Flat detector versus image intensifier in cardiology. Why are patient doses initially higher?

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Abstract. Our purpose in this paper is to study the differences in patient doses imparted using dynamic flat detectors (FD) as opposed to using image intensifier (II) technology for interventional cardiology within two different European Centres, and then analyse the reasons for such differences. Several x-ray systems from two different manufacturers equipped with FDs and IIs were used over the last 4 years in two separate interventional cardiology services both subject to common quality assurance programmes agreed during the European SENTINEL Coordination Action. The same team of cardiologists worked simultaneously or in sequence in laboratories equipped with FD and II technologies. No differences were found regarding specific patient characteristics in the different catheterisation laboratories. Kerma area product (KAP) values were measured and analysed for large samples of procedures. In centre M, median KAP values were consistently and significantly higher with FD than with II, with percentages of 55-113%. In centre U, the KAP increase was 7-29% comparing FD with II. Without a dedicated optimisation programme, initial patient dose values can result significantly higher with FD technology in comparison with II. This might be related to the use of non optimum initial setting protocols of the x-ray systems (dose per frame, pulses/s, filtration etc), bigger radiation filed sizes for FD and the scarce use of collimation and wedge filters in the new systems equipped with FDs. Preventing this problem and improving the management of patient doses warrant further studies

KEYWORDS: Interventional cardiology, patient dosimetry, flat detector, image intensifier.

1. Introduction

Imaging technology in interventional cardiology (IC) is going through great changes with the introduction of dynamic flat detectors (FD). Image intensifiers (II) have become obsolete and most of the new x-ray equipment for catheterization laboratories now comes with FDs. Flat panel detectors are less complex and more compact; they bear no geometric distortion, they also show excellent uniformity of response and spatial resolution across their area and have a wider dynamic range [1].

Cardiac angiographic systems with FD are influencing the practice and not always for the best management of patient doses. A better imaging performance sometimes prevents or even reduces in some cases, the use of wedge filters and x-ray beam collimation while the smaller size of the imaging part of the C-arms allows more angulated cranio-caudal projections [2]. Unfortunately this advance in digital imaging technology has resulted in some increases in patient doses as the evaluation carried out for the European SENTINEL Coordination Action [3] tends to prove.

Some initial studies comparing FD versus II in cardiology systems [4] showed that entrance surface air kerma (ESAK) to phantoms of polymethyl methacrylate (PMMA) was similar for both detectors, but that the image quality for these dose settings was better for the FD systems. The authors came to the

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conclusion that one could set systems with dynamic FD to lower doses than was possible with II versions, especially for digital cine runs, and thus benefit from improved image quality if dose settings were maintained.

Imaging performances of the FP, and particularly its high dynamic quantum efficiency (DQE), present a potential for a significant reduction of the dose to the patient. The design of the system has been optimised to take advantage of these performances and some of the clinical studies performed up to now demonstrate in some cases a 20–30% dose reduction in routine clinical conditions [5].

The purpose of this paper is to study the differences in patient doses during clinical practice for a large sample of patients, using dynamic FDs and IIs for interventional cardiology in two different European Centres, then compare the results and analyse the differences.

2. Material and Methods

X-rays systems from different manufacturers equipped with FDs and IIs were used over the last years in two separate interventional cardiology services, both in university hospitals, one in Spain and the other one in Italy. Similar quality assurance programmes were applied in both centres according to the protocols agreed during the European SENTINEL Coordination Action [3]. The results were submitted to a centralized data base in each of the Centres. The same team of cardiologists worked using both imaging technologies in their respective hospitals, simultaneously or in sequence and patients were not specifically selected for the different catheterisation rooms.

The cardiologists from Hospital M performed the procedures in two Philips Integris 5000 (Philips Medical Systems, Best, The Netherlands) equipped with IIs and a Philips Allura with FD. The cardiologists from Hospital U used a Philips Integris 3000 (with II) and a GE Innova 2000 with FD (General Electric, Buc, France).

Integris systems have three available fields of view (FOV) sizes of 14, 18 and 23 cm. Fluoroscopy modes (low, medium and high dose) were set with different added Cu filtration (usually higher filtration for low dose modes) and at 12.5 pulses/s. Cine mode was set typically without extra Cu filter and also at 12.5 (and in some cases at 25) frames/s. The fluoroscopy mode routinely used was the low dose mode. For the FOV of 18 cm, the irradiated area of the detector should be 254 cm$^2$ or 162 cm$^2$ if we consider only the internal square field.

