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Occupational doses in interventional angiography after radiological protection training and use of a real-time direct display dosimeter

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Abstract

Vascular x-ray guided interventions are complex and may result in high occupational doses to ionising radiation if staff do not take appropriate actions to minimise their exposure. In this prospective intervention study, ten staff members wore an extra personal dosimeter on the upper body above their regular protective clothing during four consecutive periods. Between each period either additional practical radiological protection training was given or a real-time direct display dosimeter were provided to the staff. Each staff's personal dose equivalent, Hp(10) normalised to the total air kerma-area product for the procedures where each staff were involved, KAPt, was used as the dependent variable. A focus-group interview with the staff were performed about the usefulness of the training and real-time dose rate display system. Our aim was to investigate if the interventions (practical training or real-time dose rate display) did affect the staff doses in the short and long term (five months later). Significant ($p < 0.05$) reductions of staff doses Hp(10)/KAPt were found after practical radiological protection training, but not after using real-time dose rate displays. Significant reductions were maintained after five months without additional interventions. The results from the focus-group interview indicated that making radiation 'visible', during practical training and usage of real-time direct display dosimeter, made it easier to understand how to act to lower occupational doses.

1. Introduction

The importance of appropriate education in radiation safety is accentuated due to rising occupational doses during radiological interventions (RIs) [1]. According to European legislation education in radiation safety should include both theoretical knowledge and practical training [2]. Recommendations from the International Commission on Radiological Protection (ICRP) prescribe that education for operators of radiological equipment, generally physicians, should extend to at least 15 h. This education would include theoretical courses in radiation physics and radiobiology. Practical training with the operator's own radiological equipment is recommended [3]. ICRP recommend that education for nurses and other health assistant professionals should comprise knowledge about radiation hazards and how to minimize occupational and patient exposure during RI, but the extent of these aspects of their education is not specified [3].

Some earlier studies on the effect of education in radiation safety in medical practice has focused on acquaintance and maintenance of theoretical knowledge. These studies indicate that when radiation safety education is only theoretical the knowledge will decrease over time [4, 5]. If theoretical education is combined with practical training, preferably with the equipment that the staff will use in practice, the acquired knowledge results in lower patient doses and higher compliance to as low as reasonably achievable (ALARA) principles [6, 7]. The immediate effect on occupational doses when using a real-time display system during RI has been evaluated [8–11]. The radiation dose to staff working close to the patient decreased significantly when using a real-time display system [8–10]. The radiation doses to all involved personnel were lower on the group level [10]. Lasting effects of practical training and usage of a real-time display system were evaluated in a setting with experienced staff and mainly fixed positions during RI. The study reported lower median occupational doses [11]. The same method was used in the present work, but in a different clinical setting with more complex procedures and with higher patient doses. There is a great need for new ways to better manage occupational doses in this environment.

There are concerns about occupational doses in vascular surgery that involves a complex and long-lasting RI [12, 13]. There are indications that technological aspects such as the use of fusion techniques and working in a hybrid room lead to lower occupational doses, but there is still a need for improved awareness about radiation risks via education [12, 13].

Earlier studies indicate that combining theoretical and practical education are advantageous when learning radiation safety [11]. Practical training with the imaging equipment used by staff led to a higher degree of compliance with ALARA-principles [7]. There are few studies about the lasting effects on occupational doses of education and the use of real-time display systems for educational purposes.

Therefore, the primary aim of this study is to investigate the immediate and lasting effects on occupational doses after practical radiological protection training and the use of a real-time dose rate display system. Secondly the staff's experience of learning and practising radiation safety will be explored.

2. Materials and methods

2.1. Materials

This is a prospective study with single case research experimental design and four study periods, using both quantitative and qualitative methods. Ethical approval was obtained from the Ethics Review Authority of Sweden for the study (Dnr 2020-004928).

The Seldinger unit at the University hospital in Linköping, Region Östergötland Sweden, performed 811 radiological interventional procedures on two fixed C-arms (General Electric Innova 4100 pro and Siemens Axiom Artis Zee Ceiling) during 2021.

Ten members of staff (six physicians specialising in vascular surgery or radiology and four radiographers) participated in this prospective study. Four of the six physicians and all radiographers worked throughout the whole period of data collection. One physician failed to make his extra dosimeter available for analysis, while another physician only performed two procedures during the third period of the study. The five physicians had 5, 6, 9, 19 and 21 years of experience of working with RI in vascular surgery. The four radiographers had 3, 20, 25 and 30 years of experience working with RI. Four different staff member roles were identified. Their positions during procedures are shown in an arranged photograph (figure 1). The radiographer responsible for non-sterile tasks will receive minimal doses as they are often not inside the room, but since radiographers change roles we decided to give all radiographers a dosimeter and include them in the study.

