula into a vein, prior to the radiopharmaceutical administration, is prevalent in many hospitals in terms of dose reduction [5] to the staff members performing this task.
The internal organisation of these three basic tasks can differ from department to department. Radiopharmacy staff can carry out kit preparation and dispensing, while nursing staff is responsible for administration (AZ-VUB). In other hospitals radiopharmacy staff prepares the kits after which nursing staff dispenses the syringes and administers the activity. In some hospitals, nursing staff members walk through the entire procedure.

2. Extremity dose assessments

The radiation dose to the hands of staff members in nuclear medicine is mainly received during the above-described manipulations. Extremity dose assessments are usually carried out using thermoluminescent dosimeters (TLDs) because of their convenient size. For accurate measurement of $H_s(0.07)$ the dosimeter must be physically thin to avoid significant attenuation of the radiation. The dosimeter also needs to be robust because it may be placed on the hands carrying out manual work. The position on the hand at which a dosimeter is worn and the choice of hand on which it is placed both have a large influence on the value of the assessed dose, especially when working with localised sources. Since the skin dose limit is applied to the dose averaged over any area of $1\text{cm}^2[1,2]$, it is necessary to identify, as accurately as possible, the location of the highest dose. Extremity dose monitoring in a nuclear medicine department can be carried out by TLD-tapes or finger stalls which enables to measure doses at the tip of the finger. However, these dosimeters are often inconvenient during manipulations, which can result in longer exposure time. Ringdosemeters are usually worn at the base of the middle finger and are quite convenient during manipulations but give an underestimation of the highest dose. A wristdosemeter does not hamper most manipulations but results in a significant underestimation of the dose due to the distance between the wrist and the possible highest dose location. Ideally a dosimeter should be used to monitor the part of the extremity receiving the highest dose. If this is impractical, it may be necessary to monitor a different part in which case a factor may be employed to ensure dose limits are not being exceeded.

This study emphasises the distribution of the extremity doses during kit preparation and dispensing (FIG. 1.) since only two radiopharmacy staff members carry out these manipulations in AZ-VUB and substantial extremity doses were recorded during routine monitoring.

3. Materials and methods

The use of cotton gloves, prior to protective latex gloves, enables to attach PVC capsules at 18 locations (FIG. 2.) on the palm of each hand. These capsules have an attenuation thickness of $20\text{mg/cm}^2$ and can easily hold TLD100H chips (LiF:Mg,Cu,P:3.2 x 3.2 x 0.5mm). The TLDs were calibrated on a rod phantom and exposed to N150 X-rays according to ISO 4037 [3]. The exposure measurements for this calibration were conducted with a $30\text{cm}^3$ cylindrical ionisation chamber (Model PM-30 Capintec) connected to an electrometer (Model 192, Capintec). Doses were
calculated with consideration of the accompanying conversion factors $h_{ak}(0.07;N)$ for air kerma $K_a$, to equivalent dose $H_p(0.07)$. The TLDs were processed with a Harshaw-Bicron 5500 TLD reader in an atmosphere of inert nitrogen and annealed in a PTW-TLDO oven.

The time in which a single radiopharmaceutical kit or syringe is prepared (FIG. 1.) can vary. For this reason, the extremity dose measurements were carried out during a procedure, which covers the preparation of a number of kits or the dispensing of a number of syringes. The radiopharmacists logged the total handled activity during a procedure so that the results can be expressed as ‘specific skin dose’: $S_{hp}(0.07)$ (mSv/handled GBq) at a certain location (FIG 2.) on the hand. A set of 4 background TLDs was placed in the radiopharmacy during each procedure in addition to the 36 TLDs on the cotton gloves. The total batch of 40 TLDs was read out after each procedure and the average background value of the 4 TLDs was deducted before calculating the specific skin dose. The total number of procedures per radiopharmacist, the average number of manipulations and the average handled activity per procedure is shown in TABLE 1.

![FIG. 2. Location of 18 TLD100H chips on the palm of each hand. TLDs R08 and R18 correspond respectively with the position of routine ringdosemeter and wristdosemeter.](image)

### TABLE 1. Overview of the total number of extremity dose measurements

<table>
<thead>
<tr>
<th>Type of procedure</th>
<th>Number of monitored procedures per radiopharmacist</th>
<th>Average number of monitored kits/syringes per procedure</th>
<th>Average handled activity per procedure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kit preparation of $^{99m}$Tc-labelled radiopharmaceuticals</td>
<td>10</td>
<td>3</td>
<td>45 GBq</td>
</tr>
<tr>
<td>Dispensing syringes $^{99m}$Tc-labelled radiopharmaceuticals</td>
<td>30</td>
<td>5</td>
<td>4 GBq</td>
</tr>
<tr>
<td>Dispensing syringes $^{18}$FDG</td>
<td>10</td>
<td>5</td>
<td>3 GBq</td>
</tr>
</tbody>
</table>

