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RADIATION DOSES IN INTERVENTIONAL NEURORADIOLOGY

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Abstract

Patient radiation doses during interventional radiology (IR) procedures may reach the thresholds for radiation-induced skin and eye lens injuries. This study investigates the radiation doses received by patients undergoing cerebral embolization. Measurements were conducted using thermoluminescent dosimeters. Radiotherapy verification films were used in order to visualise the radiation field. For each procedure the fluoroscopic and digital dose-area product, the fluoroscopic time, the total number of acquired images and entrance-skin dose calculated by the angiographic unit were recorded. In this paper, the skin, eye and thyroid glands doses on a sample of patients are presented. From a preliminary study of 13 patients having undergone cerebral embolization, it was deduced that six of them have received a dose above 1 Gy. Detailed dose data from patients undergoing IR procedures will be collected in the future with the aim of developing a model to allow estimation of the dose prior to the procedure as well as to look at techniques of dose reduction.

1. Introduction

In 1994 the Food and Drug Administration (FDA) [1] reported a number of severe radiation-induced skin injuries to patients resulting from interventional radiology (IR) procedures. Since then numerous reports have been published on patient and staff radiation doses in IR procedures [2,3,4]. Cerebral embolization (CE) is a neuroradiological procedure and it is considered to be a high dose IR procedure. It is used for treatment of life-threatening diseases such as aneurysms and/or arteriovenous malformations (AVMs). Alternative treatments are surgery and radiosurgery. Embolization results in the occlusion of aneurysms and/or AVMs from the blood supply. The efficacy of the procedure is monitored by injection of contrast media in the vessels in conjunction with fluoroscopy and digital subtraction angiography (DSA). Materials that are used for the occlusion of the vessels are metal coils (platinum) in the case of aneurysms and chemical agents (superglue) in the case of AVMs. The metal coil is supplied in a cartridge which allows it to be fed into the catheter and then into position in the area of interest. Superglue has a liquid form and it solidifies as soon as it comes in contact with blood and it reaches the area of interest via a catheter. In most of the cases, the AVM embolization is likely to be repeated in a short period of time and it is followed by radiosurgery at which the dose to the target volume (AVM) may reach levels as high as 25 Gy. Thus, the cumulative dose resulting from embolization and radiosurgery may reach high levels. Many authors have reported doses in CE varying from few hundreds of mGy up to few Gy [2,3,4]. This study investigates the entrance-skin doses (ESD), the dose-area product (DAP) and organ doses to thirteen patients undergoing CE and the radiation doses to the physician performing the CE. Also, the dose distribution over the patient's skin area has been obtained by means of thermoluminescent dosimeters (TLDs) and it is compared with that obtained from films placed at the irradiated area. The relationship of the dose with some technical parameters such as fluoroscopy time, number of acquired images and with the ESD which is calculated by the unit is investigated.

2. Methods and materials

Measurements were made on a Siemens biplane X-ray system consisting of a lateral (LAT) and a posterior-anterior (PA) Megalix X-ray tube and a Polydoros IS-Ax2 (Neurostar) pulse generator. Tube settings are controlled by the automated exposure control (AEC). The X-ray

unit is equipped with a DAP-meter which provides the user with the cumulative DAP for each plane and for each mode (fluoroscopy-DSA) separately. The ESD and the ESD rate are calculated by the unit at a focus skin distance (FSD) of 55 cm giving an estimation of the ESD during the procedure in each plane. It also provides the user with useful technical parameters such as tube voltage, tube current and exposure time, magnification, frames/sec, number of acquired images for each DSA run. During the fluoroscopy mode the ESD and the ESD rate as well as the tube voltage, mA, pulses/sec and the DAP are provided. Three different protocols for DSA mode can be used when CE is performed. The user has the option to change the settings of the program and the most frequently changed parameters are the frame rate, scene duration and pulses/sec (fluoroscopy). In the following table (I) the parameters for the three different protocols are shown.