The Philips Allura system (Xper FD10) was set with the 3 typical fluoroscopy modes, with constant added filtration (0.4 mm Cu and 1 mm Al for low mode) and 12.5 pulses/s, and one cine mode (without added filtration) at 12.5 frames/s. Images were acquired in metrics 1024x1024 and 12 bits and typically archived in 512x512 pixels and 8 bits. Available FOVs measured as diagonal dimension of the FD, were 25, 20 and 15 cm. For the FOV of 20 cm (diagonal dimension), the irradiated area of the detector should be 318 cm$^2$ (a 26% or 96% higher than the equivalent with the II).

The GE Innova system has a FD detector of 20x20 cm$^2$ and 1024x1024 pixels. The field sizes available in this system are 12, 15, 17 and 20 cm. Two fluoroscopy modes (low and normal) at 15 pulse per second and two cine modes (low and normal) at 15 frames/s were set up for the clinical use. For the FOV of 17 cm, the irradiated area of the detector should be 289 cm$^2$ (a 14% or 78% higher than the equivalent with the II).

All the systems have an internal flat ionisation chamber for Kerma area product (KAP) measurement (Diamentor K2; PTW, Freiburg, Germany) that is periodically calibrated according to the local quality assurance programmes. All patient dose results were corrected by the appropriate calibration factors.

X-ray systems were characterized using the protocol agreed during the SENTINEL European programme [6-7]. PMMA plates of dimensions 25 cm $\times$ 25 cm $\times$ 1 cm were used, building thicknesses of 16, 20, 24 and 28 cm. The ratio between the PMMA and the patient chest thickness can be
considered to be approximately 1.5 [9]. A test object (Leeds TOR 18-FG; http://www.leedstestobjects.com/products/tor/product-tor-18fg.htm, Leeds, UK) was positioned at the isocentre and in the middle of the PMMA thickness during the measurements, thus providing the best geometry to simulate real clinical conditions. Different detectors (RadCal ionisation chambers - http://www.radcal.com/index.html and UNFORS solid-state detectors - http://www.unfors.com) were used to measure incident air kerma (IAK) or ESAK [8]. A back scatter factor of 1.3 was used [8] to estimate ESAK from IAK when necessary. The detector was always positioned at the entrance of the PMMA, outside the automatic exposure control (for solid state detector) to avoid influence on the radiographic technique adjusted by the system. Measurements were made without removing the antiscatter grid. The test object increases the dose rate at the entrance to the PMMA due to the automatic exposure control of the system. However, this experimental condition may be considered as a constant slight increase in patient thickness or equivalent to the effect of the iodine contrast.

For the evaluation of patient doses in the clinical cardiology practice, samples of the data of patients who underwent coronary angiography (CA) and percutaneous transluminal coronary angioplasty (PTCA) or combined procedures (CA + PTCA) were examined in terms of KAP values. Other relevant parameters as fluoroscopy time and number of cine frames per procedures were also included in the database. During the period of collection of the dosimetric data reported in this paper, all the interventional cardiologists did the procedures in the different catheterisation rooms accepting work as it came in the respective clinical services without any discrimination

3. Results

Examples of the performances (ESAK for cine frame) of some of the systems compared are shown in figures 1 and 2 (centre M). In centre M, during the initial setting, the FD system was adjusted at a higher dose for cine than was the II system. In centre U, dose settings (measured during the characterization of the systems for different PMMA thicknesses) were lower for the FD system (80 µGy/frame for 20 cm PMMA) than for II system (260 µGy/frame for 20 cm PMMA). The FOV largely used were 18 cm for II systems and 17 cm for GE Innova FP system in centre U. In centre M, the most frequently used FOVs were 20 cm (diagonally) for the Allura system and 18 cm for the Integris II systems. As described in the previous section, there are important differences in the radiation field sizes between the different systems when collimation is not applied.

Figures 1 and 2: ESAK per cine frame for FD and II systems in centre M

The sample analysed in centre U included 421 procedures with the II system, of which 305 patients underwent CA and 116 patients PTCA. The number of procedures with the FD system (GE Innova) was 1321, 955 of which were CAs and 366 PTCAAs. Patient samples were comparable both for age and the complexity of the procedures.
The sample analysed in centre M included 2,766 procedures with the II systems, 1,861 of which underwent CA, 459 PTCA and 440 a combined CA + PTCA. The number of procedures with the FD systems (Philips Allura) was 582, 377 of which were CA, 50 were PTCA and 155 were CA + PTCA. Patient samples were also comparable both for age and the complexity of the procedures. Table 1 presents the relevant results for KAP.

