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The Effect of Realtime Monitoring on Dose Exposure to Staff Within an Interventional Radiology Setting

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Abstract
Purpose The purpose of this study is to evaluate a new device providing real-time monitoring on radiation exposure during fluoroscopy procedures intending to reduce radiation in an interventional radiology setting.
Materials and Methods In one interventional suite, a new system providing a real-time radiation dose display and five individual wireless dosimeters were installed. The five dosimeters were worn by the attending, fellow, nurse, technician, and anesthesiologist for every procedure taking place in that suite. During the first 6-week interval the dose display was off (closed phase) and activated thereafter, for a 6-week learning phase (learning phase) and a 10-week open phase (open phase). During these phases, the staff dose and the individual dose for each procedure were recorded from the wireless dosimeter and correlated with the fluoroscopy time. Further subanalysis for dose exposure included diagnostic versus interventional as well as short (<10 min) versus long (>10 min) procedures.
Results A total of 252 procedures were performed ($n = 88$ closed phase, $n = 50$ learning phase, $n = 114$ open phase). The overall mean staff dose per fluoroscopic minute was 42.79 versus 19.81 μSv/min ($p < 0.05$) comparing the closed and open phase. Thereby, anesthesiologists were the only individuals attaining a significant dose reduction during open phase 16.9 versus 8.86 μSv/min ($p < 0.05$). Furthermore, a significant reduction of total staff dose was observed for short 51 % and interventional procedures 45 % ($p < 0.05$, for both).
Conclusion A real-time qualitative display of radiation exposure may reduce team radiation dose. The process may take a few weeks during the learning phase but appears sustained, thereafter.

Keywords Real-time feedback · Radiation exposure · Reduction

Introduction

The exposure to radiation is a growing concern due to its cumulative effect on the interventional working environment and is most extensive in procedures using fluoroscopy [1–3]. Occupational dose reduction relies on two basic processes: X-ray output reduction and proper radiation protection [4]. X-ray reduction has matured over the last decade and includes optimization of fluoroscopy technique using lower dose protocols, improved sensitivity of hardware, and advanced image processing [5]. However, proper radiation hygiene and protection may be warranted further scrutiny to reduce radiation dose to the operators since the team dose is predominantly a product of scatter radiation [6]. There are various measures for radiation protection including lead aprons, shields, optimizing X-ray projection

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angle, the distance of subject to detector, the proper use of magnifications, collimators, and wedges [7]. In addition, there are behavioral components to radiation protection including the amount of fluoroscopy, the number of digital subtraction acquisitions, and the location of team members during the procedure. For control purposes, most institutions apply legislated monthly feedback methods [8]. The thermoluminescent dosimeter badges record the radiation dose for the particular month as well as cumulative annual radiation exposure [9]. Based on these radiation recordings, a written report with corrective actions is typically only instituted if a monthly or annual dose limit is exceeded.

Lately however, a system providing real-time monitoring on radiation exposure during interventional procedures has been introduced. The purpose of the present study was to evaluate whether the use of a real-time feedback system on radiation exposure may reduce radiation dose in an interventional radiology setting.

Materials and Methods

Study Design

This study was approved by the IRB and all the data were recorded in a HIPAA compliant manner. The duration of the present study was 22 weeks consisting of three phases:

- *Closed phase* display for qualitative radiation dose not activated but evaluated (6 weeks).
- *Learning phase* display for qualitative radiation dose activated but not evaluated (6 weeks)
- *Open phase* display for qualitative dose activated and evaluated (10 weeks)

The dose readings for all phases were stored safely but not analyzed prior to completion of the study period. Accordingly, there was no demonstration of any preliminary data on radiation dose from DoseAware to the staff members. In line, there were no teaching or behavioral inputs provided.

