

Importance of Dose Settings in the X-Ray Systems Used for Interventional Radiology: A National Survey

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Received: 7 July 2008 / Accepted: 30 October 2008 / Published online: 4 December 2008
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Abstract The purpose of this work was to investigate the differences in dose settings among the X-ray units involved in a national survey of patient doses in interventional radiology (IR). The survey was promoted by the National Society of IR and involved 10 centers. As part of the agreed quality control for the survey, entrance doses were measured in a 20-cm-thick acrylic phantom simulating a medium-sized patient. A standard digital subtraction

angiography (DSA) imaging protocol for the abdomen was used at the different centers. The center of the phantom was placed at the isocenter of the C-arm system during the measurements to simulate clinical conditions. Units with image intensifiers and flat detectors were involved in the survey. Entrance doses for low, medium, and high fluoroscopy modes and DSA acquisitions were measured for a field of view of 20 cm (or closest). A widespread range of entrance dose values was obtained: 4.5–18.6, 9.2–28.4, and 15.4–51.5 mGy/min in low, medium, and high fluoroscopy mode, respectively, and 0.7–5.0 mGy/DSA image. The ratios between the maximum and the minimum values measured (3–4 for fluoroscopy and 7 for DSA) suggest an important margin for optimization. The calibration factor for the dose-area product meter was also included in the survey and resulted in a mean value of 0.73, with a standard deviation of 0.07. It seems clear that the dose setting for the X-ray systems used in IR requires better criteria and approaches.

This paper was presented as a scientific poster at the CIRSE annual meeting in Copenhagen, September 2008.

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Keywords Dose settings · Fluoroscopy · Dose rate · National survey · Dose-area product

Introduction

In 2006, the National Society of Interventional Radiology (IR) agreed to launch a pilot program to obtain representative values of patient and staff doses during fluoroscopically guided diagnostic and therapeutic procedures [1]. Similar surveys were completed in 2003–2004 in the United States [2, 3] and, more recently, on a much smaller scale, in some European countries for the European Concerted Action SENTINEL [4, 5]. As part of its International Action Plan for Protection of Patients, the

International Atomic Energy Agency conducted an international research project to propose dose reference levels for cardiology procedures [6]. In all those programs, a basic quality control of the X-ray systems was conducted and it was recommended that such measurements should be included in similar future exercises involving patient dose evaluations.

The American RAD-IR study [3] contained a set of physics data supporting the validity of the evaluation of patient doses. Constancy checks at intervals ranging from 1 week to 1 month were decided on. From the physics evaluation of the RAD-IR study, involving 12 fluoroscopy units over the 3-year-study, the authors estimated the overall error in clinical cumulative dose measurements to be 24%. In our case, and considering that the local regulation compels us to perform regular quality controls (QCs) according to the national protocol and to introduce corrective actions when appropriate, medical physicists were asked to evaluate the dose setting of different X-ray systems. They were then to analyze the potential variability that would justify some of the differences in patient dose values and henceforth suggest optimization actions.

The National IR Society, in charge of promoting the program, selected 10 hospitals that agreed to be involved in the exercise on a voluntary basis. One of the goals of the survey was to obtain national dose reference levels for a group of frequent fluoroscopically guided diagnostic and interventional procedures. The patient doses measured at these 10 hospitals were to be published at the Web site of the society, with free access for any hospital, which would allow comparison of these values to their own and the decision whether to apply any corrective action, should their values be substantially higher than the “reference” values.

A European study [5], recently carried out as part of the Concerted Action SENTINEL [4], collected patient doses for a few common fluoroscopy-guided procedures (excluding cardiologic ones) from 13 European countries. This study resulted in a wide range of dose values and seemed to indicate no clear correlation among the dose values, the fluoroscopy time, and the number of acquired images. This could infer that different settings of X-ray systems could have a relevant influence on the results.

