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ENTRANCE SURFACE AIR KERMA IN X-RAY SYSTEMS FOR PAEDIATRIC INTERVENTIONAL CARDIOLOGY: A NATIONAL SURVEY

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The aims of this work were to report the results of a national survey on entrance surface air kerma (ESAK) values for different phantom thicknesses and operation modes in paediatric interventional cardiology (IC) systems and to compare them with previous values. The national survey also offers suggested investigation levels (ILs) for ESAK in paediatric cardiac procedures. ESAK was measured on phantoms of 4–16 cm thickness of polymethyl methacrylate slabs. For low fluoroscopy mode (FM), ESAK rates ranged from 0.11 to 33.1 mGy min^{-1} and for high FM from 0.34 to 61.0 mGy min^{-1}. For cine mode, values of ESAK per frame were from 1.9 to 78.2 μGy fr^{-1}. The ILs were suggested as the third quartile of the values measured. This research showed lower ESAK values than in previous research, particularly for ESAK values in cine modes. This work represents a first step towards launching a national programme in paediatric dosimetry for IC procedures.

INTRODUCTION

The most significant use of X-rays outside radiology departments has been in interventional procedures, predominantly in cardiology[(1)].

During interventional cardiology (IC) procedures, patients may receive high doses of radiation. This is of particular concern for paediatric patients, because some of their organs or tissues are more radiosensitive compared with those of adult patients[(2, 3)]. Paediatric patients face a longer lifespan during which potential neoplasms may develop[(4)]. The cancer risk for those exposed to radiation as children is uncertain and might be a factor of two to three times as high as estimates for a population exposed at all ages[(4)].

Radiation safety optimisation programmes including patient dose measurements rely in part on the assessment of entrance surface dose rate[(5, 6)]. The use of diagnostic reference levels (DRLs) should be a priority in paediatrics.

Interventional systems may at times use adult patient settings for paediatric patients, as a result of which entrance surface air kerma (ESAK)[(5)] rates in fluoroscopy or cine modes may be too high for the smallest patients. Unfortunately, there are no international recommendations on the range of ESAK values to be used in paediatric cardiac systems to account for the different patient size.

Hence, the aims of this work were to report the results of a national survey on ESAK values for different phantom thicknesses and operation modes in paediatric IC systems and to compare them with previous national evaluations[(7)], from which resulting suggestions had included optimisation strategies and changing old equipment. The ESAK quantity was suggested in this work as investigation levels (ILs)[(8)] for the setting of the IC systems. The results of this paper will be used as part of a national optimisation programme after a survey of patient dose values in clinical practice and proposal of DRLs.

MATERIALS AND METHODS

Six X-ray systems, three with image intensifiers (IIs) and three with flat detectors (FDs), dedicated to paediatric IC procedures were evaluated (Table 1)[(7)]. The characterisation protocols developed by the European DIMOND and SENTINEL research programmes[(9, 10)] were used. Polymethyl methacrylate (PMMA) slabs of dimensions 25 × 25 × 0.5 cm (1 and 2 cm) were employed, building thicknesses of 4, 8, 12 and 16 cm to simulate the full range of equivalent paediatric patients. The ratio between PMMA and patient chest thickness can be considered to be ~1.5[(11)]. A test object was positioned at the isocentre and at the middle of the PMMA thickness during all measurements to simultaneously evaluate image quality. However, image quality results are not reported in this paper. The image detector was always positioned at 5 cm from the PMMA, as in working clinical conditions.

Table 1. X-ray fluoroscopy systems evaluated in the survey.

ID no.	Manufacturer	Model	Image detector	Name protocols	Year of installation
1	Siemens[a]	Axiom Artis dBC, biplane	FD	Paediatric 20 kg	2008
2	Philips[a]	Allura Xper FD20, monoplane	FD	5 kg, child of 5–15 kg and child of 15–40 kg	2005
3	Philips[b]	Allura Xper FD20, biplane	FD	5 kg, child of 5–15 kg and child of 15–40 kg	2012
4	General Electric[c]	Advantx, monoplane	II	Cine A, B, C and D	1994
5	Siemens[a]	Axiom Artis BC, biplane	II	Newborn, infant and child	2005
6	General Electric[c]	Advantx, biplane	II	Cardio Ped	2009

[a]Evaluated and optimised X-ray systems[7].
[b]New X-ray system.
[c]Non-optimised X-ray systems.

An Unfors Xi dosimeter with a solid-state detector[12] in contact with the PMMA was used to measure incident air kerma[5]. The detector was placed inside the radiation field, but not in the automatic exposure control area. A backscatter factor of 1.3 was used[5] to calculate the ESAK, thereby facilitating the comparison of the results with other published measurements.

