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FULL PAPER

Retrospective study of patients radiation dose during cardiac catheterization procedures

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Objective: Cardiac catheterization procedures provide tremendous benefits to modern healthcare and the benefit derived by the patient should far outweigh the radiation risk associated with a properly optimized procedure. With increasing utilization of such procedures, there is growing concern regarding the magnitude and variations of dose to patients associated with procedure complexity and techniques parameters. Therefore, this study investigated radiation dose to patients from six cardiac catheterization procedures at our facility and suggest possible initial dose values for benchmark for patient radiation dose from these procedures. This initial benchmark data will be used for clinical radiation dose management which is essential for assessing the impact of any quality improvement initiatives in the cardiac catheterization laboratory.

Methods: We retrospectively analyzed the dose parameters of 1000 patients who underwent various cardiac catheterization procedures: left heart catheterization (LH), percutaneous coronary intervention (PCI), complex PCI, LH with complex PCI, LH with PCI and cardiac resynchronization therapy (CRT) pacemaker in our cardiac catheterization laboratories. Patient's clinical radiation dose data [kerma-area-product (KAP) and air-kerma at the interventional reference point ($K_{a,r}$)] and technique parameters (fluoroscopy time, tube potential, current, pulse width and number cine images) along with demographic information (age, height and weight) were collected from the hospital's RIS (Synapse), Sensis/Syngo Dynamics and Siemens Sensis Stats Manager electronic database. Statistical analysis was performed with the IBM SPSS Modeler v. 18.1 software.

Results: The overall patient median age was 67.0 (range: 26.0–97.0) years and the median body mass index (BMI) was 28.8 (range: 15.9–61.7) kg/m². The median KAP for the LH, PCI, LH with complex PCI, complex PCI, LH with PCI and CRT-pacemaker procedures are 44.4 (4.1–203.2), 80.2 (18.9–208.5), 83.7 (48.0–246.1), 113.8 (60.9–284.5), 91.7 (6.0–426.0) and 51.1 (7.0–175.9) Gy-cm². The median $K_{a,r}$ for the LH, PCI, LH with complex PCI, complex PCI, LH with PCI and CRT-pacemaker procedures are 701.0 (35.3–3794.0), 1384.7 (291.7–4021.8), 1607.0 (883.5–4448.3), 2260.2 (867.4–5311.9), 1589.3 (100.2–7237.4) and 463.8 (67.7–1695.9) mGy respectively.

Conclusion: We have analyzed patient radiation doses from six commonly used procedures in our cardiac catheterization laboratories and suggested possible initial values for benchmark from these procedures for the fluoroscopy time, KAP and air-kerma at the interventional reference point based on our current practices. Our data compare well with published values reported in the literature by investigators who have also studied patient doses and established benchmark dose levels for their facilities. Procedure-specific benchmark dose data for various groups of patients can provide the motivation for monitoring practices to promote improvements in patient radiation dose optimization in the cardiac catheterization laboratories.

Advances in knowledge: We have investigated local patients' radiation doses and established benchmark radiation data which are essential for assessing the impact of any quality improvement initiatives for radiation dose optimization.

INTRODUCTION

Cardiac catheterization procedures continue to provide tremendous benefits to modern healthcare and the benefit derived by the patient should far outweigh the risk associated with a properly optimized procedure. Cardiac catheterization procedures are minimally invasive using image-guidance to diagnose and treat an expanding range of cardiovascular conditions.^{1–15} These procedures require fluoroscopic image guidance to place a catheter within the heart or the coronary vessels and inject radio-opaque contrast to locate and potentially treat an area of obstruction. The global increase in both the number and complexity of cardiac catheterization procedures has created a growing concern in terms of the radiation-induced health effects (both deterministic and stochastic radiation risks) associated with fluoroscopically guided procedures involving extended fluoroscopic exposure times.^{1–36} According to Picano *et al*,¹ although interventional procedures account for only 2% of all radiological procedures, they contribute to about 20% of the total collective dose each year. The potentially high entrance skin doses to patients can result in deterministic effects, such as erythema or temporary epilation, once the threshold level of exposure has been exceeded.⁴ Extended fluoroscopic exposures have also been found to result in higher patient effective dose with a direct relationship to increased risk for radiation-induced carcinogenesis.^{2,4} Additionally, the same patient may often require repeated cardiac catheterization procedures that further increase the radiation exposure and risk.³⁶ Pantos *et al*⁶ reviewed doses to adult patients from 72 relevant published studies in international scientific literature. Published results indicated that patients' radiation doses vary widely among different cardiac catheterization procedures and even among equivalent studies. The variations in doses are related to patient size, procedure type, physician's practice, and fluoroscopic equipment. The cardiac catheterization laboratory is a primary source of radiation exposure to both patients and operators and it is important to have good radiation safety practice to limit exposure to as low as is reasonably achievable.⁶

