INFLUENCE OF DIFFERENT OPERATING MODES (HIGH, NORMAL AND LOW) AND FOV SIZES ON AIR KERMA RATE IN DIFFERENT INTERVENTIONAL RADIOLOGY EQUIPMENTS

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INTRODUCTION

Interventional radiology encompasses fluoroscopy-guided diagnostic and therapeutic procedures that provide the highest levels of exposure to ionizing radiation for both patients and medical staff [1-3]. Interventional procedures with long exposure times can result in absorbed doses with values above the thresholds for tissue reactions, having been associated with cases of skin and tissue lesions, whose severity is dose-dependent [4, 5]. Furthermore, exposure to ionizing radiation can induce stochastic effects, such as the development of cancer, whose probability is considered a function of the effective dose [3, 6]. Thus, it is necessary to minimize the probability of occurrence of such damage to health, especially, through processes of optimization of radiological practices.

The introduction of new imaging technologies in the diagnostic and therapeutic fields, as well as the permanent modernization of angiographies and C-arm equipment, provide a vast field for dose reduction. However, a limiting factor for dose optimization in interventional radiology procedures is the lack of correlation between the technical operating parameters and the dose rate used during the intervention. In Latin America, for example, interventional procedures are usually performed by specialist physicians, accompanied by nurses and technicians, who generally do not have adequate training in radiodiagnostic physics and radiological protection [7]. In a study carried out in ten interventional cardiology centers in Latin American countries, Vano et al. [8] found that only 14% of the pediatric cardiologists interviewed demonstrated adequate knowledge of the angiograph they used in clinical practice and only 27% were aware of the results of the quality control of such equipment. In contrast, Ghodadra et al. [9] demonstrated that the implementation of training sessions for radiologists, aimed at optimizing the dose through the appropriate setting of technical-operational parameters, as well as tracking the dose by intervention, are mechanisms capable of reducing up to 50% the dose for patients undergoing diagnostic interventional procedures.

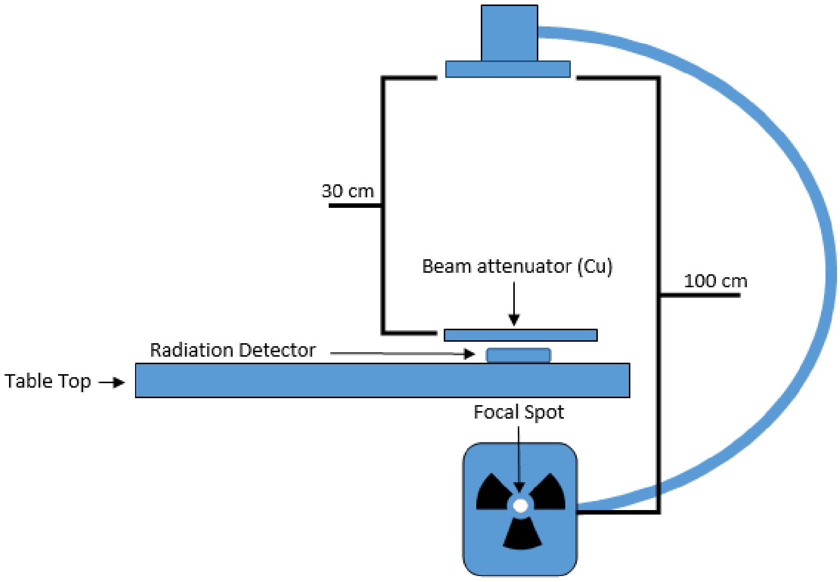
Given the potential for dose reduction through the proper selection of exposure parameters, the aim of this study was to evaluate the influence of two of these parameters on the entrance skin air kerma rate, namely: the different Exposure Modes and the Sizes of the Field of View (FOV) available in angiographic or C-arm equipment equipped with an image intensifier or flat panel.

METHODOLOGY

The dosimetric quantities Kerma Area Product (KAP) and reference point air kerma ($K_{a,r}$) are indicated to compare similar fluoroscopic procedures, so that these quantities are dependent on the exposure time. Since the objective of the present study is to demonstrate the variation in the amount of radiation through different adjustments of the exposure parameters, it was decided to adopt the air kerma rate as a dosimetric quantity, which is invariable with the exposure time. Five angiographs and four C-arm devices were evaluated using a RaySafe Xi solid state radiation detector. To simulate a typical adult patient, 3 mm thick copper attenuators were used, as shown in Figure 1.