### 4. Results

#### 4.1. Specific skin dose during manipulations

The specific skin dose $S_{hp}(0.07)$ (mSv/handled GBq) at a dose location during a procedure of several manipulation was calculated using following formula:

$$S_{hp}(0.07)_{m,i,j} = \frac{H_p(0.07)_{m,i,j} - B_{hp}(0.07)_{m,i}}{A_m} \quad (1)$$

Where: $H_p(0.07)_{m,i,j}$: Skin dose at location $j$ for radiopharmacist $i$, during a procedure of several manipulations $m$ (µSv)

3
BHp(0.07)\textsubscript{m,i}: Background value of skin dose for radiopharmacist i during a procedure of several manipulations m (µSv)

A\textsubscript{m}: Total handled activity during a procedure of several manipulations m (GBq)

The results give generally a good reproducibility for the individual radiopharmacist, despite the general bad reproducibility during manipulations of localised sources. Particular personal habits in handling the radiopharmaceuticals determine the location and the order of magnitude of the highest skin dose. FIG. 3 shows the average SHp(0.07) in function of the handled activity at the 36 different locations during kit preparation. Both radiopharmacists are right-handed and the highest specific skin dose can be found at the tip of the middle finger. However, the dose distribution of the left hand is not similar. The injection of the activity in the kit vial is carried out with a shielded syringe, which radiopharmacist B often supports with the left hand and in this way results in a dose distribution comparable to the distribution of the right hand.

![FIG. 3. SHp(0.07) at 36 locations on the hand during kit preparation of 99mTc-labelled radiopharmaceuticals](image)

During dispensing of radiopharmaceuticals, a syringe shield will not allow a good view of the liquid in the syringe. The use of the shield is impractical and hampers when an accurate volume and corresponding activity has to be drawn. Moreover, after measurement of the syringe in the activity calibrator, adjustment of the volume and removal of air bubbles from the syringe can lengthen the procedure. The specific skin dose during the dispensing of 99mTc-labelled radiopharmaceuticals (FIG. 4.) is much higher then during kit preparation, especially for radiopharmacist B, who carries out more adjustments to the drawn volume. The high results on the non-dominant left hand are caused by the removal of air bubbles from the syringe.
**FIG. 4.** SHp(0.07) at 36 locations on the hand during dispensing of $^{99m}$Tc-labelled radiopharmaceuticals

$^{18}$FDG causes much higher (7x) exposure rates than $^{99m}$Tc-labelled radiopharmaceuticals. However nursing staff members use a 3-way valve during administration, which allows the presence of air bubbles in the syringe after dispensing. The dose distribution of the hands (FIG. 5.) shows a substantial difference between both radiopharmacists.

**FIG. 5.** SHp(0.07) at 36 locations on the hand during dispensing of $^{18}$FDG
Radiopharmacist A draws the $^{18}$FDG-syringes without the use of a syringe shield. After activity measurement and possible volume (activity) adjustment, the syringe is mounted in a tungsten shield, ready for use by the nursing staff. Radiopharmacist B uses a tungsten shield during dispensing, which is due to the weight, supported by the left hand. Activity measurement requires the removal of this shield during which it is also supported by the left hand. This results in much longer exposure time, especially for the left hand.

4.2. Ratio highest dose / ringdosemeter dose

Routine extremity dose assessments cannot be carried out at 36 locations. The use of a ringdosemeter is convenient during routine operation. The results of this study indicate however the location and the order of magnitude of the highest skin dose, which is manipulation related. In the future, the values of the routine measurements (location R08) can be multiplied by a factor to obtain the value of the highest dose. TABLE 2. shows for each manipulation the critical location and accompanying ratio in relation to the ringdosemeter location.

<table>
<thead>
<tr>
<th>Radiopharmacist</th>
<th>Manipulation</th>
<th>Highest dose location</th>
<th>Ratio highest dose / ringdosemeter dose</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Kit preparation $^{99m}$Tc</td>
<td>R06: Tip middle finger</td>
<td>1.4</td>
</tr>
<tr>
<td></td>
<td>Dispensing $^{99m}$Tc</td>
<td>L01: Tip thumb</td>
<td>7.0</td>
</tr>
<tr>
<td></td>
<td>Dispensing $^{18}$FDG</td>
<td>R04: Middle part index finger</td>
<td>2.3</td>
</tr>
<tr>
<td>B</td>
<td>Kit preparation $^{99m}$Tc</td>
<td>R06: Tip middle finger</td>
<td>1.4</td>
</tr>
<tr>
<td></td>
<td>Dispensing $^{99m}$Tc</td>
<td>R03: Tip index finger</td>
<td>2.0</td>
</tr>
<tr>
<td></td>
<td>Dispensing $^{18}$FDG</td>
<td>L09: Tip ring finger</td>
<td>6.7</td>
</tr>
</tbody>
</table>

Applying de average or the highest ratio as the future factor for routine monitoring would be incorrect since the contribution of the different manipulations to the monthly skin dose is not equal. TABLE 3. shows the average monthly workload of the nuclear medicine department AZ-VUB in terms of prepared $^{99m}$Tc-labelled kits and dispensed syringes with either $^{99m}$Tc-labelled radiopharmaceuticals or $^{18}$FDG.