Patients' characteristics such as age, weight, height, and medical history pose additional risk factor resulting from ionizing radiation.^{6,16–25} A thoracic stent-graft implantation study found higher levels of radiation dose when patients' body mass index (BMI) was greater than 25 kg/m².²³ Certain procedures and technical factors (*e.g.* angle of projection, complexity or type of procedure, exposure time, number of cine images) additionally influence radiation dose to patients. The left anterior oblique projection is associated with high radiation dose to patients,^{24,25} as the body absorbs more radiation with projections with high angulations due to the increased volume of tissue in the beam path.^{26,27} Procedures requiring more precise implantation will additionally result in greater patient exposure to ionizing radiation.²³ Due to the increased procedure time and therapeutic nature of percutaneous coronary intervention (PCI) procedures, its effective dose is shown to be almost twice as high as that for diagnostic cardiac catheterization procedures and the second highest radiation dose received amongst various cardiovascular imaging procedures.²⁸ The transradial approach for coronary angiography is gaining momentum as a viable alternative to

the transfemoral approach. While technically it may have some challenges due to patient anatomy, catheter design (most catheters are designed for femoral access) and increased radiation doses, there are significant benefits including increased procedure efficiency, reduced patient discomfort, improved time to ambulation, shorter recovery times, short hospital stay, use of local anesthetics, lowered costs and reduction in potentially life-threatening complications compared to traditional surgical methods.^{35,37}

Establishing local benchmark radiation dose data are essential for assessing the impact of any quality improvement initiatives for radiation dose optimization.^{36–47} The International Commission on Radiological Protection (ICRP) does not give dose limits for patients undergoing medical diagnostic exposures, but requires adherence to the principle of justification and optimization by comparing patient doses with diagnostic reference levels (DRLs) for common procedures.⁴ DRL is used in medical imaging using ionizing radiation as a guide to whether, under routine conditions, a patient dose from a specific procedure is unusually high or low for that procedure.⁴ Therefore, the need for cardiac catheterization laboratories to establish radiation safety programs that include the establishment of local facility data set (that can be compared to multifacility advisory data set or DRL) is imperative and essential in the management of radiation doses delivered to patients in cardiac catheterization laboratories. Consequently, the goal of this study was to retrospectively analyze the exposure parameters of patients who underwent various cardiac catheterization procedures at our cardiac catheterization laboratory and suggest possible initial values for benchmarks for patient radiation dose from these procedures. This study presents procedural stratified radiation doses for six common procedures in our cardiac catheterization laboratory. The derived initial benchmark dose data will serve as baseline for measuring the effectiveness of any future quality improvement activities by the laboratory and also compared to any future multifacility advisory data set.

METHODS AND MATERIALS

We retrospectively analyzed the exposure parameters of 1000 patients who underwent various cardiac catheterization procedures at our catheterization laboratory from November 2017 to March 2018. All procedures were performed in two catheterization laboratories on similar Siemens Artis Zee (Siemens Healthcare GmbH, Henkestr, Germany) systems using the same departmental protocols. Collimation and magnification were used during the procedures according to the clinical requirements (*e.g.* pulsed fluoroscopy typically operated at 4–7.5 frames/s). The air-kerma at the interventional reference point ($K_{a,r}$) and the kerma-area-product (KAP) during each procedure was recorded using the KAP meter incorporated in the imaging system. The kerma-area-product measured in Gy-cm² is the integral of the air-kerma free-in-air (*i.e.*, in the absence of back-scatter) over the area of the X-ray beam in a plane perpendicular to the beam axis.³⁹ It is a quantity independent of the distance to the X-ray tube focal spot and is considered a surrogate measure of the patient's risk of stochastic radiation effects.³⁸ The KAP for all practical radiation protection purposes is equal to dose-area-product (DAP). However, strictly speaking $DAP = KAP \times (1 \text{ g})$,

