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TECHNICAL NOTE

Staff Radiation Doses in a Real-Time Display Inside the Angiography Room

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Abstract
Methods The evaluation of a new occupational Dose Aware System (DAS) showing staff radiation doses in real time has been carried out in several angiography rooms in our hospital. The system uses electronic solid-state detectors with high-capacity memory storage. Every second, it archives the dose and dose rate measured and is wirelessly linked to a base-station screen mounted close to the diagnostic monitors. An easy transfer of the values to a data sheet permits further analysis of the scatter dose profile measured during the procedure, compares it with patient doses, and seeks to find the most effective actions to reduce operator exposure to radiation.
Results The cumulative occupational doses measured per procedure (shoulder-over lead apron) ranged from 0.6 to 350 μSv when the ceiling-suspended screen was used, and DSA (Digital Subtraction Acquisition) runs were acquired while the personnel left the angiography room. When the suspended screen was not used and radiologists remained inside the angiography room during DSA acquisitions, the dose rates registered at the operator's position reached up to 1–5 mSv/h during fluoroscopy and 12–235 mSv/h during DSA acquisitions. In such case, the cumulative scatter dose could be more than 3 mSv per procedure.
Conclusion Real-time display of doses to staff members warns interventionists whenever the scatter dose rates are too high or the radiation protection tools are not being properly used, providing an opportunity to improve personal protection accordingly.

Keywords Radiation protection · Occupational dosimetry · Real time

Introduction

Fluoroscopy-guided diagnostic and interventional procedures are widely used in clinical practice. Their incidence is growing constantly, but radiation doses delivered to patients and staff members are a matter of growing concern.

It is well known that occupational radiation doses in fluoroscopy-guided interventional procedures are the highest registered among medical staff [1–5]. Interventional radiologists represent one of the most important groups of medical specialists involved in such practices. Scatter radiation levels in the vicinity of the patient can be relatively high, even under routine working conditions. If protection tools and good operational measures are not used, and several complex procedures are performed daily, radiation-induced lesions of the eye may occur after several years of work [6].

Consequently, the greatest care must be taken to ensure the safety of these professionals and determine when additional tools are needed to keep personal doses in

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accordance with the ALARA (as low as reasonably achievable) principle. Lead aprons, protective eyeglasses, gloves, and screens suspended from the ceiling are some of the radiation protection (RP) tools used in angiography rooms, and European and national regulations require that physicians and paramedical personnel working in interventional radiology have specific training in radiological protection. We believe that a real-time staff warning will enhance users' motivation to use the RP equipment more effectively throughout high-scatter dose-rate conditions and will also help physicians recognize, and correct when possible, the undesirable high dose-rate positions.

The importance of the topic was raised by the board of the Cardiovascular and Interventional Radiological Society of Europe, which recently created and implemented guidelines in cooperation with the American Society of Interventional Radiology, under the title *Occupational Radiation Protection for Interventionalists: A Joint Guideline of the Cardiovascular and Interventional Radiology Society of Europe and the Society of Interventional Radiology* [7].

Here we present the first experience carried out with a new prototype of electronic occupational dosimeter fitted to register the dose-rate values every second, and to display the real-time dose rate and cumulative occupational doses on a screen inside the angiography room.

Materials and Methods

A dosimeter, placed at shoulder level over the protective apron, allows estimation of the exposure to the lenses of the eyes and neck, making sure that the dose to the lens and thyroid do not exceed the recommended limits. The dose limits for occupational exposures are expressed in equivalent doses for deterministic effects in specific tissues and expressed in effective doses for stochastic effects throughout the body.

The effective dose measures the global risk for a person exposed to ionizing radiation and combines the equivalent doses and the radiosensitivity of each organ. This quantity, measured in sieverts (Sv), can be related to the increases of cancer and hereditary effects [8].

The equivalent dose takes into account the weighting factor of radiation imparting the energy and it is measured in sieverts [8]. For X-rays, it is numerically equal to the absorbed dose measured in grays (Gy).

A typical personal dosimeter reports two values, Hp(0.07) and Hp(10), which represent the personal dose equivalent (dose equivalent in soft tissue at 0.07 and 10-mm depths, respectively) [9]. Hp(0.07), measured from a collar dosimeter worn over protective garments (apron, thyroid shield), provides a reasonable estimate of the dose delivered to the surface of the unshielded skin and to the lens of the eye. In addition, an approximate value of the dose under the apron could be obtained, taking into account the lead equivalent of the apron and the quality of the scattered radiation in the angiography room.

A prototype of a Dose Aware System (DAS) is currently under trial in our medical center. The dosimeter used has a solid-state detector equipped with a wireless connection that sends the scatter dose rate and cumulative scatter dose readings to a base station every second when it detects a certain level of radiation. To save energy and increase battery life, whenever the dosimeter does not detect any significant radiation levels, no information is transmitted to the base station.

