Towards a specific education and training programme in radiological protection for practitioners in interventional cardiology

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Abstract
With respect to exposures in the medical sector, doses to patients and practitioners are among the highest in interventional cardiology. The ongoing FANC study in Belgium shows that in case of difficult interventions skin doses in patients exceed frequently the threshold dose for direct effects of 2 Gy. Appropriate education and training in radiological protection for practitioners in interventional cardiology is an urgent need to keep doses at an acceptable level. Apart from general radiation protection issues applicable to all medical uses of X-rays, education and training programmes of cardiologists and other practitioners in the catheterisation laboratory should deal with the specific measures to be taken to reduce patient and personnel doses when using C-arm X-ray equipment in fluoroscopy and cine mode. Based on the data of the FANC multicenter study in Belgium a number of important recommendations for this specific interventional cardiology section in radiation protection education programmes are given. The use of the DAP-reading as on-line patient dose indicator is discussed.

1. Introduction

The dose inventory study performed for the Federal Agency for Nuclear Control (FANC) has confirmed literature data indicating that interventional cardiology procedures involve high doses to the patient sometimes exceeding the threshold dose for skin deterministic effects of 2 Gy [1-4]. Several observed radiation induced skin injuries have been reported [5-6]. At the same time also high doses to personnel involved in the interventional procedures at the catheterisation room are reported [7]. Cardiologists have an active role in the reduction of patient's doses and the avoidance of radiation injuries from interventional procedures. The International Commission on Radiological Protection (ICRP) has published a report with recommendations for the avoidance of these radiation injuries [8]. Council directive 97/43/EURATOM specifies that member states have to assure theoretical and practical training in radiation protection issues related to the applied radiological techniques [9]. For cardiology, education programmes should cover not only general radiation protection matters but also specific topics related to interventional cardiology. Training in radiation protection for interventional radiology in general was already discussed in the past by Vano et al. [10]. As a result of the FANC study special attention should be paid to the practical training of the cardiologists with training in the use of the dose information displayed at the operator's position by e.g. a dose-area product meter.

2. Overview of important topics and issues necessary to include in radiation protection training of personnel involved in interventional cardiology

X-ray equipment

During the last years manufacturers of X-ray equipment for interventional radiology have put a lot of effort to introduce dose reduction techniques and devices. These include additional and variable (Cu) filtration, pulsed X-ray beams with low frame rate, last image hold, and "STORE FLUORO" mode. Recent data show also dose reduction by digital flat panel detectors compared to conventional image intensifiers. In this way contemporary X-ray equipment for fluoroscopy and cine allows an important reduction of patient's doses if used correctly. Therefore the following topics are considered to be essential in the theoretical and practical training of cardiologists and other catheterisation room personnel:

(1) Dose reduction by high additional filtration
(2) Dose reduction by pulsed X-ray beams versus continuous beams
(3) Importance of image hold
(4) Effect of low- and high dose fluoroscopy modes on image quality and dose

(5) Dose increment associated by the antiscatter grid
(6) Effect of magnification on the dose received by the patient

Dosimetric quantities

The FANC inventory study of the research group has shown that the cumulative dose-area product (DAP) can be used as action level to avoid patient's skin overexposures. Furthermore a very good correlation between the DAP and the effective dose was established with a effective dose/DAP conversion factor of 0.185 mSv/Gy.cm^2 . The study has also confirmed the need for double dosimetry for personnel dosimetry in interventional cardiology. In view of these conclusions of the FANC study the following topics related to dosimetric quantities are proposed as key issues in radiation protection education programmes:

(1) Definition and importance of dose-area product as patient dose monitor
(2) Correlation between skin entrance dose – DAP in complex geometries : use of the DAP reading as on-line alarm and action level with respect to patient's skin dose
(3) Definition of effective dose for risk estimation for late effects of exposure to X-rays with description of the methodology for determination of patient's organ doses, uterus and gonadal doses in X-ray fields
(4) Relationship between effective dose and cumulative DAP reading
(5) Dependence of skin, organ and effective doses on X-ray source quantities (mA, time, distance, kV, filtration)
(6) Overview of measuring techniques for occupational and patient dosimetry (TLD, ionometry, film, electronic dosemeters)
(7) Personnel dosimetry with double dosimetry when using personal protection clothing as leaded aprons with special attention paid to the position of the dosemeters.

Radiobiology

Different deterministic radiation effects to patient's skin after diagnostic and therapeutic interventions are already reported in the literature: erythema, moist desquamation, ulceration to necrosis [6]. It is obvious that the medical practitioner needs the basics of radiobiology and –pathology. In paediatric interventional cardiology effective doses are also high necessitating an overview of the important variables as gender and age in the individual patient risk assessment with respect to late effects as cancer and leukaemia [11]. Furthermore, issues related to X-ray exposure of female patients and pregnancy have to be treated in the radiobiology course. With respect to biological effects for personnel recent data point to the incidence of cataract formation in workers at the catheterisation room. The following topics are therefore considered to be the frame of the radiobiology sessions:

(1) Characteristics of deterministic direct and stochastic late effects
(2) Overview of the different deterministic effects on the skin with threshold dose . Examples of skin injuries due to overexposures in interventional cardiology –time course.
(3) X-ray exposure of female patients and pregnancy. Measures to be taken to avoid in utero exposure. Risk estimations for patients and staff
(4) Radiation induced cataract formation in the lens
(5) Overview of the UNSCEAR report data on late radiation effects: cancer and leukaemia, hereditary (genetic) effects [12]. Discussion of the different variables influencing the risk of late radiation effects with emphasis on age dependence: difference between risk assessment in paediatric and adult patients.