DoseAware Equipment

In a single interventional suite at a tertiary care vascular center, we installed a real-time radiation dose display screen and five individual wireless personal dosimeters (PDMs) (DoseAware, Raysafe, Hopkinton, MA). The dose screen adjacent to the fluoroscopic display showed which PDMs are in the room and provided real-time monitoring for every PDM on the current radiation dose exposed. For that reason, the individual dose rate per PDM was visually displayed as a color bar that increases in size and changes color as the radiation thresholds increase from 0.2 (green), 2 (orange), and 20 (red) mSv/h. The minimal reading was set to 0.04 Sv/h. Of note, the monitor only displayed snapshot information of radiation exposure for every PDM during fluoroscopy or digital subtraction angiography imaging but no information on the accumulated procedural dose was displayed, they were only recorded. The absolute radiation doses were retrospectively downloaded to a computer for evaluation purposes. The PDMs were worn by the attending, fellow, nurse, technician, and anesthesiologist for every procedure performed in that one suite at collar height and facing the front. For that purpose, every PDM was strictly assigned to one specific subgroup (attending, fellow, nurse, technician, anesthesiologist). If one subgroup did not attend a procedure, the zero reading for that procedure was not taken into account for radiation evaluation.

The PDMs were meant to measure the effective dose on the operators. For that purpose and to include the total body scatter dose, the personal dose equivalent $Hp(d)$ was regarded the dose equivalent in tissue at a depth of $d = 10$ mm; $Hp(10)$ according to the International Commission on Radiation Units and Measurements [10].

Measurements and Documentation

The accumulated radiation dose for every single procedure included in that trial was recorded and locked in the PDM. On a weekly basis, dose readings were exported from the PDMs to the DoseManager software and stored in a password secured manner by a blinded physician for further analysis. Of note, all dose readings were de-identified and thus it was not possible to assign one or the other reading to the specific staff member i.e., for teaching, demonstration, or behavioral adaption purposes. In addition, the fluoroscopy time was recorded for all procedures. Based on that, the radiation dose of every single procedure was correlated with fluoroscopy time [dose per fluoroscopic minute (PFM)] and procedural radiation dose [dose area product (DAP)]. In addition, every procedure performed during the study period was documented on a case report form. Table 1 illustrates case variables to be obtained for every procedure. Thereby and among others, the type of procedure and its duration were documented. Based on that, diagnostic and interventional as well as long (>10 min) and short (<10 min) procedures were differentiated.

Statistics

Continuous variables are reported as means and differences were assessed using a student t test. A p value <0.5 was considered to indicate statistical significance. Statistical analysis was performed using SPSS.

Table 1 Characteristics of procedures performed

Procedure type	Number of procedures		Average fluoroscopy time (min)		Average dose area product (mGycm^2)		Average DAP PFM (mGycm^2/min)	
	Closed	Open	Closed	Open	Closed	Open	Closed	Open
Aorta peripheral angiogram WI	10	14	15.6	18.8	414,549	363,929	19,172	28,031
Aorta peripheral angiogram WO	2	2	3.0	18.4	241,104	1,056,242	64,731	113,520
Aortic arch WI		2		24.7		255,226	12,209	
Aortic arch WO		1		6.2		195,003	31,452	
Biopsies	4	4	5.0	6.1	191,510	129,769	19,865	16,673
Carotid angiograms WI	2	1	16.2	22.8	207,611	276,960	12,147	13,222
Carotid angiograms WO	3	3	11.3	5.8	254,315	139,400	22,315	28,218
Central line placement	14	13	3.1	2.6	21,441	33,825	12,443	8071
Dialysis catheter placement	2	5	14.0	7.2	139,779	44,413	9750	15,599
Endovascular stent grafts	9	13	24.0	33.2	878,438	931,991	35,458	37,940
Extremity angiogram WI	2	6	21.1	38.8	114,057	279,467	12,122	7167
Extremity angiogram WO	3	4	9.6	8.5	21,741	30,738	7313	9074
Gastrostomy tube	1	8	5.6	7.6	72,742	42,835	6601	12,990
Hepatic chemo embolization	3	8	26.5	24.3	929,763	761,826	31,769	36,241
IVC filter replacement	5	9	11.1	3.3	148,304	98,547	34,810	29,428
Mesenteric angiogram WI	2	4	23.4	22.6	630,301	1,070,724	60,142	21,322
Mesenteric angiogram WO	3	6	15.0	43.1	1,317,741	1,017,536	24,930	99,618*
Nephrostomy tube placement	7	2	18.7	11.2	244,803	149,953	12,024	13,370
Port placements	5	2	1.8	3.2	19,265	25,752	8743	24,568
Renal angiogram WI	1	1	18.5	14.8	350,655	516,947	34,929	18,954
Renal angiogram WO	2	4	5.4	12.3	237,401	535,389	100,699	49,721
Uterine fibroid embolization	5	2	23.8	31.8	537,253	646,895	23,504	20,927
Sub classifications								
Short (fluorotime <10 min)	41	50	3.2	3.9	98,027	97,047	25,859	25,148
Long (fluorotime >10 min)	44	64	22.6	27.9	578,882	638,566	27,316	26,015
Diagnostic	13	20	9.6	20.1	441,415	554,770	56,709	40,474
Interventions	72	94	13.9	16.8	329,883	368,353	21,180	22,478
Grand total	88	114	13.3*	17.4*	346,941	401,058	26,086	23,049