The first important step in any patient dose survey is to verify the setting of the X-ray systems, the accuracy of the dose indications, and their constancy during the program. Modern vascular units for IR include an enormous number of protocols that can be personalized according to the preferences of the radiologist. In addition, the geometry of the imaging system during the procedure has a significant influence. A recent study by Othee and Lin [7] reported variations of 32% in the values of entrance patient doses upon moving the angiography table from the highest to the

lowest position. It is quite difficult to check all the available protocols and the logic of the automatic exposure control (AEC) curves [8], but some basic QC tests should always be performed during the commissioning of a new system in order to explain the sometimes big differences in patient doses from one center to another, for similar clinical procedures.

The aim of this work was to investigate, at the national level, the differences in dose settings among X-ray systems when used in a similar way and with the same geometrical setup simulating the clinical practice.

Materials and Methods

In addition to the local QC program [9, 10] already existing at the centers involved in the survey (mandatory according to the local regulations), another simple test was requested from the participants every year. This test was to be sent to the central database as part of the national survey. Dose measurements in a standard geometry with setting parameters similar to those used in clinical practice were agreed on by the participants at the beginning of the program. The differences among manufacturers protocols make it difficult to find common criteria when the X-ray units have to be tested with a specific common protocol, especially for digital subtraction angiography (DSA) acquisitions, mainly because most systems are customized according to the preferences of the local users.

Ten X-ray units from 10 hospitals taking part in the survey reported their results in time to be included in this paper (Table 1). They are identified as numbers 1–10; five of them (nos. 6–10) are equipped with flat panel detectors (FDs) and the others (nos. 1–5) have image intensifiers (IIs) as image detectors. Each participant measured the entrance dose rate (including backscatter [BS]) in a phantom of 20-cm-thick polymethyl metacrylate (PMMA) centered at the isocenter of the X-ray system and with the II or FD 5 cm from the phantom. All participants were requested to use PMMA to avoid uncertainties due to phantom material [11]. The angiography table and mattress were in the X-ray beam during the measurements. The typical distance from source to II or FD was 90 cm, therefore the distance from source to phantom was nearly 65 cm. It was recommended that participants select an “abdomen” protocol of 2–3 images per second (frequently used in several clinical procedures) and to measure the entrance dose per image in the DSA mode. In all cases, a calibrated dosimeter (traceable to a secondary standard laboratory) was used for the measurements.

The fluoroscopy modes differed in each X-ray generator and at each hospital. Some participants used pulsed fluoroscopy modes of from 7 to 30 frames per second, and

Table 1 The X-ray systems involved in the survey

ID no.	Manufacturer	Model	Image detector (ID)	ID size	Year of installation
1	Toshiba	Infinix VC-i	Image intensifier	40.6 cm Ø	2004
2	Philips	Integris V3000	Image intensifier	38.1 cm Ø	1993
3	Toshiba	Cas 8000 V	Image intensifier	35.6 cm Ø	1999
4	Siemens	2000 angio star plus	Image intensifier	40 cm Ø	1999
5	Siemens	Axiom Artis	Image intensifier	40 cm Ø	2004
6	Philips	Allura	Flat detector	30 × 40 cm ²	2002
7	Philips	Allura	Flat detector	30 × 40 cm ²	2005
8	Philips	Allura	Flat detector	30 × 40 cm ²	2005
9	Philips	Allura	Flat detector	30 × 40 cm ²	2003
10	Siemens	Polydoros A-100	Flat detector	30 × 35 cm ²	2007

others used continuous fluoroscopy mode. The wide range of operation modes in modern vascular units made it difficult to harmonize the fluoroscopy modes at the different centers. All participants were requested to use a field of view (FOV) as close as possible to 20 cm in diameter (for II) or diagonal (for FD). In practice, the values used for FOV moved from 17.5 to 25 cm. The results for low, medium and high fluoroscopy dose rates and DSA acquisition mode were also on the agenda. As a general rule, the low fluoroscopy mode has the lowest dose rate with the highest additional filtration, giving the lowest image quality. This seems to be the most used fluoroscopy mode. The medium and high fluoroscopy modes have higher dose rates with less additional filtration, producing a better image quality. Moreover, the pulse rate and the dose per pulse are sometimes modified when the different fluoroscopy modes (low, medium, and high) are set.

Four participants provided results of similar measurements with additional thicknesses of PMMA (16, 24, and 28 cm) along with the behavior of the entrance dose values against patient thickness.