Three fluoroscopy modes (FMs) (except system ID no. 6): low (LF), medium (MF), high dose (HF) and a unique cine (CI) mode, were available in most of the X-ray systems. The operation modes were configured from 7.5 to 30 pulses s^{-1} in all the systems. The field of view used during the measurements was as close as possible to 23 cm in diameter for II, and 25 cm for FDs (diagonal dimension).

RESULTS

Tables 2 and 3 show values of ESAK per minute and ESAK per frame in all FMs and cine mode, respectively, for all evaluated X-ray systems.

Table 4 shows the evolution in the values of number of pulses per second for FMs and number of frames per second during cine acquisition for the three X-ray systems previously evaluated and optimised.

Third quartile values for the ESAK quantity were used as ILs[8]. These levels are established for the different phantom thicknesses and operation modes investigated in the survey (see Figures 1 and 2).

DISCUSSION AND CONCLUSIONS

Service engineers often determine the initial or default settings of X-ray systems, and such settings may not always be appropriate for paediatric patients. To customise the equipment and operation protocols for paediatric patients may result in significant improvements in radiological protection, delivering lower doses for similar (or better) image quality[13].

Table 2. ESAK per minute (mGy min^{-1}) for the different X-ray systems in all FMs (LF, MF and HF dose) to entrance surface of different thicknesses of phantom (PMMA).

PMMA cm	ID no. X-ray systems						
	FM	1	2	3 (mGy min^{-1})	4	5	6
4	LF	0.43	0.62	0.62	2.00	0.11	0.37
4	MF	1.65	1.40	1.20	4.06	0.18	0.83
4	HF	1.85	3.32	3.43	5.38	0.34	a
8	LF	1.00	1.37	1.42	3.78	0.24	0.86
8	MF	3.00	3.11	2.94	7.72	0.42	1.91
8	HF	5.23	5.83	6.01	10.48	0.94	a
12	LF	2.34	2.49	2.93	11.47	0.58	2.04
12	MF	4.97	5.60	6.08	23.17	1.01	5.34
12	HF	9.22	9.92	11.93	31.82	2.11	a
16	LF	6.90	5.30	5.46	33.15	1.40	6.16
16	MF	9.23	11.45	11.23	53.82	2.50	15.21
16	HF	16.69	16.61	18.10	61.00	5.56	a

[a]Denote mode unavailable.

Table 3. ESAK per frame (μGy fr^{-1}) for different thicknesses of phantom (PMMA) in cine mode for the different X-ray systems.

ID no. X-ray systems						
PMMA cm	1	2	3 (μGy fr^{-1})	4	5	6
4	3.0	2.6	2.4	5.3	2.9	1.9
8	8.1	9.8	9.8	6.2	7.8	3.7
12	30.5	16.92	31.11	13.83	11.11	15.6
16	78.2	62.22	59.80	69.58	32.34	51.5

Table 4. Number of pulses per second for FMs (LF, MF and HF dose) and number of frames per second during cine acquisition (CI) for three X-ray systems previously evaluated for the same thicknesses of phantom (PMMA).

PMMA cm	ID no. X-ray systems						
	FM	1		2		5	
		2009–13		2009–13		2009–13	
4	LF	15	7.5	15	7.5	10	10
4	MF	15	15	30	30	10	10
4	HF	15	15	30	30	10	10
4	CI	30	15	30	15	30	30
8	LF	15	7.5	15	7.5	10	10
8	MF	15	15	30	30	10	10
8	HF	15	15	30	30	10	10
8	CI	30	15	30	15	30	30
12	LF	15	7.5	15	7.5	10	10
12	MF	15	15	30	30	10	10
12	HF	15	15	30	30	10	10
12	CI	30	15	30	15	30	30
16	LF	15	7.5	15	7.5	10	10
16	MF	15	15	30	30	10	10
16	HF	15	15	30	30	10	10
16	CI	30	15	30	15	30	30

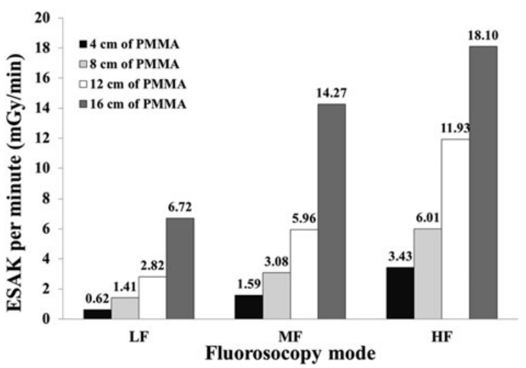

Figure 1. ILs (third quartile) derived for the X-ray systems in FMs for 4, 8, 12 and 16 cm of PMMA.