In each equipment we selected the clinical protocol with the highest frequency of use in the sector and collected the air kerma rate in all modes of operation (Low, Normal and High) and on each available field size.

Figure 1 – Configuration used for measuring the entrance skin air kerma rate in patients.



Methodology adapted from IAEA TRS 457 [10].

RESULTS AND DISCUSSION

Usability is not the scope of this work, however, in general, the buttons, drawings or identifications on the panel of the evaluated equipment do not provide a clear and objective indication for switching between low, normal and high operating modes, nor for selecting the different field sizes. Thus, the difficulty in locating and operating these tools can become an obstacle to dose reduction for the patient and the medical team, negatively affecting the optimization process.

Table 1 describes the equipment evaluated in this study. Among the angiographers, only one did not have the Flat panel detection system, on the other hand, among the C-arm equipment, all were equipped with an image intensifier. Regardless of the technology adopted, all had at least two different field sizes for the operator and the possibility to choose between three dose rate modes (Low, Normal and High).

Table 1 – Type, manufacturer, model and detection technology of the evaluated equipment.

Type	Manufacturer	Model	Detection Technology
Angiograph	Philips	Allura Xper FD20	Flat Panel
Angiograph	GE	Innova IGS 520	Flat Panel
Angiograph	Philips	Integris Allura	Flat Panel
Angiograph	Siemens	Artis Zee	Flat Panel
Angiograph	Philips	Integris Allura	Image intensifier
C-arm	Siemens	Cios Select	Image intensifier

C-arm	GE	Brivo OEC 850	Image intensifier
C-arm	Philips	Cenos Plus	Image intensifier
C-arm	Philips	BV Vectra	Image intensifier

As expected, in all equipment analyzed, the smallest available Field of View Size (FOV) had the highest dose rate, while the largest FOV provided the smallest, as shown in Table 2.

Table 2 – Entrance skin air kerma rate values for different FOV's and exposure rate modes, according to the protocol adopted in each equipment.

Manufacturer	Model	Protocol	FOV (cm)	Dose rate (mGy/min)		
				Low	Normal	High
Philips	Allura Xper FD20	Cardiac Left	15	13.10	38.10	72.00
			19	10.80	34.50	63.00
			22	9.04	32.00	55.30
			27	7.30	29.50	48.70
			31	6.41	27.80	44.60
			37	5.76	26.28	42.20
			42	5.44	25.50	40.50
			48	4.68	23.00	36.60
GE	Innova IGS 530	Vascular DAS	12	46.35	98.30	104.00
			16	47.70	97.80	102.00
			20	42.00	79.80	104.00
			30	19.46	57.60	84.90
Philips	Integris Allura	Cardio	12	15.50	37.90	42.15
			20	13.30	35.70	39.40
			25	11.40	31.30	35.70
Siemens	Artis Zee	Card CTO	10	24.98	51.33	150.60
			16	22.80	49.56	127.00
			22	23.63	50.56	102.00
			25	11.00	39.87	49.00
Siemens	Cios Select	Application 2	16	16.10	22.70	38.50
			23	11.50	19.42	33.80
Philips	Integris Allura	Digital Vascular	14	5.19	10.89	62.60
			17	5.50	11.33	52.30
			23	3.43	7.02	43.90
GE	Brivo OEC 850	Fluoroscopy	11	2.17	14.90	25.10
			15	1.84	12.80	20.90
			23	1.24	7.41	10.80
Philips	Cenos Plus	Standard	16	29.69	53.93	83.2
			20	27.53	49.01	74.37
			24	21.72	42.93	65.54
Philips	BV Vectra	Fluoroscopy	12	21.00	35.12	75.50
			16	16.18	29.30	61.44
			23	13.60	24.70	51.23

The greatest variation between the values presented in Table 2 was recorded for the Siemens Artis Zee angiograph in which the dose rate for the FOV of 10 cm is 207% higher than for the FOV of 25 cm in high dose mode. The smallest variation was identified in the Siemens Cios Select C-arm, which has only two field sizes, with a 13% variation in the dose rate between the FOV's. It is recommended to use the smallest FOV only when the anatomical region under study requires greater detail, otherwise it is recommended to use the intermediate FOV's. The larger field, in turn, is indicated for specific circumstances according to the clinical pathology, as it offers less detail.