The participants were also asked to measure a calibration (or correction) factor of the integrated kerma area product (KAP) meter in the X-ray system that took into account the attenuation of the table and the mattress. A common written protocol, based on the one already existing in the European Research Program SENTINEL [12], was agreed on among the participants. For this purpose, the measurements carried out at each center of the radiation field size (using a radiographic film) and the incident dose (without BS) with a calibrated ionization chamber (measured over the table and the mattress) were used to calculate the correction factor. Copper absorbers allowed driving the generator to 80 kV. Copper plates were placed between the ionization chamber and the II or FD, 20 cm above the chamber (to avoid BS). The calibration (or correction) factor was calculated as the quotient of KAP measured by the X-ray system (KAP measured using the

reference ionization chamber). All KAP values for patients collected during the national survey were corrected by the particular correction factor at each center.

A statistical analysis using a nonparametric test was performed with SPSS 12.0 (www.spss.com).

Results

Global results are summarized in Fig. 1. In the different fluoroscopy modes, there is a mean factor of ~ 3.5 from the minimum to the maximum values of dose rates; for DSA this factor (entrance dose per image) is about 7. For low fluoroscopy mode, entrance dose rates increased from 4.5 to 18.6 mGy/min. For medium fluoroscopy mode, values ranged from 9.2 to 28.4 mGy/min; and for high fluoroscopy mode, from 15.4 to 51.5 mGy/min. For DSA images, values ranged from 0.7 to 5.0 mGy/image. Table 2 lists the results in detail.

When the differences between manufacturers were analyzed in the four operation modes, no statistical significance was found except for the high fluoroscopy mode between Philips and Siemens. We found that the entrance dose settings with the Philips systems were approximately twofold the values measured with the Siemens units (Mann–Withney U test, $p = 0.036$). The differences found in the systems equipped with II versus FD were not statistically significant in our survey. When we analyzed the relationship between the age of the systems and the entrance doses measured, we did not find any correlation between these two variables.

Figures 2–5 show the variation of normalized entrance dose against PMMA thickness for the four centers that completed these measurements. It can be seen that, for thin phantoms, the behavior was similar in all systems and operation modes, but with thicker phantoms, significant differences appeared in the dose increases among the X-ray systems evaluated.

Fig. 1 Entrance doses per image (with BS) for DSA and entrance dose rates (with BS) for fluoroscopy for a 20-cm-thick acrylic phantom for the different participants

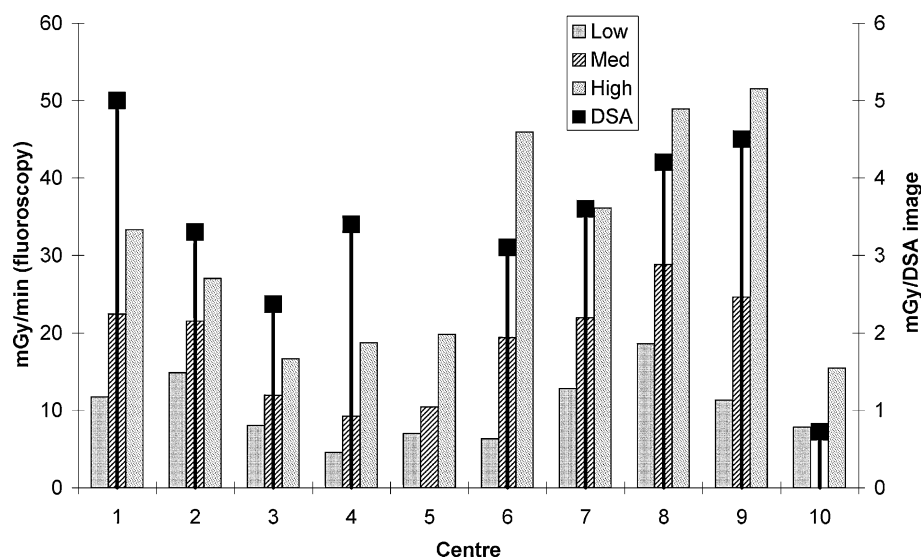


Table 2 Results of entrance dose rate in fluoroscopy mode (mGy/min), entrance dose/DSA image (mGy/image), and PDA meter correction factor for the different systems

