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PRELIMINARY ASSESSMENT OF THE DOSE TO THE INTERVENTIONAL RADIOLOGIST IN FLUORO-CT-GUIDED PROCEDURES

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A preliminary assessment of the occupational dose to the intervention radiologist received in fluoroscopy computerised tomography (CT) used to guide the collection of lung and bone biopsies is presented. The main aim of this work was to evaluate the capability of the reading system as well as of the available whole-body (WB) and extremity dosemeters used in routine monthly monitoring periods to measure per procedure dose values. The intervention radiologist was allocated 10 WB detectors (LiF : Mg, Ti, TLD-100) placed at chest and abdomen levels above and below the lead apron, and at both right and left arms, knees and feet. A special glove was developed with casings for the insertion of 11 extremity detectors (LiF:Mg, Cu, P, TLD-100H) for the identification of the most highly exposed fingers. The $H_p(10)$ dose values received above the lead apron (ranged 0.20–0.02 mSv) depend mainly on the duration of the examination and on the placement of physician relative to the beam, while values below the apron are relatively low. The left arm seems to receive a higher dose value. $H_p(0.07)$ values to the hand (ranged 36.30–0.06 mSv) show that the index, middle and ring fingers are the most highly exposed. In this study, the wrist dose was negligible compared with the finger dose. These results are preliminary and further studies are needed to better characterise the dose assessment in CT fluoroscopy.

INTRODUCTION

Staff doses in interventional radiology procedures are generally higher than those received in other radiology practices(1). The use of personal protective devices such as lead aprons, gloves, thyroid shields and goggles is recommended, and depending on the practice this may be complemented with other devices such as screen and table shields. As the dose distribution pattern is often unknown, the individual monitoring of staff also raises some questions like the number and correct positioning of the whole-body (WB) and of the extremity dosemeters. Vañó and Faulkner(2) recommend the use of robust and adequate monitoring arrangements for staff. The analysis of individual monitoring data generated by WB and extremity measurements is not easy and suggests the need of further studies, particularly for some techniques(3).

Computerised tomography (CT) is a useful imaging technique to guide biopsies and other interventional procedures such as radiofrequency ablation, benefiting from the identification of very small lesions and allowing the visualisation of the needle tip and of the critical structures along its entry path, as well as providing evidence that the sample was collected from the place of interest(4). The CT-fluoroscopy mode(5), available commercially since 1994, is increasingly used in the more complex cases such as lung biopsies, where real time in room imaging presents a clinical advantage. During CT-fluoroscopy-guided procedures, the interventional radiologist is generally located in the treatment room close to the patient and the source detector plane. The use of needle holders has been suggested as a way to move the operator's hand away from the direct beam, but the use of such devices is not always possible due to loss of grip and sensitivity(6). Due to the characteristics of the beam the dose distribution pattern may produce an exposure of the upper and lower limbs as well as a highly inhomogeneous exposure of the needle-holding hand. Since CT fluoroscopy was introduced in IPOPFG, E.P.E. in 2007, staff dose assessment became an increased concern, and several new measures were implemented(7).

The individual monitoring system at ITN provides customers a WB dosemeter based on a TLD-100 detector exchanged on a monthly basis, while the extremity detector is mainly based on TLD-100H. In this work, a preliminary study was made to