Table I. DSA protocols

Protocols	kVp	ms[1]	Scene(sec)[2]	dose[3]	Frame rate	Pulses/sec
AngioDSA Carotids	73	160	80	4.8	2	7.5
Angio DSA AVM Glue	70	125	20	4.8	3	7.5
Angio DSA Vertebral	70	64	40	4.8	2	7.5

[1]maximum pulse width in milliseconds
[2]maximum duration of a scene in seconds
[3]input dose per frame in μGy, measured at the following nominal conditions: 70kV, 2.5 mm Copper filter and 17cm Image Internsifier

Lithium fluoride TLDs (TLD-100) were used to measure the ESD for the PA and for the LAT plane. The TLDs were arranged in a grid form as shown in figure 1 to measure the dose distribution. The TLDs were placed on two exposed films. One of the two films was placed on the back side of the patient's head to measure the dose from the PA plane and the second one on the right side of the patient's head in order to measure the dose from the lateral plane. The grid was square with dimensions (15x15)cm^2 and every three cm for both vertical and horizontal dimension (bullets in the figure) a TLD was placed, giving 36 TLDs for each plane. The dose to the eyes and to the thyroid glands of the patient and the doses to the physician's eye were measured with TLD-100H which are suitable for measuring low doses due to their high sensitivity.

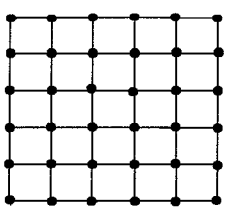


Figure 1

For doses above 1 Gy, correction factors have been applied to TLD-100 doses in order to account for supralinearity.

Kodak X-OMAT V radiotherapy verification film has been used to visualise the radiation field for two patients and for both planes.

Dose rates have been measured using a tissue equivalent phantom (15x15x15) cm^3 for both fluoroscopy and DSA. Different field sizes, pulses/sec, frames/sec have been used.

3. Results and discussion

In figures 2 and 3 the isodose curves obtained from the TLD grids for PA plane and LAT plane for respectively are superimposed onto the images taken from the films. Figures 2 and 3 correspond to two different patients. Starting from the edges of the grid the first isodose curve is that of the lowest dose range. The dose scales shown in the figures are in mGy.

From figure 2 it may be seen that an area of (8x7) cm^2 receives a dose above 400mGy and from figure 3 an area of (6x6)cm^2 receives a dose above 1750mGy. By not using TLDs arranged in a grid form the irradiated area cannot be estimated and from those two examples it may be seen that a large area of the patient's head has received the highest dose. In both figures the x-ray tube has been moved throughout the procedure. Due to the movement of the X-ray tube during the procedure there is a risk of placing the TLDs outside the field size or outside the area of the highest dose unless a large TLD grid is used. Although the grids are (15x15) cm^2, it may be seen that they are not large enough to cover the whole radiation field since the isodose curves for the low doses are interrupted.