2.2. Data collection

During the first period ('Baseline', February 2021), there were no instructions or interventions other than placing an extra dosimeter (DIS Mirion Technologies RADOS Turku Finland [14]) in a pocket on the chest outside of each staff member's individual protective clothing.

During the second period ('Training', March, and April 2021) practical radiological protection training and demonstration was performed with the staff on two separate occasions (4 March and 1 April). An anthropomorphic pelvis phantom replaced the patient as scattering material, and a handheld ion chamber survey meter (Victoreen 451B, Fluke Biomedical, Eindhoven, The Netherlands) measured the ambient dose equivalent, $H^*(10)$ from scattered radiation in the room. This handheld survey meter was used to demonstrate how the dose rate was modified by different positions in the room, distance to the phantom, protective shielding (personal, couch-mounted and ceiling-mounted shields) and settings on the x-ray units (e.g. field-of view, dose rate, pulse rate etc). During the training session, the medical physicist focused mainly on practical methods to minimise staff exposure, but imaging system settings that change dose and pulse rates were also included. For this and other reasons, we also monitored the patient doses—see section 2.3. However, no changes in the standard imaging protocols were made during this study.

During the third study period ('Raysafe', May and until 15 June 2021) the real-time direct dose rate display system (Raysafe i3, Unfors Raysafe AB, Billdal, Sweden) was presented and introduced to the staff during the RI. A maximum of four staff members simultaneously wore the extra dosimeter on the upper body above their protective clothing. It displays—both graphically and numerically, the individual's personal

Figure 1. The staff positions during work, from left to right: radiographer responsible for non-sterile tasks, assistant radiographer, second operator and first operator.

dose equivalent $H_p(10)$ dose rate in real-time on a monitor in the room and hence gives direct feedback to the staff. Its cumulated reading was not stored. Our ordinary legal dosimeter (Mirion DIS) was used to measure staff doses in this study. The patient procedures were performed in two adjacent rooms, so the single Raysafe i3 system could not be used for all procedures if two were conducted simultaneously.

During the fourth study period ('Five months later', November and until 15 December 2021) the real-time direct dose rate display system was removed, and no additional training was offered. The staff were asked to continue working as before and the extra (Mirion DIS) dosimeter was again kept in a pocket on the chest outside of their protective clothing to continue monitoring staff doses. This period was motivated to study whether the radiological safety awareness was maintained five months after our intervention, i.e. 'Training' and 'Raysafe'.

2.3. Staff and patient dosimetry

The extra dosimeter (Mirion DIS [14]) worn outside of the protective clothing was of the same type as the ordinary legal dosimeter, which staff wore under their protective clothing in accordance with local rules. The dosimeter's position was kept constant during all study periods. When the staff were not working in the x-ray room, the extra dosimeter with their personal protective clothing was kept in a corridor with 2 mm lead shielding in the walls and was thus well shielded from room-generated x-rays. The dosimeter measured the operational dosimetric quantity $H_p(10)$ and was calibrated at the Swedish Radiation Safety Authority's secondary standard calibration laboratory in Stockholm. The calibration accuracy is $\pm$5% at 1 mSv using^{137}Cs [14]. The dosimeters were read after each period by the authors and corrected for background radiation, estimated to be 0.17 mSv month^{-1}. The range of the Mirion DIS dosimeter for measuring $H_p(10)$ is 1 μSv–40 Sv [14].

The patient dose index, air kerma area product, KAP, was obtained from the RIS along with the names of the staff that participated during a particular RI. A range of different procedures were performed, e.g. angiography of the leg, pelvis, aorta and kidney.

KAP_t is the total KAP for those patients in the procedures that each staff member took part in. $H_p(10)$ and KAP_t are positively correlated and hence the ratio between the $H_p(10)/KAP_t$ was used as the dependent variable in the statistical analysis. It is reasonable to assume that more scattered radiation is generated in a procedure which results in a larger KAP. By normalising the $H_p(10)$ with KAP_t we further considered that each staff member did not participate in the same number of procedures during each study period.