**Table 1**: Results for KAP (in Gy.cm\(^2\)) obtained in centres U and M.

<table>
<thead>
<tr>
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<th>Centre U (Gy.cm(^2)) mean values [1]</th>
<th>Centre M (Gy.cm(^2)) median values</th>
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<tbody>
<tr>
<td></td>
<td>CA</td>
<td>PTCA</td>
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<tr>
<td>Flat detector</td>
<td>33.4</td>
<td>66.9</td>
</tr>
<tr>
<td>Image Intensifier</td>
<td>31.1</td>
<td>52.0</td>
</tr>
<tr>
<td>Dose increase with FD</td>
<td>7%</td>
<td>29%</td>
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The differences in fluoroscopy times for centre U were not statistically significant for procedures performed with the two systems, which tend to imply a similar complexity of procedures in both samples [1]. In centre M, fluoroscopy times are slightly higher for II systems but differences are not substantial.

Figures 3 and 4 show the histograms of KAP for diagnostic and therapeutic procedures (PTCA and combined CA + PTCA procedures) for centre M. Median and interquartile values are the best descriptors for these patient dose distributions.

**Figures 3-4**: Patient dose distributions for centre M
4. Discussion

In this paper we have neither analysed in detail the x-ray system settings nor the protocols, as we considered that the main objective was only to present global results on a new technology using FDs applied to clinical use in two representative university hospitals, each belonging to two different European Countries. Following the results stated in this paper, several actions have been initiated to optimize the use of the new systems and in a later stage, we plan to analyse the different factors involved in the increase in patient doses and to work in cooperation with the industry to improve our approaches when dynamic FDs are installed in the catheterization laboratories.

However other studies have found different results. Tsapaki et al. [10] compared patient doses in a limited sample of around 170 cardiac procedures, done with a Siemens Angioscop (with II) and a Philips Allura (with FD). The settings of the systems for cine mode allow to measure ESAK values (using 2 mm of Cu as absorber) of 64 $\mu$Gy/frame for a field of view of 23 cm (for II) and 192 $\mu$Gy/frame for FD and field of view of 25 cm (diagonal dimension). These 3 times higher doses per frame of cine have no negative impact on the global results because, as the technology changes, cardiologists modify their protocols substantially, moving from 25 fr/s to 12.5 fr/s for cine acquisitions. Median patient dose values resulted 30% lower for coronary angiography but 15% higher for percutaneous transluminal coronary angioplasty. The authors came to the conclusion that “the increased cine dose (for FD) reveals the need for dose/frame reduction”. In centre M, a similar result has been found during the present study.

The good dynamic range and post processing capabilities of the FDs are sometimes negative factors for the good management of patient radiation doses. Some cardiologists, especially if they have not been trained in radiation protection, are not aware of the importance of still using collimation and wedge filters to reduce the unnecessary exposure to patients and to improve image quality.

In addition, the new technology makes it difficult to audit important parameters related to patient doses. The FOV used is a critical parameter influencing image quality, KAP and skin doses. In the II versions of the Philips systems (Integris models), this parameter was presented in the patient dose reports and the values were in a public tag (0018, 1162) of the DICOM header. The new Allura FD systems are not including the FOV in the standard dose reports and to audit this important parameter it is necessary to look in the private tag (2003, 1003) of the DICOM header, where this value is now archived.

In centre M, a process of optimisation has already been initiated in cooperation with the local Philips engineers. An alternative “low dose” protocol has been prepared with a reduction of around 25% in dose and cardiologists can already select this new protocol. After a year's experience, the clinicians accepted the protocol and considered the image quality good enough for the procedures. More optimisation actions will follow in the months to come.

5. Conclusions

From the point of view of the detector technology, there is no reason why doses should result higher for FD than for II, but this has been the case in the present survey. It seems clear that the setting and protocols for the use of FDs need to be optimized.

When comparing the quality of the clinical images based on FDs with the ones obtained with IIs, clinicians tend to prefer the new technology, but they should be made aware that using this technology they are most likely to have setting in dose per frame higher than the one used with IIs. So it is important to stress that the appropriate image quality should be their goal and that the best image quality could mean an unnecessary over-irradiation of patients.

More studies on the initial settings of interventional x-ray systems balancing image quality versus patient doses are necessary and a good training in dose management for clinicians is needed especially
concerning the new imaging technology that offers excellent image quality without collimation and without the use of wedge filters.

Industry should make all the necessary information to audit the dosimetric aspects of the procedures easily available to the users (cardiologists and medical physicists). There is no reason why basic parameters (as FOV) should be archived in private DICOM tags and not appear in the patient dose reports.

Acknowledgements

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REFERENCES