The ESAK rate values are summarised in Table 2 for the different FMs. The ratio between the maximum and the minimum value of dose rates for the different systems was 555 times. For LF mode, ESAK rates ranged from 0.11 to 33.1 mGy min^{-1}. For MF mode, values ranged from 0.18 to 53.8 mGy min^{-1} and for HF mode, from 0.34 to 61.0 mGy min^{-1}. For cine mode, the ratio between the maximum and the minimum value of ESAK per frame for the different systems was 41 times and their values ranged from 1.9 to 78.2 μGy fr^{-1} (see Table 3). The General Electric Advantx, monoplane X-ray system stood out in showing the highest dose rate. The

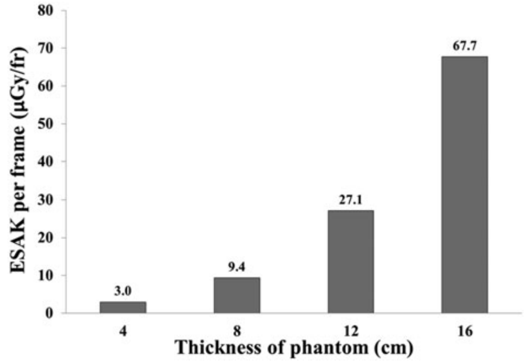

Figure 2. ILs (third quartile) for the X-ray systems in cine mode for 4, 8, 12 and 16 cm of PMMA.

ESAK rates to phantom entrance did not seem to be strictly manufacturer dependent (local settings could be different). However, ESAK rate values for the two Philips systems were very similar. In this case, dose rates were manufacturer-dependent, this result being similar to those reported by Dowling *et al.*[14, 15]. Differences found in ESAK values do not seem to derive from different imaging technologies (II or FD), but rather from age, examination protocols and different settings used locally for the X-ray systems (the use of different AEC curves, number of pulses per second, pre-selection of tube potential, pulse time, tube current and added filter etc.)[7, 16].

Comparing the results with a previous national evaluation made in 2010[7], it was found that current dose values were lower, particularly for ESAK values for CI modes. These differences are explained mainly due to the Siemens Axiom Artis dBC biplane (ID no. 1), Philips Allura Xper FD 20 monoplane (ID no. 2) and Siemens Axiom Artis BC biplane (ID no. 5) X-ray systems having been previously evaluated and optimised (see Table 1). Essentially, the applied optimisation strategies for the ID no. 1 and ID no. 2 X-ray systems were to decrease the number of pulses per second during FMs and the number of frames per second for cine acquisition (see Table 4). For the Siemens Axiom Artis BC biplane system (ID no. 5), the X-ray tube was changed in 2012. It is also important to consider that the Philips Allura Xper FD20 biplane angiography system (ID no. 3) has recently replaced the former Toshiba system, which showed the highest ESAK values for Chile.

The ILs obtained during the survey for the different PMMA thicknesses and FMs (low, medium and high dose) were as follows: 0.62, 1.59 and 3.43 mGy min^{-1}, respectively, for 4 cm PMMA; 1.41, 3.08 and 6.01 mGy min^{-1}, respectively, for 8 cm PMMA; 2.82, 5.96 and 11.93 mGy min^{-1}, respectively, for 12 cm PMMA and 6.72, 14.27 and 18.10 mGy min^{-1}, respectively, for 16 cm PMMA (see Figure 1). For cine mode (see Figure 2), the values for the different PMMA thicknesses (4, 8, 12 and 16 cm) were 3.0, 9.4, 27.1 and 67.7 μGy fr^{-1}, respectively.

This survey obtained a preliminary set of typical ESAK values in paediatric IC and third quartile, suggested as potential ILs. Medical physicists and service engineers can use these values for guidance in setting cardiac equipment and paediatric protocols and suggesting further potential optimisation actions when appropriate. Furthermore, the ILs could serve as criteria to replace X-ray systems that are older or that deliver more doses.

The results of this survey could also be considered by the Health Regulatory Authorities to update national Chilean legislation on radiation protection, requiring quality assurance programmes, especially in paediatric medical exposures. This survey allowed one to understand the impact of the X-ray system settings and the clinical protocols used (values of fluoroscopy time and number of cine frames). It also represents a first step towards launching a national paediatric dosimetry programme for IC procedures.

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