2.4. Statistical analysis

A non-parametric statistical test of related (paired) samples (Wilcoxon signed-rank test) was used to test whether median H_p (10)/KAP_t changed significantly during the study periods. SPSS Statistics version 28 was used. An $\alpha = 0.05$ (false positive fraction) was selected, and the null hypothesis was that neither practical radiological protection training nor the use of the real-time direct display dosimeter system (Raysafe i3) would change the H_p (10)/KAP_t between study periods. If the p-value was less than α, the null hypothesis was rejected. The Mann-Whitney U-test uses independent or unpaired data and was employed to explore whether the median KAP for each study period was significantly different, hence an indication of whether the patient dose index was affected by our 'dose-awareness' intervention.

2.5. Focus-group interviews and data analysis

One focus-group interview was conducted at the end of study period three to explore the staff's experiences about learning and practicing radiation safety during work. The nine participants who worked throughout the whole study were invited. The four radiographers accepted the invitation. The focus-group interview was conducted in a conference room at the interviewees' workplace. The interview was conducted by one of the authors (LL). A digital Dictaphone was used for recording the interview. The interviewer made a verbatim transcription of the interview.

The interview-guide entailed three open-ended questions. These questions were:

(a) What does the word radiation safety mean to you?
(b) How would you know you are working in a radiation-safe environment when using the C-arm equipment?
(c) If you were planning training/education in radiation safety, how would you plan it/the curriculum?

Analysis of data from the focus-group interview was inspired by the inductive thematic analysis of Braun and Clarke [15] and resulted in two themes.

3. Results

3.1. Staff and patient doses

Table 1 shows the number of procedures that each staff member participated in and the individual staff doses per total KAP_t, H_p (10)/KAP_t, during the four study periods, denoted Baseline, Training, Raysafe, and five months later. Table 2 shows the test statistics and p-values for the comparisons of H_p (10)/KAP_t between Baseline and Training, between Baseline and Raysafe, and between Baseline and five month later, respectively. In all cases but one a statistically significant reduction ($p < 0.05$) in staff doses was obtained. Table 3 shows the median $H_p(10)$/KAP_t for all staff and separately for physicians and radiographers. This table also shows the third quartile, minimum and maximum values.

There was an increase in median patient KAP between periods Baseline and the other three study periods, but it was only significantly increased between periods Baseline and Raysafe ($p = 0.032$). The number of procedures that any member of staff took part in is shown in table 4, as well as the mean, median, third quartile, minimum and maximum air kerma-area product (KAP) in each study period.

3.2. Focus-group interviews

3.2.1. Learning experiences

Radiographers gain theoretical knowledge about radiation safety in their radiography education. However, this knowledge was not specifically applied to practical work in interventional radiology. Therefore, the radiological protection training was valuable for attaining knowledge about how to work and act in a radiation safe manner in an RI lab. The practical training was useful for understanding how radiation was distributed in their own lab. 'Seeing' the level of radiation in numbers in different parts of the lab using a handheld ion chamber instrument was proposed as a valuable pedagogical tool for these purposes. Usage of a real-time dose rate system was useful for discovering the importance of one's own position in the lab during work and how the operator's setting for the C-arm affected the level of their own occupational doses. The need for continuous recurrent radiological protection training was emphasized as a reminder of how to work in a safe manner even though the radiographers had gained theoretical knowledge in their education.

> *Interviewee A: Then we've had these reviews where we've had the meter, so we get proof of where the radiation is in the room, which I thought was fascinating even if you knew it from the start, so it was still a little bit more about where in the room.*

Table 1. Personal dose equivalent per patient's total kerma-area product $H_p(10)/KAP_t$ for the individual staff members (physicians and radiographers) during the four study periods. The numbers inside the parentheses (N) are the number of procedures that each staff member participated in during each study period.

Staff member	$H_p(10)/KAP_t$ (N) (μSv Gycm^2)	$H_p(10)/KAP_t$ (N) (μSv Gycm^2)	$H_p(10)/KAP_t$ (N) (μSv Gycm^2)	$H_p(10)/KAP_t$ (N) (μSv Gycm^2)
	February Baseline	March, April Training	May, June Raysafe	November, December five months later
Physician 1	2.486 (16)	—	—	—
Physician 2	1.832 (20)	1.500 (33)	1.224 (34)	1.087 (17)
Physician 3	3.002 (11)	1.517 (41)	1.927 (27)	0.755 (17)
Physician 4	0.906 (15)	0.047 (3)	7.601 (2)	0.343 (13)
Physician 5	5.254 (12)	1.765 (29)	1.369 (24)	4.035 (15)
Physician 6	0.672 (6)	0.545 (14)	0.121 (7)	0.237 (5)
Radiographer 1	0.059 (24)	0.038 (56)	0.072 (48)	0.018 (33)
Radiographer 2	0.074 (30)	0.077 (40)	0.062 (24)	0.156 (19)
Radiographer 3	0.161 (23)	0.044 (57)	0.030 (34)	0.007 (32)
Radiographer 4	0.096 (38)	0.027 (55)	0.028 (40)	0.071 (46)

