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COMPARISON OF TWO ANGIOGRAPHIC SYSTEMS IN PAEDIATRIC INTERVENTIONAL CARDIOLOGY

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The aim of this work was to analyse the radiation dose for patients and staff between X-ray systems, a new biplane with flat-panel detectors (FDs) and a conventional system equipped with image intensifier (II). Entrance surface air kerma (ESAK) and scatter doses were measured on polymethyl methacrylate (PMMA) phantoms of different thicknesses (from 4 to 16 cm). The ESAK values for the different acquisition modes and PMMA thicknesses were higher for the II in comparison with FDs. For the II, the scatter dose rates ranged from 0.67 to 12.2 mSv h^{-1} at the eye position of the cardiologist during fluoroscopy and cine modes. At the lower extremities, these values were 1.11 and 24.24 mSv h^{-1}. In the case of the FDs, these values ranged from 0.24 to 0.67 mSv h^{-1} for eye lens and from 0.73 to 2.01 mSv h^{-1} for the position of cardiologist's ankle. The newly installed X-ray system showed an average reduction factor of up to 9.7 times for ESAK values. For the staff with an average reduction factor of 15.9 times at the eye position during fluoroscopy and cine modes, no protective tools are used. At the lower extremities, this value was 7.6 times.

INTRODUCTION

The cardiology procedures that use ionising radiation are increasing in number and complexity. The benefits for patients are clear, but radiation doses for both patients and staff are important and must be managed appropriately(1–3).

At least for some tissues and organs the paediatric patients are even more susceptible than adults to the effects of ionising radiation. For ~15 per cent of the cancer types (e.g. colon cancer), children appear to have about the same radiosensitivity as adults. For ~10 per cent of cancer types (e.g. lung cancer), children appear less sensitive to external radiation exposure than adults(4).

Staff doses are linked to patient doses because they result from scattered radiation arising mainly from the patient. Staff may also be exposed to primary leakage radiation that is generated at the X-ray target and which has penetrated the leaded X-ray tube housing(5).

There have been considerable advances in fluoroscopic technology over the past decades(6). The introduction of digitising in image intensifier (II) systems from film-based analogue II-systems undoubtedly delivered many ergonomic advantages to the user, not least in the removal of film handling and processing. New dynamic flat-panel detectors (FDs) are now available to replace the II-systems(7). These detectors promise not only increased image quality but also the potential of a reduction in radiation dose(7–9).

However, other changes have also occurred in clinical practice due to increasing awareness in radiation protection as the use of lower frame rates in comparison with the practice some years ago. These procedural changes and the introduction of the new technology have brought a significant reduction in patient and staff doses(9, 10). But, several studies indicate that the use of FDs does not infer an automatic improvement in dose efficiency over the II-systems(7, 11, 12).

Therefore, the purpose of this study was to analyse the levels of radiation exposure for patients and staff of a new biplane X-ray system based on FD technology in a paediatric cardiac catheterisation laboratory and to compare with the results obtained with the previous existing conventional system equipped with II.

MATERIALS AND METHODS

The comparison has been made at the Roberto del Rio Hospital of Chile where a Toshiba 'rebuilt' (from other old X-ray systems), monoplane X-ray system with an II was used during the last 14 y at the paediatric interventional cardiology service (see Figure 1) and recently changed by a Philips Allura Xper FD20/20, biplane FD (see Figure 2).

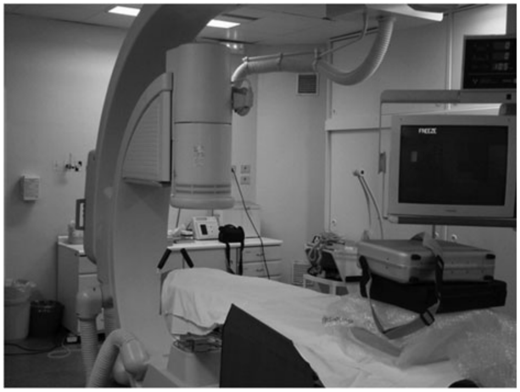

Figure 1. Toshiba 'rebuilt', monoplane X-ray system.

Figure 2. Philips Allura Xper FD20/20, biplane X-ray system.

The old Toshiba system with II had two available field of view sizes (FOVs) (16 and 23 cm) and an only exam protocol. That system had automatic exposure control (AEC) and three fluoroscopy modes: low, medium and high, set at 30 pulse per second (pps) and a cine mode also set at 30 frame per second (fps). The system had not dose–area product (DAP) meter(13).