<table>
<thead>
<tr>
<th>Type of manipulation m</th>
<th>Preparation $^{99m}$Tc-labelled kits</th>
<th>Dispensing $^{99m}$Tc-labelled syringes</th>
<th>Dispensing $^{18}$FDG syringes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average monthly workload WL$_m$ (GBq)</td>
<td>1000</td>
<td>600</td>
<td>60</td>
</tr>
<tr>
<td>Fraction of monthly handled activity $F_{m,i}$</td>
<td>Radiopharmacist A</td>
<td>75%</td>
<td>75%</td>
</tr>
<tr>
<td></td>
<td>Radiopharmacist B</td>
<td>25%</td>
<td>25%</td>
</tr>
</tbody>
</table>

The monthly skin dose at 36 positions of the hand can be predicted by using following formula:

$$ MHp(0.07)_{i,j} = \sum_{m=1}^{3} (SpHp(0.07)_{m,i,j} \times WL_m \times F_{m,i}) \quad (2) $$

Where: $MHp(0.07)_{i,j}$: Average monthly skin dose for radiopharmacist i at location j (mSv/month)

$SpHp(0.07)_{m,i,j}$: Specific skin dose for radiopharmacist i at location j during a procedure of several manipulations m ($\mu$Sv/handled GBq)

$WL_m$: Average monthly workload for type of manipulation m

$F_{m,i}$: Fraction of monthly handled activity by radiopharmacist i during manipulation m (%)
The results of the calculation (2) are shown in FIG. 6. and FIG. 7. for respectively radiopharmacists A and B and confirm the accuracy of the SHp(0.07) values at location R08 since the average routine results of the ringdosemeter (year 2002) can be compared to the values calculated with formula (2).

FIG. 6. Radiopharmacist A: Distribution of MHp(0.07) for 3 main manipulations

FIG. 7. Radiopharmacist B: Distribution of MHp(0.07) for 3 main manipulations
The results point out an overall ratio “highest dose/ringdosemeter dose” of “2.3” for both radiopharmacists. Without radiation protection measures, these staff members will easily exceed the yearly dose limit of 500mSv.

Former studies [4, 5, 9, 10] indicate the highest dose location on the dominant hand (fingertip index finger). Some of these studies also calculated the ratio between doses at the fingertip and doses at the base of middle finger during dispensing of $^{99m}$Tc-labelled radiopharmaceuticals. References [5] and [10] found ratios ranging from 4 to 5 between the doses at these two locations. Dhanse et al. [9] state that trained staff members show ratios of only 2 when proper syringe shields are used.

5. Options of radiation protection measures

Many dose reduction tools are commercially available for elution vials, kit vials and syringes. Materials are usually lead, tungsten and high-density lead glass. The attenuation factors range from 4 to 200 depending on the design, material and the radionuclide for which the protective tool is used. These attenuation factors do not result in dose reduction by the same order of magnitude. Quality assurance and radiation protection of patients in a nuclear medicine department requires activity measurements in the dose calibrator, which involves the manipulation of unshielded syringes. Several authors [5-8] studied the value of syringe shields during dispensing of $^{99m}$Tc-labelled radiopharmaceuticals and concluded that the extremity dose is only reduced by 30% for most types of syringe shields. Due to the poor effect of most syringe shields, departments should emphasise on performing radiopharmaceutical manipulations in the minimum time. In the meantime, quality assurance regarding the nuclear medicine patient should be preserved. The results of MHp(0.07) in FIG. 7 and 8 indicate that one needs to optimise radiation protection during all three manipulations. Bad habits like supporting the syringe with the left thumb and/or index finger during removal of air bubbles can possibly be avoided in the future. Other measures like drawing $^{18}$FDG syringes without a tungsten shield are not obvious but indicate a significant difference according to FIG. 6. With the increasing number of PET-examinations automated dose dispensers for $^{18}$FDG are now commercially available. These automated systems are very expensive and do not give the excepted dose reduction compared to the use of proper syringe shields [8]. The time the staff member needs to remove the filled syringe from the automated dose dispenser is in fact approximately the same when a shielded syringe is filled manually.

Other solutions for skin dose reduction like ‘Activofix’ [11] are innovating and based on an well thought-out concept. It is however not sure that this system will cover all different aspects of the three basic manipulations in the radiopharmacy department.

6. Conclusion

Extremity dosimeters should not hamper nuclear medicine staff members in order to perform the radiopharmaceutical manipulations in the minimum time. Ringdosemeters can be worn at the base of the middle finger and are convenient during work. This study indicates the highest dose location on the hand, which is surprisingly for both radiopharmacists located on the non-dominant hand. The quantitative results emphasise the implementation of a multiplication factor to obtain the highest skin dose from routine monitoring with ringdosemeters. Avoiding bad habits during which high dose rates are received can reduce the present calculated factor of 2.3 to a value of “1.5”. Further radiation protection measures are however necessary since the skin dose would still reach the value of 400mSv/year. The distribution of monthly-received skin dose shows that these measures should cover all three described manipulations.

References