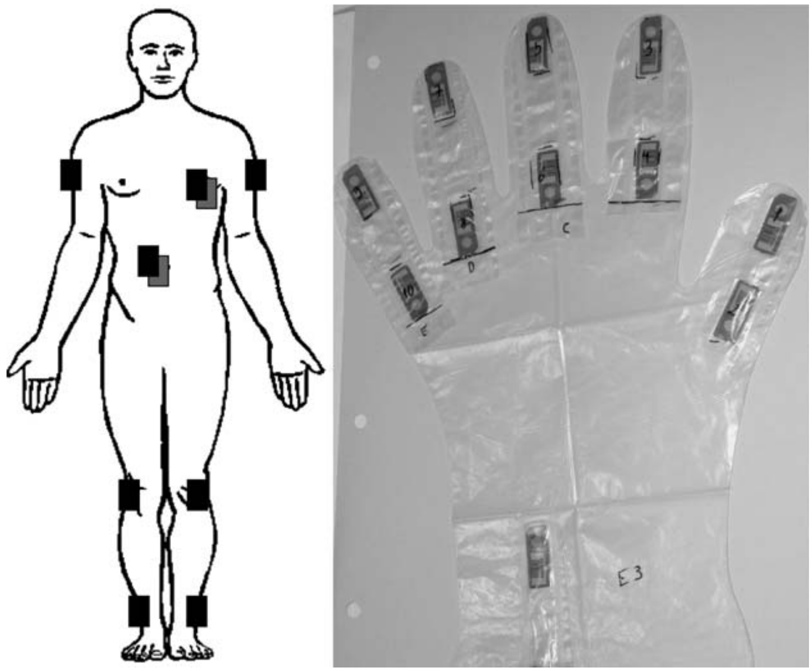

Figure 1. Left: Distribution of the 10 WB dosemeters: dark grey (■) above and light grey (■) below the lead apron. Right: glove prepared with 11 detectors inserted in casings for hand monitoring: one on the wrist position and two per finger at tip (A) and finger base (B).

measure the dose values received during eight biopsies guided by CT fluoroscopy. In the setup, the potential position and likelihood of left and/or right irradiation of the interventional radiologist by direct and scattered radiation, was considered. The aims of this work were to evaluate the possibility to measure 'per procedure' WB doses with TLD-100, both below and above the lead apron at chest and at waist levels. Considering the laterality issues typical of this examination, the possibility to measure dose levels to arms, legs (at knee level) and feet was also investigated. Relatively to the extremity dosemeters, 'per procedure' measurements were expected as the dosemeter is based on the hypersensitive TLD-100H. A special glove with several casings was designed and tested in order to better meet the purpose of allowing a sufficient number of dosemeters to identify fingers and finger spots representative of higher exposure levels, minimising sensitivity loss as much as possible.

MATERIALS AND METHODS

In this work, data were collected during eight CT-fluoroscopy-guided procedures, namely six lung and two bone biopsies. The CT scanner used was a 4-slice Toshiba Asteion, and the X-ray tube was operated at 120 kV with 8-mm beam collimation. The individual monitoring system in use at ITN is based on two Harshaw 6600 readers. The whole-body (WB) dosemeter consists of the Harshaw 8814 card and holder containing two LiF:Mg,Ti (TLD-100) detectors with the adequate filtration for the measurement of the personal dose equivalents $H_p(10)$ and $H_p(0.07)$. The extremity dosemeter is of the Ext-Rad type with LiF:Mg,Cu,P (TLD-100H) detectors for the measurement of $H_p(0.07)$. Both types of dosemeters are regularly calibrated at ITNs Laboratório de Metrologia das Radiações Ionizantes. The WB dosemeters are calibrated in terms of $H_p(10)$ and $H_p(0.07)$ using a ^{137}Cs beam incident on a ISO slab phantom[8, 9].

The dose values evaluated with the WB dosemeters were modified by a correction factor to take into account the energy dependence of the detector[10]. The extremity dosemeters were calibrated in terms of $H_p(0.07)$ using an N120 X-ray beam incident on an ISO rod phantom[9, 11]. In each procedure, the interventional radiologist was allocated 10 WB dosemeters as well as a glove with 11 extremity detectors. The WB dosemeters were positioned above and below the lead apron at the chest and waist levels, on the left and right arms, knees and feet, as described in Figure 1. The extremity dosemeters were inserted on the glove's casings, two per finger and one on the wrist, as shown in Figure 1. Radiation reduction examination gloves (Boston Scientific) were used over this glove and a third sterilised one was worn on top. The limit of detection of the dosimetry system was determined according to Hirning's[12] *Level I* (immediate readout) for each type of dosemeter. For WB detectors, the limit of detection is 0.02 mSv in terms of $H_p(10)$ and $H_p(0.07)$, and for extremity detectors is 0.07 mSv in terms of $H_p(0.07)$[11]. The dosemeters were re-set the day before the irradiations and readout using the usual procedures[10, 11] the day after the irradiations took place. Transit dosemeters were used with dose values of 0.02 mSv for the WB and of 0.10 mSv for the Ext-Rad set. Typical uncertainties for these measurements were: for WB 12 % and 9 % for $H_p(10)$ and $H_p(0.07)$, respectively, and for extremity 9 %.