ID no.	Manufacturer	Low mode	Medium mode	High mode	DSA	PDA correction factor
1	Toshiba	11.7	22.4	33.3	5.0	0.81
2	Philips	14.8	21.5	27.0	3.3	0.68
3	Toshiba	8.0	11.9	16.6	2.4	0.66
4	Siemens	4.5	9.2	18.7	3.4	0.65
5	Siemens	7.0	10.4	19.8		0.73
6	Philips	6.3	19.4	45.9	3.1	0.80
7	Philips	12.8	22.0	36.1	3.6	0.71
8	Philips	18.6	28.8	48.9	4.2	0.84
9	Philips	11.3	24.6	51.5	4.5	0.74
10	Siemens	7.8		15.4	0.7	0.68

For KAP meters calibration factors, a mean value of 0.73 was obtained, with a standard deviation of 0.07. The maximum value was 0.84, and the minimum 0.64.

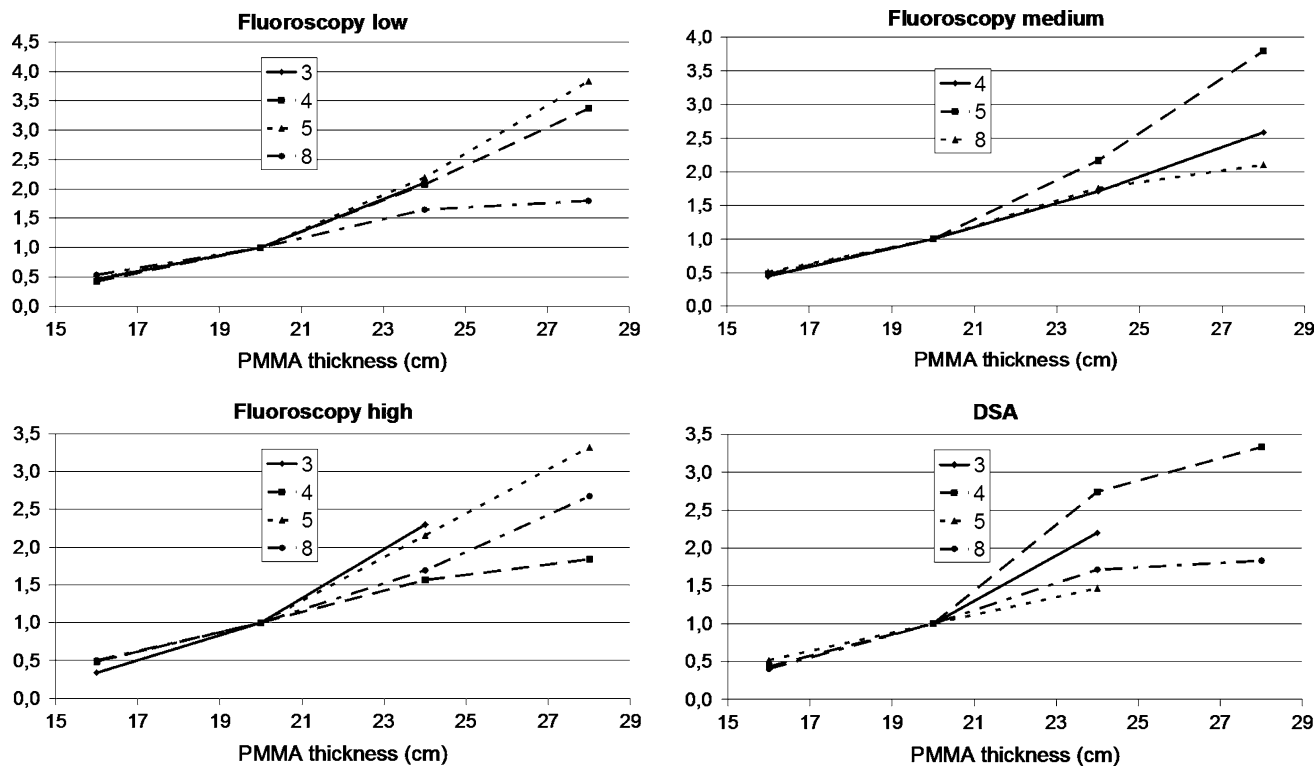
Discussion

The results of the American RAD-IR study [3] were reported for incident dose (without BS) at 55 cm from the focal spot. For 20 cm PMMA the mean values quoted were 5.3 mGy/DSA image, 14.0 mGy/min (for pulsed fluoroscopy), and 28.3 mGy/min (for continuous fluoroscopy). Measurements were completed in this case only for the most common fluoroscopy mode. The FOV used was not reported. The mattress and patient table were not in the beam during these measurements. The ratios of maximum to minimum values measured for 20 cm PMMA were 6 for fluoroscopy and 10 for DSA imaging.

As for the European survey [5], only 15 of the 28 units involved reported the calibration of the KAP meter. The

calibration factors varied from 0.37 to 1.41 (max/min ratio, 3.8), with a mean of 0.83. In this study, we obtained a more homogeneous set of values (max/min ratio, 1.31), with an average calibration factor 12% lower than the European survey. The results indicate that, without taking the calibration factor into consideration, the KAP values overestimate the true KAP on average by about 20–30%. The entrance dose rate reported in the European survey for the three fluoroscopy modes (and a FOV of 20–22 cm) varies by a factor of 6–14 within a given fluoroscopy mode. The entrance dose per image reported for two image acquisition modes (low and normal) varies by a factor of 100.

In the present study, the measurement conditions were closer to the real clinical conditions used with patients: the attenuation of the table and mattress was included and the values reported include BS factors. Bearing in mind that the attenuation of the table and mattress can be partially compensated by the BS, the differences in dose settings between the X-ray systems used in the U.S. study and those



Figs. 2–5 Relative entrance dose values versus phantom thicknesses for different centers and operation modes. Entrance doses are normalized to the value at 20-cm thickness for each center and each operation mode