where g is the fraction of energy of liberated charged particles that is lost in radiative processes in the material and the dose is expressed in absorbed dose to air and the value of g for diagnostic X-rays is very small.⁴⁸ The KAP meter (or DAP meter) technique is the most reliable measure for dynamic examinations such as fluoroscopy, in which the projections, direction, and parameters are continually varying.³⁸ The air kerma at the interventional reference point ($K_{a,r}$), also known as reference dose or cumulative dose or cumulative dose at a reference point is the air kerma accumulated at a specific point in space (the reference point is an approximate location of patient's entrance surface) relative to the fluoroscopic gantry. For C-arm fluoroscopic systems, the patient entrance reference point is a point along the central ray of the X-ray beam, 15 cm back from the isocenter toward the focal spot.⁴⁹ Air kerma at the interventional reference point is used to monitor patient dose and it is correlated with patient risk of radiation effect.³⁸

Patients were stratified according to the cardiac catheterization procedures which fall into standalone diagnostic or combined diagnostic and therapeutic interventions for a total of six procedures, namely:

- (1) LH (left heart catheterization): An angiogram of left and/or right coronary arteries which may be combined with left ventriculography (LV gram). Standalone right heart procedures are excluded as they do not substantially add to fluoroscopy exposure.
- (2) PCI (percutaneous coronary intervention): A rescheduled straightforward PCI using single balloon and stents that has occurred within 3 months of a LH procedure.
- (3) Complex PCI: A rescheduled complicated PCI using multiple catheters, balloons, and stents that has occurred within 3 months of a LH procedure. Additionally, the following are also considered complex PCI: a PCI including the use of rotablator (rotational atherectomy), a PCI to a bypass graft, a PCI when three or more interventional wires are used, a PCI when four or more stents are used, a PCI when kissing balloons are used or a PCI when a retrograde technique is used.
- (4) LH with complex PCI: An angiogram of left and coronary arteries with a complicated PCI which may include a LV gram.
- (5) LH with PCI: An angiogram of left and coronary arteries with a straightforward PCI which may include a LV gram.
- (6) CRT-pacemaker (cardiac resynchronization therapy-pacemaker): An insertion of a pacemaker or defibrillator using fluoroscopy in the cardiac catheterization laboratory.

Although we investigated data from 1000 patients', the distribution was not evenly distributed among the various procedures. In total we analyzed 634 left heart catheterizations, 291 left heart catheterizations with percutaneous coronary interventions, 14 left heart catheterizations with complex PCI, 38 percutaneous coronary interventions, 12 complex percutaneous coronary interventions and 11 CRT-pacemaker procedures.

DATA COLLECTION

Patients' clinical radiation dosimetry information generated for each examination using the equipment integrated measuring system and displayed or recorded fluoroscopy and cine KAP ($\text{Gy}\cdot\text{cm}^2$), fluoroscopy and cine air-kerma at interventional reference point (mGy), fluoroscopy time (min), type of procedure (LH, PCI, complex PCI, LH with PCI, LH with complex PCI and CRT pacemaker), procedure technical parameters during cine (tube potential (kV), current (mA), pulse width (ms), number of cine images and source-image-distance (cm)), fluoroscopy tube potential, projections (RAO/LAO and cranial/caudal) and patient's demographic information (age (years), height (cm), and weight (kg)) were collected from the hospital's RIS (Synapse), Sensis/Syngo Dynamics and Siemens Sensis Stats Manager electronic database (Siemens Healthcare GmbH, Henkestr, Germany). BMI (kg/m^2) was calculated using patient's height (m) and weight (kg). All data were collected following the completion of patient procedures and were extracted from the hospital database by a medical radiation technologist. Data were received weekly from the technologist on an encrypted USB key and transferred to an Excel workbook on a secured laptop in accordance with the requirements of the Tri-Hospital Research Ethics Board.

Statistical analysis

Statistical analysis was performed with the IBM SPSS Modeler v. 18.1 (IBM Canada Ltd, Markham, Ontario, Canada) software. Data are reported as mean $\pm$ SD, range (minimum–maximum), median, and interquartile range [first quartile (Q1) and third quartile (Q3)] for all patients and all procedures. Local benchmark dose data for dose monitoring or audit are derived using the median and comparisons are made with published data. The relationship between the dosimetric parameters (KAP and $K_{a,r}$), fluoroscopy time, tube current and pulse width for various procedures were investigated to help determine appropriate patient's dose management protocols. Relationship between tube potential (fluoroscopy and cine), patient KAP and $K_{a,r}$ and the patient BMI are also investigated and simple statistical analysis was performed to study the influence on patient radiation dose due to changes in BMI.