Table 2. P-values for the comparisons of H_p (10)/KAP$_t$ between baseline and training, between baseline and Raysafe, and between baseline and five months later, respectively, using the Wilcoxon signed-rank test. N is the number of paired comparisons and Z the test statistics.

Wilcoxons signed-rank test	N	Z	p-value
Baseline vs. Training	9	−2.55	0.011
Baseline vs. Raysafe	9	−1.36	0.173
Baseline vs. five month later	9	−2.31	0.021

Table 3. Median $H_p(10)/KAP_t$ during each period for the physicians and radiographers, separately and combined. Third quartile values are in parentheses and range is shown as [minimum–maximum].

Study period	Physicians $H_p(10)/KAP_t$ (μSv Gycm^2)	Radiographers $H_p(10)/KAP_t$ (μSv Gycm^2)	All staff $H_p(10)/KAP_t$ (μSv Gycm^2)
Baseline	2.159 (2.873) [0.672–5.254]	0.085 (0.112) [0.059–0.161]	0.789 (2.323) [0.059–5.254]
Training	1.500 (1.517) [0.047–1.765]	0.041 (0.052) [0.027–0.077]	0.077 (1.500) [0.027–1.765]
Raysafe	1.369 (1.927) [0.121–7.601]	0.046 (0.065) [0.028–0.072]	0.121 (1.260) [0.028–7.601]
Five month later	0.755 (1.087) [0.237–4.035]	0.044 (0.092) [0.007–0.156]	0.237 (0.755) [0.007–4.035]

Table 4. Number of procedures, mean, median, 3rd quartile, minimum and maximum air kerma area product, KAP, in each study period.

	Baseline	Training	Raysafe	Five months later
Number of procedures	81	183	101	106
Mean KAP (Gy cm^2)	75.2	101.6	101.5	58.2
Median KAP (Gy cm^2)	15.5	27.9	32.9	17.7
3rd quartile KAP (Gy cm^2)	82.1	90.7	108.1	74.1
Min KAP (Gy cm^2)	0.3	0.2	0.1	0.2
Max KAP (Gy cm^2)	884.7	1947.9	1121.0	651.0

Interviewee D: You get some more facts, yes, because otherwise it's a little more, yes, there's a bigger or higher dose there, and a lower dose there, but now you really got, like.

Interviewee A: Yes, there were angles in the room that we were surprised had such a high dose when we stood there on the practical radiological training day, when we stood with this direct meter that gave us figures for how much it was.

(Extract from the focus-group interview)

3.2.2. Establishing radiation safety routines

The importance of having routines for lowering occupational doses was emphasised. For example, using a contrast injector instead of hand injection means that all staff can leave the RI lab during exposure. Also, routines for using ceiling-mounted protection and other forms of lead protection were put forward as an important issue. Communication within the team during RI was significant for letting all staff know about forthcoming actions that might affect the level of occupational doses. The radiographers took responsibility for introducing new employed physicians into the worked-up routines for radiation safety. Sometimes during work with RI the operators were very focused on their own work and could forgot radiation safety aspects. The radiographers then reminded involved staff about the need to apply radiation safety during various stages.

> *Interviewee C: We are very good at either going out or moving behind a lead guard.*
> *Interviewee A: Yes, even our doctors, then, most of them.*
> *Interviewee C: Yes, or otherwise we teach them hard.*
> *Interviewee A: Exactly.*
> *Interviewee C: You have to say when you expose, everyone must have the chance to go out then.*
> *Interviewee D: It is very good that they do it.*
> *Interviewee C: There are some new people who come here and don't have the habit, I think you work differently in different places.*

(Extract from the focus-group interview)

4. Discussion

The primary aim of this study was to investigate the immediate and lasting effects on occupational doses after practical radiological protection training and use of a real-time dose rate display system. As a secondary aim, staff experiences of learning and practising radiation safety were explored.