According to Nickoloff [11], for flat panel detectors, due to the technology involved, it is possible to keep the radiation dose rate practically unchanged with an increase in the size of the FOV or with a small increase in the order of 1/FOV, according to manufacturers' recommendations. Based on Table 3, it can be seen that in all cases there was an increase in the dose rate when we decreased the FOV in equipment with flat panel technology. Only the Philips Allura Xper FD20 equipment showed homogeneous behavior between the different FOV's and in the different exposure modes, resembling the 1/FOV ratio, based on the comparative analysis between the nominal dose rate and the dose rate estimated by this relationship. In the other angiographs, the measured dose rate did not approach the 1/FOV ratio.

Another behavior identified among the evaluated equipment was that in the largest field, the dose rate values were considerably smaller compared to the next FOV and in the other fields, these values remained constant with the change in the size of the FOV, except in the Siemens Artis Zee equipment in high dose mode.

On the other hand, in equipment with image intensifiers, the dose rate needs to be increased when the FOV is reduced to maintain the same noise level in all magnification [11] with the desired behavior being $1/FOV^2$.

Table 3 – Comparison between the measured and estimated dose rate, through the 1/FOV ratio for flat panel detectors and $1/FOV^2$ for image intensifiers.

Manufacturer	Model	FOV (cm)	Measured dose rate (mGy/min)			Estimated dose rate (mGy/min)		
			Low	Normal	High	Low	Normal	High
Philips	Allura Xper FD20	15	13.10	38.10	72.00	13.7	43.7	79.8
		19	10.80	34.50	63.00	10.5	37.1	64.0
		22	9.04	32.00	55.30	9.0	36.2	59.8
		27	7.30	29.50	48.70	7.4	31.9	51.2
		31	6.41	27.80	44.60	6.9	31.4	50.4
		37	5.76	26.28	42.20	6.2	28.9	46.0
		42	5.44	25.50	40.50	5.3	26.3	41.8
		48	4.68	23.00	36.60	-	-	-
GE	Innova IGS 530	12	46.35	98.30	104.00	63.6	130.4	136.0
		16	47.70	97.80	102.00	52.5	99.8	130.0
		20	42.00	79.80	104.00	29.2	86.4	127.4
		30	19.46	57.60	84.90	-	-	-
Philips	Integris Allura	12	15.50	37.90	42.15	22.2	59.5	65.7
		20	13.30	35.70	39.40	14.3	39.1	44.6
		25	11.40	31.30	35.70	-	-	-
Siemens	Artis Zee	10	24.98	51.33	150.60	36.5	79.3	203.2
		16	22.80	49.56	127.00	32.5	69.5	140.3

		22	23.63	50.56	102.00	12.5	45.3	55.7
		25	11.00	39.87	49.00	-	-	-
Siemens	Cios Select	16	16.10	22.70	38.50	23.8	40.1	69.8
		23	11.50	19.42	33.80	-	-	-
Philips	Integris Allura	14	5.19	10.89	62.60	8.1	16.7	77.1
		17	5.50	11.33	52.30	6.3	12.8	80.4
		23	3.43	7.02	43.90	-	-	-
GE	Brivo OEC 850	11	2.17	14.90	25.10	3.4	23.8	38.9
		15	1.84	12.80	20.90	2.9	17.4	25.4
		23	1.24	7.41	10.80	-	-	-
Philips	Cenos Plus	16	29.69	53.93	83.2	43.0	76.6	116.2
		20	27.53	49.01	74.37	31.3	61.8	94.4
		24	21.72	42.93	65.54	-	-	-
Philips	BV Vectra	12	21.00	35.12	75.50	28.8	52.1	109.2
		16	16.18	29.30	61.44	28.1	51.0	105.9
		23	13.60	24.70	51.23	-	-	-

Also according to Table 3, it is noted that for all equipment with image intensifier, the dose rate was either kept constant or approached the $1/FOV^2$ ratio. The characteristic of flat panel detectors to maintain the dose rate unchanged between the FOV's is an excellent resource for optimizing the radiological practice and helps to preserve the life of the X-ray tube and the detector itself, however, this condition must be verified through of quality control tests. The fact that the image intensifier tubes maintain the dose rate unchanged or with little variation, in some cases, requires attention, as excessive noise can impair image quality. This can result in longer procedures to resolve doubts regarding the poor quality of the exam, unnecessarily exposing the patient to ionizing radiation.