* $p < 0.05$

Results

A total of 252 procedures were performed during the study period (closed phase 88 procedures, learning phase 50 procedures, open phase 114 procedures). There were 5 procedures that were regarded erroneous and thus omitted as they had extraordinary high readings (at least 10 times higher than average) that could not be explained after evaluation of the procedure type, fluoroscopy time, and DAP which were all below average.

The total staff dose PFM during closed phase was higher compared with the total staff dose PFM during open phase (42.79 vs 19.81 μSv/min; $p < 0.05$) as illustrated in Fig. 1. With respect to individual dose PFM, only a statistically significant reduction from 16.9 to 8.9 μSv/min was attained for the anesthesiologist ($p < 0.05$) when comparing the open and the closed phase (Fig. 2). Of interest, none of the individual procedure types yielded a statistical difference comparing the closed and the open phase (Fig. 3). However, a significant reduction in staff dose PFM was achieved during open phase for interventional procedures (Fig. 4). The average staff dose PFM for interventional procedures was 31.8 and 17.5 μSv/min ($p < 0.05$) during closed and open phase and 52.1 and 16.4 μSv/min ($p > 0.05$) for diagnostic procedures, respectively. Furthermore, a significant reduction in total staff dose (PFM) was attained for short procedures (closed phase 38.6 μSv/min, open phase 19.3 μSv/min, $p < 0.05$), whereas this did not account for long procedures (closed phase 31.5 μSv/min, open phase 20.2 μSv/min, $p > 0.09$) as shown in Fig. 5. For all DAP measurements, no statistical significance was obtained using the real-time monitoring system.