The new FD system has seven available FOVs from 15 to 48 cm (for the frontal C-arm) and three exam protocols (5 kg, child 5–15 kg and child 15–40 kg) and also has AEC and three fluoroscopy modes: low (12.5 pps), medium (30 pps) and high at 30 pps and a cine mode at 15 fps. The system is provided with an internal flat ionisation chamber for DAP measurement.

Both systems were characterised (Toshiba II in 2009(14) and Philips FD in 2013) in terms of phantom entrance dose and scattered dose levels at the cardiologist's eyes position and lower extremities, using the European DIMOND and SENTINEL protocols(15, 16) and adapted in the authors' case to paediatric procedures(14). Polymethyl methacrylate (PMMA) plates of dimensions 25 × 25 × 0.5 cm (1 and 2 cm) have been employed, building thicknesses of 4, 8, 12 and 16 cm simulating the full range of equivalent paediatric patients. According to Rassow(17), the ratio between the PMMA and the patient chest thickness can be considered to be ~1.5.

Table 1. Details of the experimental arrangement.

1. No kind of protection tools were used during the measurements.
2. The FOVs used were 23 cm for II and 25 cm for FDs.
3. The initial focus-to-detector distance was 74 cm for 4-cm-thick PMMA. For 8, 12 and 16-cm PMMA, this distance was decreased to 72, 70 and 68 cm, respectively, to maintain the test object at the isocentre.
4. The detectors measuring scatter radiations were positioned ~165 cm from the floor and ~77 cm from the isocentre (position of the cardiologist eyes) and ~10 cm from the floor and ~113 cm from the isocentre (position of the lower extremities measuring point).

Dosemeters Unfors, Xi(18) were used to measure the dose rate at the entrance of the simulated patient without backscatter or incident air kerma scatter. Backscatter factor throughout the experiment to obtain the quantity entrance surface air kerma (ESAK) was 1.3 and two solid-state-detectors EED-30(18) to measure the scatter doses rates, expressed as a personal dose-equivalent Hp(0.07)(13) at the usual location of the cardiologist during working conditions to estimate doses to the eyes and lower extremities were used. The detectors were duly calibrated, traceable to official calibration laboratories. Table 1 describes the experimental arrangement.

RESULTS

Table 2 shows the ESAK per minute values in all fluoroscopy modes for the two evaluated X-ray systems. Figure 3 illustrates the ESAK per frame values in cine mode for the two evaluated X-ray systems. Figures 4 and 5 show scatter dose rates Hp(0.07) in cine mode, for both X-ray systems at the position of cardiologist's eyes and lower extremities, respectively.

DISCUSSION AND CONCLUSIONS

Due to the age of the system with II, radiographic parameters were not transferred to the image DICOM header; thus, they have not been included in Table 1, thereby it cannot be known how the AEC responds to different acquisition modes and thicknesses of phantom. Furthermore, this system had only an exam protocol for all patient sizes, which goes against the recommendations of the International Commission Radiological Protection(19). The system with FD shows a large variability in their examination protocols and radiographic parameters, such as potential (from 50.9 to 82 kV for fluoroscopy modes, and from 64.8 to 68.4 kV for cine

Table 2. ESAK per minute (mGy min^{-1}), tube potential (kVp) and tube current (mA) for the two X-ray systems in all acquisition modes (AM) [low fluoroscopy (LF), medium fluoroscopy (MF), high fluoroscopy (HF) and cine (CI)] for the different thicknesses of phantom (PM).

		X-ray systems with FD			X-ray systems with II		
PM	AM	mGy min^{-1}	kVp	mA	mGy min^{-1}	kVp	mA
4	LF	0.62	64.9	1.0	1.42	*	*
4	MF	1.20	60.1	4.0	2.01	*	*
4	HF	3.43	50.9	5.0	2.86	*	*
4	CI	2.18	68.4	96.0	89.47	*	*
8	LF	1.42	70.2	2.0	2.76	*	*
8	MF	2.94	64.3	7.0	3.91	*	*
8	HF	6.01	58.7	5.0	5.42	*	*
8	CI	8.81	70.6	108.0	146.41	*	*
12	LF	2.93	76.0	3.0	6.16	*	*
12	MF	6.08	69.1	10.0	8.47	*	*
12	HF	11.93	63.9	8.0	11.37	*	*
12	CI	28.00	64.8	330.0	243.91	*	*
16	LF	5.46	81.9	4.0	15.38	*	*
16	MF	11.23	73.8	13.0	16.26	*	*
16	HF	18.10	72.8	7.0	21.01	*	*
16	CI	53.82	67.5	463.0	581.80	*	*

*Mode unavailable.