Physicians and radiographers reduced their median $H_p(10)/KAP_t$ by between 36% and 62%. Only one physician (number 4) showed a larger $H_p(10)/KAP_t$ in a later study period than during the initial Baseline period. The doses to the physicians were notably higher (<8 μSv Gy cm^2) than for the radiographers (<0.2 μSv Gy cm^2), which was also reported by Racadio *et al* [8]. In our study, the radiographers were positioned further away from the patient's irradiated body part compared to the physicians, which is probably the reason for this result (see figure 1).

By normalising the personal dose equivalent to the total patient air kerma area product for the procedures for which each staff member took part, in line with Kirkwood *et al* [16] we controlled to some extent for the fact that the number of procedures and procedure complexity may have varied between study periods for each staff member. In fact, the median KAP did increase from the Baseline study period to the other study periods, which will decrease $H_p(10)/KAP_t$ provided $H_p(10)$ does not increase in proportion to KAP_t. Forty-five percent of the procedures during 2021 were included in the survey during the six months that the extra dosimeters were used by the staff, which is a large portion of the annual work load.

The significant reduction in staff doses $H_p(10)/KAP_t$ is interesting and somewhat unexpected given the small number of participating members of staff. Similar results were, however, found by Racadio *et al* [8] and Sandblom *et al* [10]. Nevertheless, we cannot be sure that it was the additional practical radiological protective training that was the cause of the reduction in staff dose, but it was the only known aspect of the survey that was changed. One reason for the dose reduction for physicians might be the more appropriate use of the ceiling-mounted lead glass shield during the later study periods. The result from the focus-group interview indicates that the training and the direct dose rate display system acted as a reminder to the staff that they can, at least to some extent, alter their exposure by relatively small measures. Such measures include taking a step back, when possible, positioning the ceiling-mounted lead glass shield correctly, and collimating the x-ray beam. For the most part, a non-significant reduction in staff doses was found by Lundvall and Sandborg [11] in x-ray guided bronchoscopy using similar methods. In that setting, the staff mainly had fixed positioning during RI, which affected the possibilities to take steps away from the radiation. The occupational doses were also low [11]. In the present study, the doses to the operators (physicians) were higher than in Lundvall and Sandborg [11] due to more complex procedures and a thicker patient body part.

The result from the focus-group interview displayed that practical training in their own environment and within their own lab is valuable for the radiographers, even though they have existing theoretical knowledge from their education. Visualising the level of radiation in different parts of their own lab through using a handheld ion chamber instrument and using a real-time dose rate system was mentioned as a particularly important learning experience for knowing how to act in a radiation-safe manner. Similar results about the usefulness of the practical training and usage of a real-time dose rate system were reported in Lundvall and

Sandborg [11] but the results in this study added that—in this setting, during RI in vascular surgery—the real-time dose rate system was found to be useful for understanding the effects of different C-arm angles on occupational doses, which De Ruiter *et al* [17] identified as a risk factor for increasing occupational doses.

Unfortunately, it was not possible to perform a second focus-group interview due to high workload in the RI lab. It was planned to have focused on the lasting effects of practical training and usage of a real-time dose rate system.

The focus-group interview was conducted in the interviewees' workplace, which is not optimal due to their opportunities to talk freely about their work. However, this was the only possible time and venue for the interview. The interview was held first on an ordinary working day before the work in the lab began, so that it would be conducted under undisturbed conditions. Unfortunately, not all staff members were willing to take part in the interview, which may have limited our conclusions about the usefulness of the training and the real-time display dosimeters.

This survey was limited to just ten staff members, and all except for one physician (who changed job) participated in the subsequent study periods. The physicians participated in fewer procedures than the radiographers, and two physicians in particular (numbers 4 and 6) performed fewer procedures than their colleagues. Whether these physicians' $H_p(10)/KAP_t$ values are representative of their work can be questioned, as—during some study periods—they participated in fewer than ten procedures (see table 1), which is a limitation. The radiographer responsible for non-sterile tasks and the assistant radiographer do change their roles. However, we do not know to what degree they participated in either of these two roles during the study periods, which may have caused a bias.

5. Conclusion

We found that the normalised staff doses $H_p(10)/KAP_t$ were significantly reduced after additional practical radiological protection training in the x-ray rooms but not after using a real-time dose rate display dosimeter. Significantly lower median staff doses were maintained five months later. This suggests that dose awareness was increased by this intervention and was maintained over time by the staff. Practical radiological protection training and usage of a real-time display system helped them to understand how scattered radiation was distributed in their lab and how to act to lower occupational doses.

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Conflicts of interest

The authors declare that there are no conflicts of interest.

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