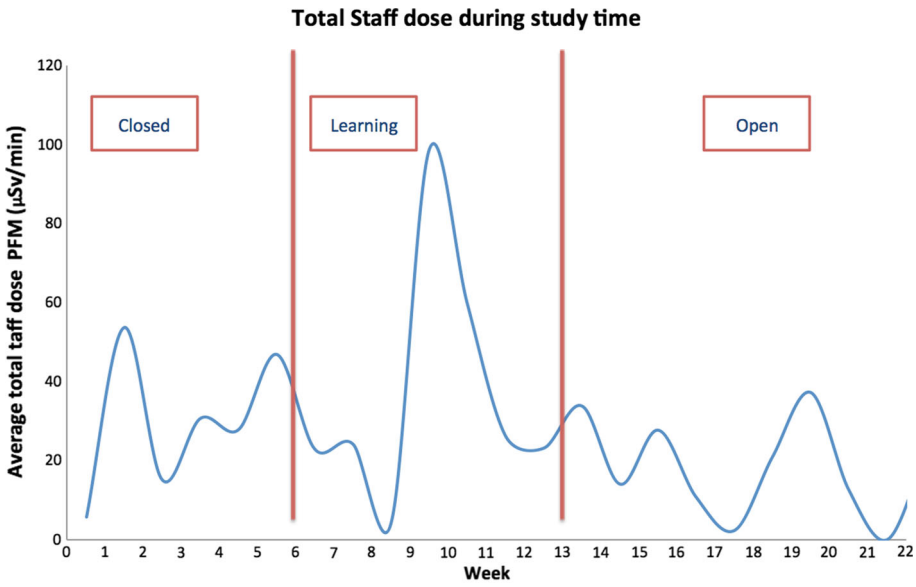

Fig. 1 Trend of dose per minute of fluoroscopy during study. Total staff dose per minute of fluoroscopy time, displayed in week intervals, for all phases of the study

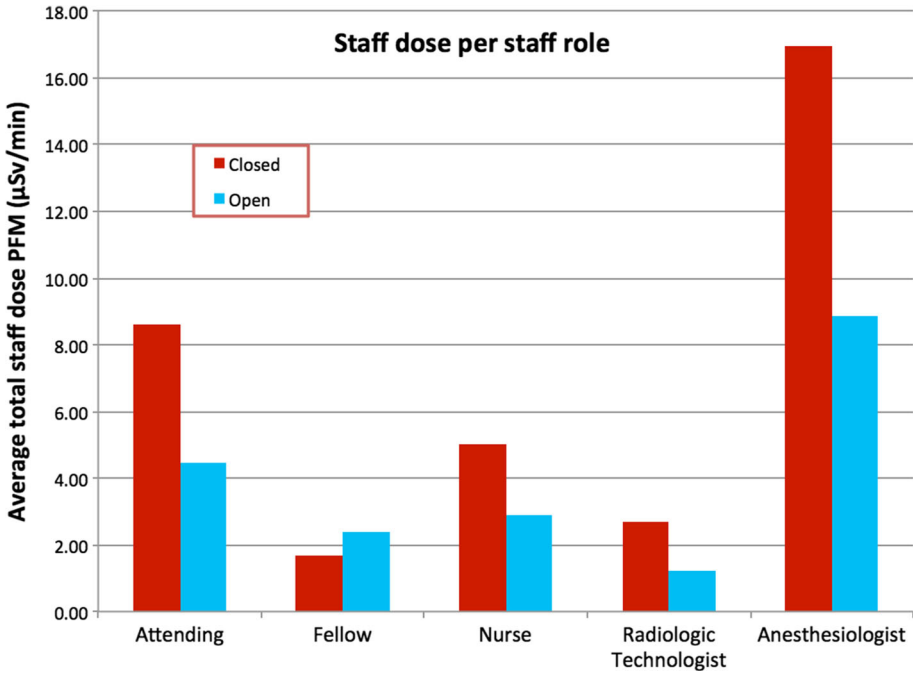

Fig. 2 Total staff dose per procedure for both open and closed phase. None of individual procedures yielded a statistically significant reduction by using the real-time feedback system

Discussion

The present study demonstrated that a real-time monitoring system on radiation allows for an overall reduction of radiation dose PFM. Further subgroup analysis, however, revealed only anesthesiologists to benefit significantly, thereof. In addition, a lower radiation dose was obtained for the subset of interventional as well as short procedures.

Exposure to radiation within occupational settings is a rising concern. There are various strategies and attempts to reduce radiation while applying intensified training and education. The findings of the present study, however, illustrate the extent of unawareness to radiation exposure. The unawareness of exposure to radiation within the setting of interventionists was demonstrated earlier and particularly for shorter procedures [11]. Accordingly, the lack of awareness may explain the benefit to radiation exposure for the subgroup of anesthesiologists within the present study. In addition, anesthesiologists are consistently close to the patients for the purpose of monitoring, thus allowing for easier detection of significance. Of interest however, that the subgroup of attending physicians did not show a