RESULTS AND DISCUSSION

The optimization of patient radiation dose in image guided interventional cardiac catheterization procedures usually uses procedure-specific protocols tailored to patient age or size, region of interest and clinical indication to ensure that patient radiation doses are as low as reasonably achievable for the clinical purpose of the examination. However, radiation doses from these procedures vary widely between institutions, typical procedures and equipment. Consequently, it is clinically expedient for standardization of dose and reduction in dose variation without compromising the clinical purpose of the procedure. Procedure-specific benchmark dose data derived at the local facility (facility data set) for various groups of patients can provide the motivation for monitoring practices to promote improvements in patient radiation safety and dose reduction taking into consideration local equipment and protocols. As procedures for examinations are not identical, each procedure needs its own benchmark dose

Figure 1. Total (fluoroscopy + cine) KAP (Figure 1a) and the air-kerma at the interventional reference point ($K_{a,r}$) (Figure 1b) stratified by the various procedures. Results are expressed as median, 25th percentile, 75th percentile, minimum and maximum values of the distribution. KAP, kerma-area-product.

data and hence we have derived benchmark dose data for six commonly used procedures in our cardiac catheterization laboratories. The suggested initial benchmark dose data will serve as baseline for measuring the effectiveness of any future quality improvement activities by the laboratory and also for comparison with any future multi facility advisory data set.

We have analyzed patient radiation doses from six commonly used procedures in our cardiac catheterization laboratories to suggest possible initial values for benchmarks doses from these procedures for the fluoroscopy time, KAP and air-kerma at the interventional reference point. Figure 1 shows a plot of the statistical summary of the patients KAP (Figure 1a) and the $K_{a,r}$ (Figure 1b) stratified by the various procedures. The results are expressed as median, 25th and 75th percentiles, minimum and maximum values of the distribution. The median KAP for the LH, PCI, LH with complex PCI, complex PCI, LH with PCI and CRT-pacemaker procedures are 44.4 (range: 4.1–203.2), 80.2 (range: 18.9–208.5), 83.7 (range: 48.0–246.1), 113.8 (range: 60.9–284.5), 91.7 (range: 5.7–426.0), and 51.1 (range: 7.0–175.9) Gy-cm² respectively and the median $K_{a,r}$ are 701.0 (range: 35.3–3794.0), 1384.7 (range: 291.7–4021.8), 1607.0 (range: 883.5–4448.3), 2260.2 (range: 867.4–5311.9), 1589.3 (range: 100.2–7237.4), and 463.8 (range: 67.7–1695.9) mGy respectively (Table 1).

The relationships between the fluoroscopy KAP as a function of the fluoroscopy $K_{a,r}$ and the cine KAP as a function of the cine $K_{a,r}$ is shown in Figure 3. The median

Figure 2 shows a plot of the statistical summary of the fluoroscopy time stratified by the various procedures. The median fluoroscopy time for the LH, PCI, LH with complex PCI, complex PCI, LH with PCI and CRT-pacemaker procedures are 3.7 (range: 0.8–41.6), 12.7 (range: 2.2–33.6), 13.0 (range: 7.3–46.9), 26.3 (range: 12.8–50.9), 12.0 (range: 3.5–65.1), and 11.8 (range: 5.1–28.2) mins respectively. The relationships between the fluoroscopy KAP as a function of the fluoroscopy $K_{a,r}$ and the cine KAP as a function of the cine $K_{a,r}$ is shown in Figure 3. The median

Table 1. Statistical summary of the radiation dose parameters (kerma-area-product and air-kerma at the interventional reference point ($K_{a,r}$)) stratified by procedure