Radiation protection of staff

To keep personnel doses below the ICRP 60 levels of 20 mSv per year for occupational exposed workers protective clothing is indispensable. Also the dose to the eye lens with a limit of 150 mSv per year is critical. Furthermore, occupational doses are not only due to scattered radiation but fingers and hands of the interventionalist can also be exposed by the primary X-ray beam especially during the catheterisation. Radiation protection training for personnel protection issues may not be restricted to theoretical education programmes but has to include also practical training how to reduce doses. In this framework the following issues have to be discussed:

(1) Dose reduction by the use of protective clothing : leaded aprons (thickness), gloves, eyeglasses, thyroid collar
(2) Effect of distance between staff and patient on doses: repercussions on operational procedures during image acquisition
(3) Dependence of occupational doses on X-ray C-arm positioning, illustrated by isodose curves in the catheterisation room

(4) Effect of position of TV monitor on the eye lens dose
(5) Importance of collimation, kV, cine- and fluoroscopy mode on the occupational dose
(6) Overview of typical values of the occupational dose quantities (effective dose, extremity dose, eye lens dose) for the cardiologist and other personnel in the catheterisation room during most common cardiological interventions (coronary angiography, PTCA, stent-implant).

Radiation protection of patients: avoidance of overexposures

The programme related to radiation protection of patients has to be focussed on patient dose reduction related to the risk for late radiation effects and on the avoidance of skin injuries due to localised hot spots in exposure to the skin. The multicenter study performed for the FANC has shown that even with the use of contemporary equipment in about 3 % of all patients undergoing an interventional cardiological procedure the dose threshold of 2 Gy is exceeded. While the complexity and difficulty of a particular intervention is the main cause of these overexposures, other contributing factors are long fluoroscopy times, a relatively large skin-image intensifier distance, the use of single incidences for long runs as well in fluoroscopy as in cine, the use of pure lateral incidences (LAO90) and the lower experience of cardiologist assistants in training. Cardiologists have to be trained in procedures to avoid or reduce the impact of these factors. Also practical training in the use of the DAP as on-line dose monitor with action levels is indicated. Our FANC study has shown that DAP values of 125 and 250 Gy.cm^2 can be used as action levels for skin doses of 2 and 3 Gy respectively. In case of DAP values exceeding 125 Gy.cm^2 registration of the location and extent of the skin site that received the largest dose according to the cardiologist (together with the DAP value) in patient's record is indicated. The cardiologist can also decide that the patient has to be followed up for radiation skin effects based on the difficulty of the procedure and the total fluoroscopy time especially in single projection directions. This decision has to be based on a comparison with the local reference procedure. For DAP values exceeding 250 Gy.cm^2 the patient and his personal physician should be informed about possible radiation effects. It is clear that the practical training for this part of the radiation protection education programme has to take place in a catheterisation room.

The most important issues dealing with patient's dose reduction and avoidance of radiation injuries are the following:

(1) Reference DAP values. Typical values of patient entrance skin dose rate in high and low dose fluoroscopy modes and typical values of patient entrance skin dose per image for cine runs. Typical values of patient effective dose per unit of DAP
(2) Effect of the focus-to-skin distance and patient-to-image intensifier distance on skin dose
(3) Use of the cumulative DAP value as patient skin dose monitor during a procedure
(4) Determination of skin doses for a number of patients in case of normal procedures for most common types of procedures : to allow for the interventional physician to have operational knowledge of the patient's skin dose.
(5) Protocol for using different C-arm orientations to avoid overexposures in case of complex and long procedures
(6) Discussion of the counselling given to a patient before the intervention on the doses they can receive and the effects involved. Importance of patient's informed consent with respect to radiation risks.
(7) Decision of radiopathological follow-up of a patient based on the operational knowledge of the patient's skin dose by the cardiologist (complexity and duration) and the DAP value. Written protocol for the radiopathological follow up of patients including the information of patient's personal physician.
(8) Data regarding the radiation exposure to be recorded in patient's records: cumulative DAP for every patient, localisation of the most exposed skin site in case of exceeding the DAP action levels.

3. Conclusions

Radiation protection education programmes in the medical field have to be evidence-based and oriented practically: apart from the necessary basic subject material they should discuss also the application in daily practice. In view of the high radiation burden of patients and staff in interventional cardiology, dedicated programmes have to focus especially on the reduction of the effective dose of patients and staff and on the avoidance of radiation injuries in patients due to localised hot spots in skin exposure.

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