RESULTS AND DISCUSSIONS

Table 1 shows the results obtained with the WB dosemeters for the assessment of $H_p(10)$ at the chest and waist levels, as well as the fluoroscopy time corresponding to the time the medical doctor was inside the treatment room and an estimate of the effective dose as described below. The $H_p(10)$ 'per procedure' dose values varied between 0.20 and 0.03 mSv for the dosemeters above the lead apron and between 0.06 and 0.03 mSv for the dosemeters below the lead apron. In most cases, the dosemeters located beneath the lead apron showed very low dose values. Above the lead apron, the dose values measured at the waist level showed a shorter range between 0.08 and 0.02 mSv, while at chest level the values varied between 0.20 and 0.03 mSv. Although few results were obtained, it seems possible to measure dose values per procedure with WB dosemeters based on TLD-100 detector material. A preliminary estimate of the effective dose E can be performed based on the expression recommended in the legislation[13] $E = H_p(10)_u + 0.05 H_p(10)_o$, where subscripts u and o stand for under and over the lead apron, respectively. Considering the values provided by the chest dosemeters, the effective dose 'per procedure' ranged from 0.07 and 0.03 mSv.

In Table 2 the results of $H_p(0.07)$ measured in each procedure with the WB detector positioned at the arm, knee and foot levels are shown. For the left arm the values ranged between 0.59 and 0.07 mSv and for the right arm, from 0.17 to 0.03mSv. It was observed that in five procedures, the left arm detector presented dose values 10 times higher than the right arm. The detectors placed at the foot level presented dose values that ranged between 0.17 and 0.04 mSv, but there is no predominance of the left compared with the right detector. The dose measurements performed at the knee level are lower and less spread, varying from 0.11 to 0.02 mSv, evenly distributed, again with no predominance of the right or left side. From the results presented on both tables, the use of TLD-100 based WB dosemeters for the assessment of occupational doses per procedure seems feasible.

In Table 3 the assessments of $H_p(0.07)$ performed in each procedure with the extremity dosemeters inserted on the glove casings as shown in Figure 1 are presented. The results show that in each procedure, the finger dose values may vary considerably (first, 17.58–0.58 mSv; second, 36.29–0.94 mSv; third, 19.31–0.91 mSv; fourth, 5.72–0.20; fifth, 0.36–0.05; sixth, 9.41–0.35; seventh, 0.17–0.06 and eight, 25.76–2.27 mSv). However and although the results are still preliminary, it is already possible to state that the wrist dose value ranging from 0.57 to 0.07 mSv in all procedures is not representative of the hand values. In fact, wrist doses are negligible compared with the finger doses as they represent

Table 1. $H_p(10)$ dose values (mSv) measured with the WB dosemeters at chest and waist levels, above and below the lead apron, fluoroscopy time FT (s), and effective dose E (mSv), in each procedure.

Procedure	FT (s)	E (mSv)	Chest		Waist	
			Above	Below	Above	Below
1. Lung	22	0.03	0.03	0.03	0.04	0.03
2. Lung	41	0.03	0.02[a]	0.03	0.07	0.03
3. Lung	25	0.04	0.07	0.04	0.05	0.03
4. Lung	43	0.04	0.16	0.03	0.04	0.02
5. Lung	4	0.06	0.04	0.06	0.04	0.06
6. Lung	29	0.07	0.16	0.06	0.08	0.02
7. Bone	22	0.03	0.09	0.03	0.02[a]	0.02[a]
8. Bone	85	0.05	0.20	0.04	0.08	0.05

[a]Close to the detection limit (see text).

Table 2. $H_p(0.07)$ dose values measured with the WB dosemeters positioned on the right (R) and left (L) arm, knee and foot, in each procedure (mSv).

Procedure	Arm		Knee		Foot	
	L	R	L	R	L	R
1. Lung	0.17	0.17	0.06	0.05	0.04	0.06
2. Lung	0.21	0.02[a]	0.06	0.04	0.11	0.04
3. Lung	0.31	0.04	0.06	0.05	0.05	0.06
4. Lung	0.22	0.03	0.11	0.04	0.04	0.07
5. Lung	0.07	0.06	0.04	0.04	0.06	0.06
6. Lung	0.27	0.04	0.04	0.02	0.17	0.07
7. Bone	0.16	0.03	0.07	0.02[a]	0.10	0.06
8. Bone	0.59	0.03	0.07	0.06	0.08	0.12

Table 3. $H_p(0.07)$ dose values measured in each procedure with the 11 extremity detectors inserted on the left hand glove: tip (A) and base (B) of each finger and one on the wrist (mSv).