When the dosimeter is not connected to the base station, it has a potential of storing instantaneous dose rate and cumulative dose values for up to 1 h of radiation (3600 readings). The personal dosimeter (Fig. 1) is small (4.5 × 4.5 × 1 cm), which makes it easy to carry during interventions. Physicians and other paramedical personnel can see the personal dose equivalent Hp(10) (measured in μSv) and the dose rate (measured in μSv/h) on the screen mounted in the angiography room next to the diagnostic monitors and therefore be alerted, which allows them to avoid high dose rates by making better use of the RP tools (mainly the ceiling-suspended screen) or, in the case of paramedical personnel, increasing their distance from the patients, if the clinical procedure allows it.

The dose rate is displayed on the screen (in μSv/h) with a color code in a logarithmic scale (Fig. 1). In addition, a historic record (date, time, personal dose equivalent rate, and cumulative dose equivalent) of each second of radiation is stored at the base station for each dosimeter. Dosimetry data can be downloaded from the base station to a computer, where it can then be analyzed with the appropriate software, or as a spreadsheet.

The initial test was carried out on 15 interventional procedures in two interventional radiology theaters, one of them equipped with a biplane X-ray system bearing flat detectors and dedicated to neuroradiology interventions. The second suite has a monoplane X-ray system, also with flat detector and dedicated to general interventional procedures. One dosimeter was positioned at the C arm at 45 degrees down from the horizontal plane at a distance of 85 cm from the isocenter (Fig. 1) to obtain a normalization time-scatter dose chart as well as to obtain a value directly related to the occupational radiation dose to the interventionists when they are inside the room and do not use an RP tool. In general, this value will be greater than the personal dose equivalent at the eye lens of the interventionists as a result of the different geometrical conditions, but it allows a rough and conservative estimation of the lens doses when RP tools are not used. Correlation between patient dose

Fig. 1 Detector over the specialist apron (*left*). Detector located at the C arm to have an estimation of radiation dose without protection (*center*). Base station displaying different levels of radiation with a color code

values measured as dose area product (DAP) and occupational doses were analyzed by SPSS software, version 12 (SPSS, Chicago, IL).

Occupational doses were measured during 15 procedures: 6 limb arteriographies, 1 vertebroplasty, 2 transjugular intrahepatic portosystemic shunts, 1 hepatic arteriography, 1 hepatic chemoembolization, 1 cerebral embolization, 1 cerebral arteriography, 1 cerebral stent, and 1 vena cava filter. The maximum dose rates and cumulative doses were measured and recorded.

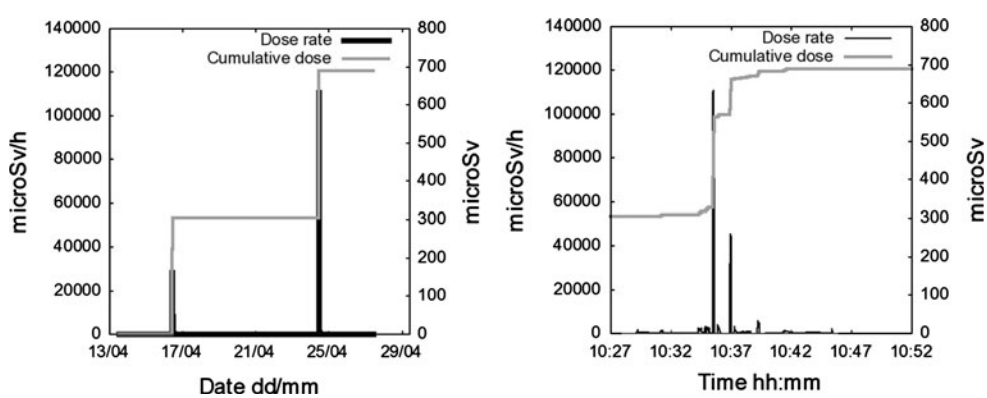
Results and Discussion

Figure 2 shows a typical graph of the evolution of scatter dose values measured by one dosimeter located at the C arm. The record contains dose rate and cumulative dose over 14 days corresponding to two procedures that were performed by means of this dosimeter to control occupational exposure. With a zoom tool, it is possible to obtain more detailed graphs and analyze scatter doses procedure by procedure. If the patient dose report is available, the scatter dose rate during each DSA (Digital Subtraction Acquisition) series and fluoroscopy runs can be identified. At the zoomed area of the scatter dose chart in Fig. 2, the dose rate and cumulative dose are shown during a lower limb arteriography procedure.

A total DAP value of 37.5 Gy cm^2 was delivered to the patient with 2.1 min of fluoroscopy and five DSA series with a total of 86 images. The main contribution to personal dose equivalent was found to be provided by DSA acquisitions. The highest dose rate at the C arm was 110 mSv/h and the cumulative dose (at the C arm) 385 μSv, with approximately 330 μSv ($\approx$85%) as a result of DSA acquisitions and 55 μSv ($\approx$15%) originating from fluoroscopy runs. It is possible to superimpose the C-arm dose record with the radiologist's dose record to check whether the radiologist was protected (or outside the angiography room) during DSA runs.