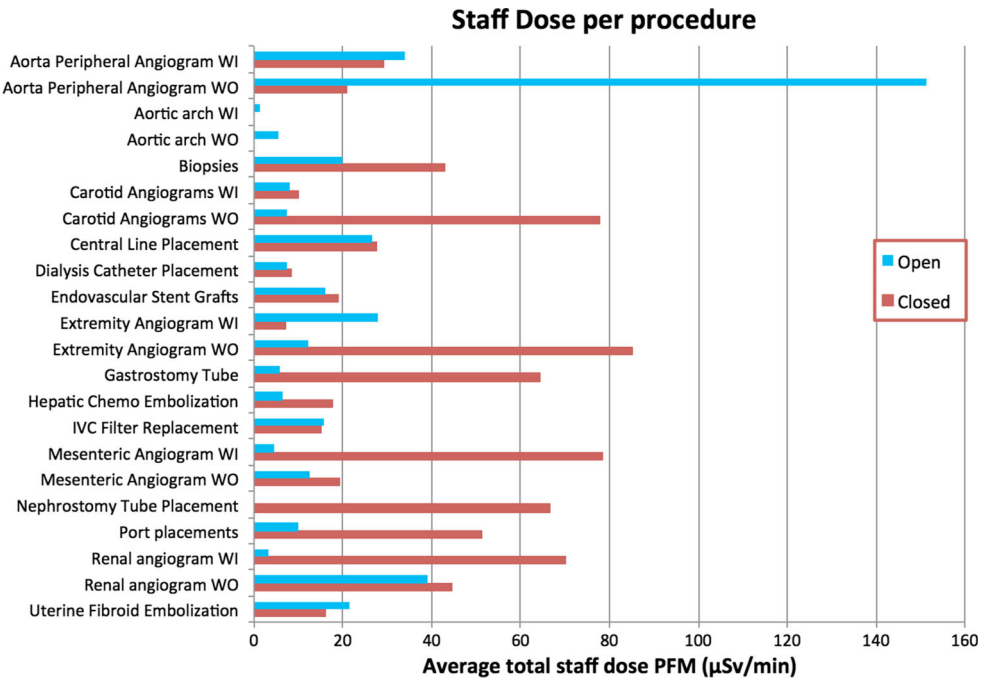

Fig. 3 Depiction of the average overall staff dose per procedure group for both the open and closed phases

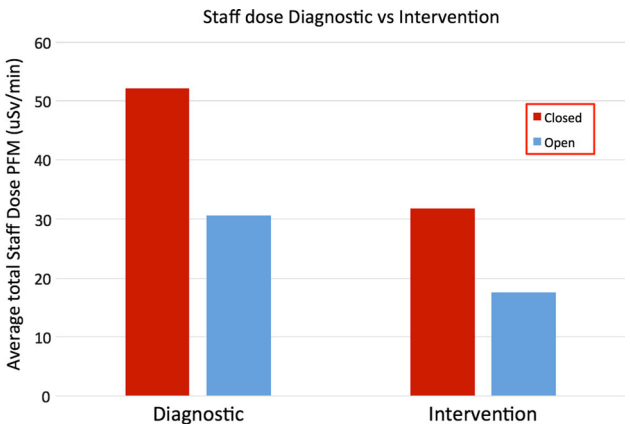

Fig. 4 Average overall staff dose comparing the closed versus the open phase for diagnostic and interventional procedures

Fig. 5 Illustration of the average overall staff dose comparing the closed versus the open phase for short and long interventions

significant reduction in radiation dose and that the fellows showed even increased radiation exposure during the open phase. Commonly, the attending physician is the closest to the patient and the radiation beam, and was shown earlier to profit from real-time radiation monitoring within a pediatric setting [12]. We assume, however, that our observations for the attending physicians and fellows may be affected by the start time of the trial and that of the fellowship. The fellows at our institution start in July whereas this trial was launched in August. Therefore, most fellows may have been mainly observing procedures during the closed phase of August/September with less exposure to radiation, whereas they started to do more hands-on and interventional work throughout the open phase. Thereby, the fellows may have enjoyed close guidance and observation from the attending physicians once they started to perform interventions during the open phase. We assume that this might explain the lack of dose reduction for the attending physicians and the increased radiation dose for our fellows during the open phase along with the prolonged fluoroscopy time for some less complex or diagnostic procedures. Of note, however, the increase of PFM values for aorto-peripheral angiograms without interventions may be explained by reduced fluoroscopy times for that specific procedure and an increase in the DSA imaging. Besides awareness, training, education, and behavioral adaption are important to reduce radiation exposure. However, and due