Regarding the dose rate modes, all equipment allowed to choose between three operating modes (Low, Normal and High). Both in the angiographs and in the C-arm equipment, there was a variation in the dose rate between the modes of operation. For the GE Innova IGS 530 equipment, for example, when changing from normal mode to high mode, in 12 cm and 16 cm FOV's, ratios between low/normal and low/high rates approximately equal to 1 were obtained, such as shows Table 4, indicating an almost imperceptible variation in the amount of ionizing radiation produced by the X-ray tube.

Table 4 – Values of the ratios between low/normal and low/high rates for each equipment according to the FOV size.

Manufacturer	Model	Protocol	FOV (cm)	Ratio	
				Low/Normal	Normal/High
Philips	Allura Xper FD20	Cardiac Left	15	0.34	0.53
			19	0.31	0.55
			22	0.28	0.58
			27	0.25	0.61
			31	0.23	0.62
			37	0.22	0.62
			42	0.21	0.63
			48	0.20	0.63
GE	Innova IGS 530	Vascular DAS	12	0.47	0.95

			16	0.49	0.96
			20	0.53	0.77
			30	0.34	0.68
Philips	Integris Allura	Cardio	12	0.41	0.90
			20	0.37	0.91
			25	0.36	0.88
Siemens	Artis Zee	Card CTO	10	0.49	0.34
			16	0.46	0.39
			22	0.47	0.50
			25	0.28	0.81
Siemens	Cios Select	Application 2	16	0.71	0.59
			23	0.59	0.57
Philips	Integris Allura	Digital Vascular	14	0.48	0.17
			17	0.49	0.22
			23	0.49	0.16
GE	Brivo OEC 850	Fluoroscopy	11	0.15	0.59
			15	0.14	0.61
			23	0.17	0.69
Philips	Cenos Plus	Standard	16	0.55	0.65
			20	0.56	0.66
			24	0.51	0.65
Philips	BV Vectra	Fluoroscopy	12	0.60	0.47
			16	0.55	0.48
			23	0.55	0.48

It is recommended that the high-dose mode be used only for patients with body structures above the typical standard. When the ratio between exposure modes is close to 1, it must be evaluated whether the quality of the images significantly interferes with the quality of the exam to the point of generating a clinically unsatisfactory procedure. There is also a need to assess excess exposure to ionizing radiation when the normal mode is adopted.

One of the requirements of the Brazilian Legislation [12] regarding quality control in interventional radiology equipment is that the ratio between the dose rates in low mode and in normal mode is less than or equal to 0.5. Among the Flat Panel equipment evaluated, only on the GE Innova IGS 530 this condition was not met. In equipment with image intensifiers, the vast majority did not meet this requirement of the legislation. The GE Brivo OEC 850 equipment, even meeting the requirement of the standard, needs attention. Because, the value of 0.15 between the modes can be indicative of overexposure or underexposure of patients to ionizing radiation.

The combined action of changing the size of the FOV and using the low mode can considerably reduce exposure to ionizing radiation. On the GE Innova IGS 530 angiograph, using the FOV of 20 cm combination in low mode was found to promote a dose rate reduction of approximately 52% compared to FOV of 16 cm in normal mode. On the GE Brivo OEC 850 C-arm, when changing from FOV of 15 cm in normal mode to FOV of 11 cm in low mode, the dose rate is reduced by approximately 88%. Thus, the decision to use a higher FOV combined with a mode of lower dose rate represents an important tool in the dose rate reduction process. However, for the optimization process to be successful, it is essential to know the behavior of the equipment in question, otherwise the image quality may be impaired. As in the case of the C-arm GE Brivo OEC

850 where the 88% dose rate reduction may not be associated with a clinical image with diagnostic quality, disrespecting the ALARA practice.

CONCLUSIONS

Adopting intermediate fields with the lowest rate is an important dose optimization tool. However, it is essential to map/study/know the behavior of each of the equipment's functions and its relationship with the dose to ensure the best result in the optimization process.

Future work to evaluate the usability of equipment commands and their impact on the optimization process is needed.

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