Among the 15 procedures analyzed, a maximum scatter dose rate at the C-arm dosimeter ranging from 12 mSv/h during a lower limb arteriography to 235 mSv/h during a transjugular intrahepatic portosystemic shunt procedure were measured. The maximum cumulative scatter dose at the same dosimeter varied from 0.16 mSv (in a lower limb arteriography procedure) to 3.35 mSv during a cerebral arteriography performed with the biplane X-ray system. Radiologist's dosimeter registered values of maximum dose rate between 0.054 and 16.4 mSv/h, and for cumulative dose, values between 0.65 and 350 μSv for other

Fig. 2 Example of the information extracted from the Dose Aware System. The graph corresponds to the dose rate and cumulative dose measured at the C arm. (*Left*) Dose rate and cumulative dose over 14 days. (*Right*) Close-up corresponding to the dose measured in a single procedure



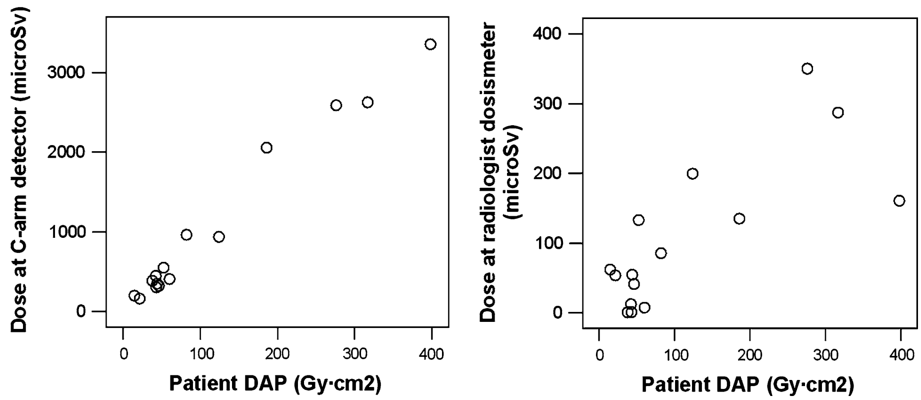


Fig. 3 Representation of personal dose equivalent measured by the C arm (*right*) and radiologist dosimeters (*left*) against patient dose area product. Note a loss in correlation (*right*) in the case of radiologist dose values (mainly due to the use of protection tools or staying outside the angiography room during radiation administration)

procedures. It should be noted that in our center, it is a common practice to use a ceiling-suspended screen and to use an automatic injector for the contrast administration, making it possible to acquire the DSA series from the control room, with the staff outside the angiography room.

The mean cumulative dose measured at the C arm during the trial was 1.04 mSv per procedure. This mean value for the radiologist's dosimeter (carried at shoulder, over the protective apron) was 10 times lower (0.11 mSv per procedure). Under the hypothesis that the C-arm dosimeter estimates the staff member's dose approximately if the staff member is not using an RP tool, one may assume that the use of RP tools can, in practice, reduce the personal equivalent dose to the eye lens roughly by a factor of 10. In theory, this factor should be around 20 (attenuation of 0.5–1.0 mm of lead equivalent) for fluoroscopy, but the lack of a proper position of the screen during part of the procedure reduces the effectiveness of the protection. The other positive aspect to be considered when explaining the differences between the dose values measured at the C arm and those measured with the staff members' personal dosimeters derives from the sensible habit of walking out of the angiography room during the DSA acquisitions.

A positive correlation was obtained between the DAP delivered to the patient and the values registered by the personal dosimeters located at the C arm (Fig. 3). The Spearman rho value was 0.914 ($P < 0.001$). The slope calculated resulted in 8.7 μSv/(Gy cm^2), which could be assimilated as the maximum personal dose equivalent at the lens of the radiologist per Gy cm^2 received by the patient, in case of nonuse of RP tools. These values are compatible with the measurements made by Vano et al. when thermoluminescent dosimeters are used in interventional cardiology suites [2]. Values from 8.0 to 12.0 μSv/(Gy cm^2) were obtained by these authors.

When correlation is tested between the radiologist personal equivalent dose and the patient's DAP values, the Spearman rho value decreases to 0.729 ($P = 0.002$). This reduction in correlation is the consequence of two factors: first, the radiologists leave the angiography room during DSA acquisitions; and second, we use a protective screen suspended from the ceiling. Despite this reduction, we still note a significant correlation, even when protection tools are used; for instance, in the sample analyzed, the radiologist (who used protection tools during the procedure) received approximately 0.7 μSv/(Gy cm^2) of radiation delivered to the patient.

Conclusions

DAS can help optimize staff members' RP during fluoroscopy-guided procedures. The real-time dose display alerts interventionists and other staff members inside the angiography room when the scatter dose rates are high and when the RP tools are not being properly used, thus giving workers the opportunity to improve personal protection and reduce occupational doses.

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Conflict of interest statement The authors declare that they have no conflict of interest.

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