used in the present survey are compatible for dose rates in fluoroscopy and dose per image in DSA acquisitions. The factors between maximum and minimum values of dose rates and dose per DSA images are higher in the U.S. study of fluoroscopy: 6, versus 3–4 in the present survey. For DSA, the figures are similar (a factor of 10 in the U.S. and seven in this study). The European survey [4] obtained a much wider range of doses for fluoroscopy and DSA.

It does not seem logical that some centers use three to seven times higher doses to obtain images that, in “theory,” offer similar diagnostic information. These differences in entrance dose values seem to derive neither from the different imaging technologies (II or FD) nor from the manufacturers or the age of the X-ray systems, but from the different dose settings on image quality used at each center. In a system, it is acceptable to have different levels of dose settings and image quality to allow radiologists to improve the quality for some procedures, but the reasons for such important differences as found in the present study for the same operation mode (e.g., low fluoroscopy mode and DSA acquisition), for the same phantom thickness and for the same FOV, must be questioned. In the future optimization programs should reduce this wide dispersion.

Figures 2–5 show the different logic in the AEC curves for different PMMA thicknesses. In the systems

investigated, the important differences in relative dose values when the phantom thickness is increased need to be explained and justified. With some systems in order to maintain a reasonably good image quality for higher phantom thicknesses, the entrance doses need to be significantly higher in percentage than with others. Further investigation into numerical evaluation of image quality and doses seems to be necessary.

Conclusion

The comparison drawn from the results of the dose settings of the X-ray systems involved in the present national survey shows significant differences and points to the benefits of an optimization program. It seems clear that the dose setting for the X-ray systems used in IR requires better criteria and approaches. The important variations in dose values for different phantom thicknesses demand an investigation into the different logic of the AEC systems and a good balance between the benefit (i.e., “image quality”) and the risk (i.e., “patient dose”) for the full range of patient thicknesses. Collaboration among medical physicists, radiologists, and service engineers will help to optimize the use of X-ray systems in IR practice.

Acknowledgment The present work has been carried out with the partial support of Grant FIS2006-08186 from the Spanish Ministry of Education and Science.

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