Procedure	Thumb		Index		Middle		Ring		Little		Wrist
	A	B	A	B	A	B	A	B	A	B	
1. L Lung	1.09	0.58	6.99	0.85	1.97	17.58	5.16	16.76	4.71	7.56	0.27
2. L Lung	14.96	2.19	3.63	2.74	7.61	2.00	36.29	0.98	2.86	0.94	0.27
3. R Lung	1.89	0.91	19.31	4.11	4.57	16.35	5.59	14.45	4.68	7.37	0.38
4. L Lung	3.43	0.42	2.95	0.33	2.25	0.44	5.72	0.19	0.40	0.20	0.10
5. Lung	0.14	0.05	0.08	0.06	0.06	0.10	0.09	0.09	0.07	0.36	0.07
6. M Lung	2.92	0.53	9.41	0.58	4.97	0.54	5.07	0.36	4.68	0.35	0.25
7. Bone	0.06	0.17	0.07	0.06	0.06	0.06	0.06	0.06	0.08	0.08	0.08
8. Bone	2.76	3.37	2.46	11.12	2.79	25.76	2.42	8.28	2.27	7.03	0.57

0.7–2.7 % of the highest value measured in each procedure. It can also be observed that the index, middle and ring fingers received the highest dose values, particularly the last two fingers. Still, the results shown in Table 3 clearly suggest that more than one finger gets a per procedure dose value >5 mSv. In the case of the middle finger, the base is more exposed than the tip, but for the index it is the other way around and in the case of the ring finger both tip and base can get an increased dose value.

Since the results presented herein are as per procedure values, and taking into consideration that the medical doctor may perform two to three procedures per week, the dose on the extremities of the physician is likely to exceed three-tenths of the annual dose limit, therefore additional dosemeters should be worn to better identify where the dose is expected to have its highest value[14]. A general overview on the use of extremity dosemeters at hospital environment is given by Vanhavere *et al.*[15], as pointed out in this study there is a large uncertainty on the best position for the extremity dosemeter[16]. This was also found in the present paper, where three possible high-dose locations were identified, making the decision of where the dosemeter should be worn quite difficult. Further studies are needed in order to increase statistics and produce sound results. However, the interventional radiologist studied in this work is likely to exceed the annual dose limit of 500 mSv for the extremities if the workload remains the same.

CONCLUSIONS

The results presented herein are preliminary and only based on eight procedures, however, it seems possible to perform measurements with this method in order to assess occupational doses in a single CT-fluoroscopy-guided procedure. For each procedure, the dose distribution on the interventional radiologist's body was evaluated using 10 WB dosemeters placed in several positions, complemented with hand-dose measurements performed with 11 extremity dosemeters inserted on a specially designed glove.

A comparison with published data is often difficult due to different methodologies used for dose assessment. Nickoloff *et al.*[17] perform measurements of the radiation dose to the hands of the radiologist with a survey meter (0.6–1.5 mGy min^{-1}). On the other hand, Buls *et al.*[18], using TLD in several fluoro-CT-guided procedures assessed entrance skin dose to the left hand (median values) of 0.18 mSv and to the right hand of 0.76 mSv.

The results obtained in this work with the WB dosemeters show that the dose distribution can vary considerably and is mainly dependent on the duration of the examination and on the physician's position relative to the beam. The measurements performed above the lead apron suggest some procedures entail a higher dose than others. Dose values below the apron were found to be relatively close to the residual signal. An estimate of the effective dose per procedure was also performed. On the other hand, dose to the arms, knees and feet are worth considering. In the procedures studied the left arm received a higher dose than the right one. However, the dose to the knees is evenly distributed and the same seems to happen with the dose to the feet. Relative to the evaluation performed with the extremity dosemeters, the wrist dose value is not representative of the exposure to the hand, and the index, middle and ring fingers receive the highest dose, although it is not clear if received on the tip or the base of the finger.

In the CT-fluoroscopy sessions, no considerations were made on the patient's age, weight and height, or on the location of the lesions, which should also be complemented with the CT beam parameters and correlated with the dose measurement if possible. Further work is currently being done in order to collect more data and get statistically significant results expected to improve the assessments of occupational doses and to provide a basis to make judgements and issue internal recommendations.

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