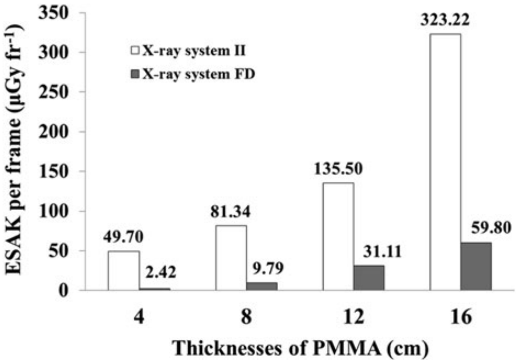

Figure 3. ESAK per frame, for the two X-ray systems in cine mode for 4, 8, 12 and 16 cm of PMMA.

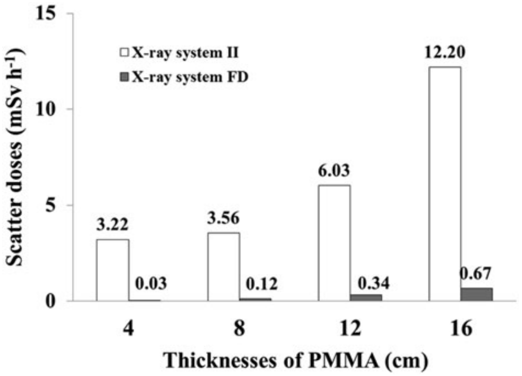

Figure 4. Personal dose equivalent Hp(0.07) values at the position of cardiologist's eyes, for two X-ray systems in cine mode for 4, 8, 12 and 16 cm of PMMA.

modes), current (from 1.0 to 13 mA and from 96.0 to 463.0 mA, for fluoroscopy and cine modes, respectively) (see Table 1).

The ESAK values for the different PMMA thicknesses and fluoroscopy modes with the II system resulted from 1.42 to 21.01 mGy per min and from 0.62 to 18.1 mGy per min for the FD-system, as also shown in Table 1. For cine mode, these values were from 49.70 to 323.22 µGy per frame (with the old II system) and from 2.42 to 59.80 µGy per frame (for the new FD system) (see Figure 3).

For the system with II, the scatter dose rates (frontal C-arm without angulation and without protection) ranged from 3.22 to 12.2 mSv h^{-1} at the eye position of the cardiologist during cine mode. These values were substantially higher than the values measured by system with FDs (from 0.03 to 0.67 mSv h^{-1}) (see Figure 4).

Figure 5 also shows the scatter dose rates for cine mode, but now at the position of cardiologist's lower extremities. For the system with II, the values were again much higher (from 3.23 to 24.24 mSv h^{-1}) than those of the system-FD (from 0.13 to 2.01 mSv h^{-1}).

The newly installed X-ray system showed lower dose values for patients (average reduction factors of 1.6 and 9.7 times in dose for fluoroscopy and cine modes, respectively). For staff, the average reduction factor resulted in 15.9 times at the eye position during fluoroscopy and cine modes, if no protective tools are

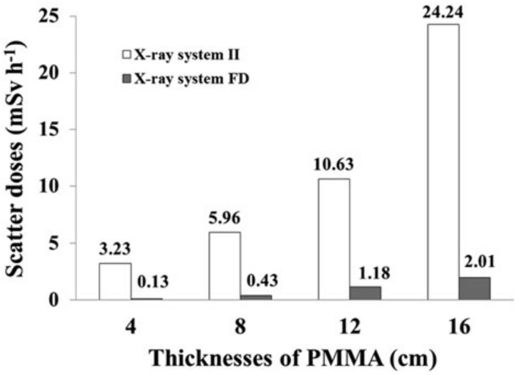

Figure 5. Personal dose equivalent Hp(0.07) values at the position of cardiologist's lower extremities, for the two X-ray systems in cine mode for 4, 8, 12 and 16 cm of PMMA.

used. At the lower extremities, this value was reduced by 7.6 times.

X-ray systems should be verified periodically on image quality, patient dose values and occupational dose values as part of the quality assurance programmes. This is especially critical for old systems and when they are used for paediatric patients. For accomplishing this, the authors suggest to revise and update Chilean legislation on radiation protection.

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