to the above-mentioned limitations based on the start of our study, radiation training and behavioral adaption were very limited for the attending physicians and the fellows within the present study. Nevertheless, the present trial included a learning period between the open and closed phases of 6 weeks. This time allowed the staff to familiarize themselves with the display panel and to begin establishing their own behavioral changes including its effect on radiation exposure. Among others (i.e., fellows starting to do more hands-on and interventional work, slightly more complicated procedures), we believe that the establishing of behavioral adaption may be one of reason for the increased radiation dose during the learning phase. In line, we believe that the behavioral adaption of the anesthesiologists, such as the use of shields, more distance from the patient and the radiation beam while monitoring the patients, may have contributed to their significant dose reduction during the open phase. However, it is difficult to clearly detect behavioral changes within the present trial for various reasons. First, operators and team members varied throughout the study period; second, there was no evaluation of preliminary data (i.e., after the learning phase) providing any feedback to the staff members; third, behavioral adaption of the staff was not systematically evaluated.

In addition to personal subgroup analysis, a significant reduction of radiation was attained for interventional and short procedures. Previous studies reported the unawareness of true dose exposure and the associated lack of preventive measures, particularly for shorter interventions [11]. Therefore, the present study underlined the importance of awareness regarding radiation and, in line, the benefit of a real-time monitoring mechanism for short procedures. The findings on interventional procedures within the present study represent the higher radiation dose applied when compared with diagnostic procedures. Accordingly, interventional procedures provide a wider scope for improvement on radiation, which was shown to benefit from real-time monitoring.

Between the open and closed phases there was no statistically significant reduction in system dose (DAP) even if normalized per procedural time. This may be related to a number of factors including the number and variability of cases and operators, which may be expected in a large institution like ours. There was a trend towards less total radiation dose PFM, but this was not shown as being statistically significant and it was difficult to prove within this study design.

Limitations

The present study contains various limitations. The effect of real-time monitoring on dose exposure was only validated by objective measurements but not for individual behavioral changes of the operators and the staff. By normalizing dose readings with fluoroscopy time, there was an attempt of comparing a large range of procedure types and different operators with a single variable to normalize for procedural complexity and time of procedure. The DAP is much more variable as it takes into account the total radiation dose including digital subtraction acquisitions which may not truly assess the time spent by the team member adjacent to the patient during the procedure. Fluoroscopy time should serve as a better surrogate for the time when team members were exposed to scatter radiation during a procedure. Interestingly, the average total fluoroscopy time increased by 4.1 min, between the closed and open phase likely related to the fellows doing more hands-on and interventional work and additionally slightly more complicated cases during the open phase. However due to the number of different operators, different patient size, and different procedural specifics it is difficult to accurately compare staff dose. Individual procedures did not yield a statistically significant reduction in team dose that are likely related to the small case numbers, and larger studies on specific procedures may be needed.

Conclusion

Real-time dose exposure monitoring may allow for behavioral changes and reduce staff exposure. However, further scrutiny on real-time monitoring systems is warranted within larger studies.

Conflict of interest Frederic Baumann: no conflict of interest. Barry T. Katzen: member of Advisory Board for Philips. Bart Carelsen: employee of Philips Healthcare who distributes the DoseAware technology. Nicolas Diehm: no conflict of interest. James Benenati: no conflict of interest. Constantino Peña: no conflict of interest.

Statement of Informed Consent This study focused on the review of data acquired during the quality assessment process. IRB permission for the retrospective use of this HIPAA compliant data was obtained and informed consent was waived.

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