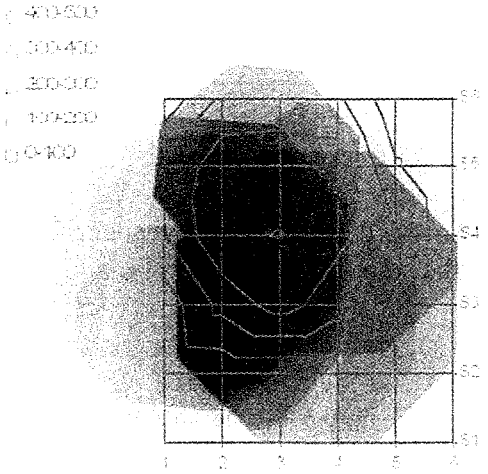


Figure 2. Patient A

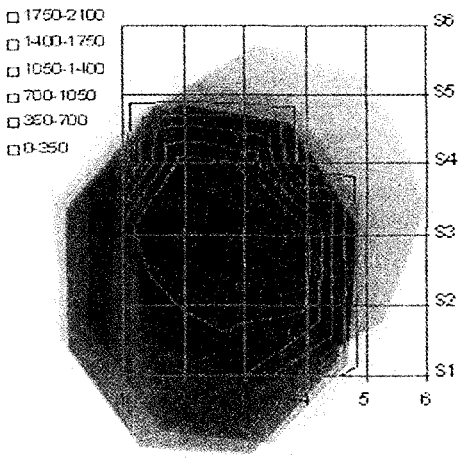


Figure 3. Patient B

In table II the results for both PA and LAT plane for the thirteen patients are shown.

It may be seen from the ESD_{TLD} that for the PA plane 4 patients have received a dose above 1 Gy and 2 of these have exceeded the threshold of 2 Gy for transient erythema [5] while for the LAT plane 6 patients have exceeded 1 Gy and one has exceeded the threshold of 3 Gy for temporary epilation [5]. Comparing the ESD_{DAP} and the ESD_{TLD} for both PA and LAT plane it may be seen that the ESD in most of the cases is higher than the ESD TLD. Thus, the ESD calculated by the x-ray unit tends to overestimate the actual dose since the actual FSD is always higher than 55cm typically between (70-80) cm and since the tube is moving during the procedure spreading the dose over the patient's head.

Table II. Patients' results

Patient	Fluoroscopy Time (min)		Number of images		DAP (Gycm^2)		ESD_{DAP}[1] (Gy)		ESD_{TLD}[2] (Gy)	
	PA	LAT	PA	LAT	PA	LAT	PA	LAT	PA	LAT
1	4.9	22.0	73	156	52.7	61.9	0.52	0.69	0.24	0.59
2	4.6	11.0	127	316	49.5	106.7	0.53	2.00	1.20	1.44
3	8.9	2.0	52	28	30.5	6.1	0.64	0.15	0.26	0.09
4	26.3	8.0	123	118	62.1	22.9	1.48	0.61	0.90	0.38
5	1.9	18.0	90	272	72.6	76.7	0.79	2.20	0.40	1.40
6	2.5	22.0	55	725	38.3	365.2	0.27	4.44	2.44	3.2
7	9.9	16.0	229	425	92.9	127.0	2.12	2.86	1.14	1.78
8	3.9	4.0	139	159	55.1	34.6	1.09	0.96	0.63	0.63
9	1.8	31.0	59	227	25.2	129.6	0.23	1.63	0.88	1.21
10	2.0	22.0	54	87	15.1	24.6	0.37	0.63	0.18	0.52
11	6.5	14.3	216	344	52.1	43.2	0.68	0.12	0.40	0.55
12	0.9	17.2	58	137	14.1	14.8	0.21	0.32	0.10	0.18
13	2.9	10.9	767	975	218.6	231.0	5.01	2.63	2.61	1.94

[1]ESD_{DAP}: the ESD calculated by the x-ray unit at 55cm FSD
[2]ESD_{TLD}: the maximum TLD dose

In table III the dose for the eyes and thyroid glands of the patient, as well as the doctor's left eye dose who performs the CE, are shown. It may be seen that the patient's right eye and right thyroid gland receives a higher dose than the left eye does and this is because the lateral x-ray tube is always on the right side of the patient's head. The eye doses are high in some patients but are below the threshold for formation of detectable opacities[6]. The doctor's eye receives a low dose and only in three cases the dose reaches the 3/10 of the annual dose limit (i.e classified worker) if one case per day (250 each year) with such a dose is performed.

Table III. Organ doses

Patient	Right eye dose (mGy)	Left eye dose (mGy)	Right thyroid dose (mGy)	Left thyroid dose (mGy)	Doctor's eye dose (mGy)
1	38.1	5.2	50.5	8.0	0.069
2	16.1	13.1	21.3	7.5	0.120
3	3.2	3.3	2.4	2.3	0.038
4	16.1	13.1	21.3	7.5	0.078
5	16.1	13.1	21.3	7.5	0.078
6	71.8	10.9	36.2	9.2	0.471
7	64.1	22.1	11.3	4.9	0.218
8	8.5	5.5	6.8	4.0	0.018
9	13.7	6.6	16.4	2.2	0.218
10	14.1	5.2	5.2	3.1	0.061
11	44.0	30.0	6.7	2.6	0.110
12	12.7	5.1	180.4	7.2	0.018
13	69.2	27.5	36.1	18.4	-

In figure 4 the relationship between the doctor's eye dose, the total DAP and the LAT DAP is shown. It may be seen that the doctor's eye dose is correlated better with the LAT DAP than with the total DAP since the LAT X-ray tube is always on the left side of the doctor. It may be seen that as the LAT DAP increases the doctor's eye dose increases linearly.

Figure 4

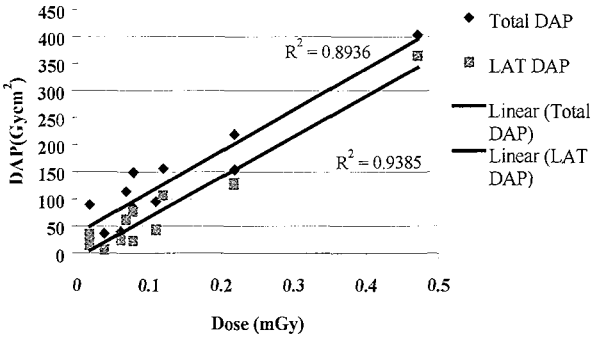
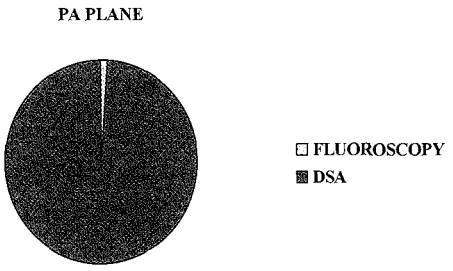


Figure 5



In figure 5 the contribution of DSA and fluoroscopy mode to the total DAP is shown for PA plane for patient 13. It may be seen that the main contribution comes from the DSA mode and not from the fluoroscopy mode. Thus, the use of DSA mode should be limited to the minimum.

From quality assurance measurements it was deduced that the ESD/sec for fluoroscopy mode is within a range of (0.029-0.2) mGy/sec which is equivalent to (1.76-11.9) mGy/min for different technical parameters while for the DSA mode the ESD/sec is in a range of (1.6-6.62) mGy/sec for the same parameters as in fluoroscopy. The ESD/frame for the DSA mode may vary from (0.73-2.65) mGy/frame. Comparing the dose rates for fluoroscopy and DSA it may be seen that the doses from DSA are much higher than that of fluoroscopy. Thus, by limiting the images obtained during a procedure the ESD may be highly reduced.

4. Conclusions

In this paper a new method to obtain dose distribution over the patient's skin area for CE procedures has been introduced. This method gives accurate and reliable results of the ESD by combining a TLD grid for measuring the ESD and films for visualising the field size. The results show that a relatively large skin area may receive a dose that can exceed the thresholds for skin injuries. The patient's eye and thyroid glands may receive a relatively high dose but it is below the threshold for causing any radiation-induced injuries. It has been found that there is a good correlation between the doctor's eye dose and the DAP from the LAT plane. It also has been found that the contribution of the DSA mode to the total DAP is much higher than that from the fluoroscopy mode. Quality assurance results showed that the ESD rate is much higher for the DSA mode than that for the fluoroscopy mode. Thus, the number of images obtained during a procedure should be kept to the minimum. Us eof distance and shielding may also reduce staff doses.

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