		Fluoroscopy		Cine		Total	
		KAP (Gy-cm ²)	$K_{a,r}$ (mGy)	KAP (Gy-cm ²)	$K_{a,r}$ (mGy)	KAP (Gy-cm ²)	$K_{a,r}$ (mGy)
LH	Mean $\pm$ SD	10.9 $\pm$ 11.8	155.5 $\pm$ 196.3	39.7 $\pm$ 21.2	637.6 $\pm$ 341.3	50.5 $\pm$ 28.7	793.1 $\pm$ 463.7
	Range (min-max)	0.8–123.8	8.7–2736.1	0.1–134.6	0.5–1989.6	4.1–203.2	35.3–3794.0
	Median	7.4	103.4	35.9	583.9	44.4	701.0
	Q1–Q3	4.4–12.9	57.5–185.1	25.4–50.4	396.4–816.5	31.3–63.6	478.2–1012.3
LH with PCI	Mean $\pm$ SD	33.3 $\pm$ 23.3	594.1 $\pm$ 476.7	72.4 $\pm$ 40.7	1304.5 $\pm$ 689.1	105.7 $\pm$ 58.6	1898.6 $\pm$ 1070.1
	Range (min-max)	1.4–135.0	22.7–3374.1	4.3–295.7	70.5–3863.3	5.7–426.0	100.2–7237.4
	Median	25.4	450.1	62.9	1155.5	91.7	1589.3
	Q1–Q3	17.8–40.2	304.9–741.3	44.5–90.9	791.7–1624.4	66.0–129.8	1149.2–2426.2
LH with complex PCI	Mean $\pm$ SD	39.5 $\pm$ 33.9	671.5 $\pm$ 593.1	71.9 $\pm$ 29.9	1287.3 $\pm$ 521.1	111.4 $\pm$ 58.9	1958.8 $\pm$ 1036.0
	Range (min-max)	14.9–134.5	264.1–2356.1	32.0–124.3	619.3–2177.7	48.0–246.1	883.5–4448.3
	Median	25.0	464.2	62.5	1184.5	83.7	1607.0
	Q1–Q3	20.0–35.2	320.6–579.0	49.5–99.3	878.2–1750.7	72.3–136.7	1254.2–2364.4
PCI	Mean $\pm$ SD	33.1 $\pm$ 22.2	622.8 $\pm$ 421.9	46.3 $\pm$ 25.6	927.6 $\pm$ 548.1	79.4 $\pm$ 42.9	1550.4 $\pm$ 876.4
	Range (min-max)	4.2–88.7	70.8–1512.4	8.5–127.6	171.4–2509.4	18.9–208.5	291.7–4021.8
	Median	28.2	447.4	43.1	776.1	80.2	1384.7
	Q1–Q3	16.4–46.2	317.7–837.1	24.1–60.6	483.1–1275.0	40.9–102.8	794.2–2149.5
Complex PCI	Mean $\pm$ SD	69.4 $\pm$ 44.6	1248.3 $\pm$ 882.8	68.3 $\pm$ 24.9	1292.7 $\pm$ 515.8	137.8 $\pm$ 61.3	2541.0 $\pm$ 1253.9
	Range (min-max)	34.0–196.4	505.1–3655.0	19.8–101.1	337.5–2022.0	60.9–284.5	867.4–5311.9
	Median	49.7	895.9	72.4	1341.0	113.8	2260.2
	Q1–Q3	40.4–80.3	711.5–1494.7	48.4–89.4	926.5–1677.2	97.9–174.0	1762.7–3407.5
CRT pacemaker	Mean $\pm$ SD	40.1 $\pm$ 33.8	382.5 $\pm$ 325.0	15.9 $\pm$ 14.9	151.4 $\pm$ 147.8	56.0 $\pm$ 45.0	533.9 $\pm$ 437.1
	Range (min-max)	5.4–134.8	52.1–1289.1	1.6–44.3	15.5–436.8	7.0–175.9	67.7–1695.9
	Median	38.2	352.4	6.6	63.9	51.1	463.8
	Q1–Q3	17.3–47.9	147.5–469.2	5.8–23.3	50.2–220.2	23.1–69.2	197.7–682.6

CRT, Cardiac Resynchronization Therapy (CRT) pacemaker; LH, Left Heart Catheterization; PCI, Percutaneous Coronary Intervention. Data are reported as mean, range (minimum–maximum), median and interquartile range(lower quartile (Q1)–upper quartile (Q3)).

tube current during cine for the LH, PCI, LH with complex PCI, complex PCI, LH with PCI and CRT pacemaker procedures are 729.1 (range: 9.8–771.7), 735.3 (range: 11.5–775.5), 735.0 (range: 257.5–767), 740.3 (range: 89.3–769.7), 735.7 (range: 10.2–777.9), and 727.4 (range: 168.7–758.9) mA respectively. The median pulse width during cine for the LH, PCI, LH with complex PCI, complex PCI, LH with PCI and CRT pacemaker procedures are 6.9 (range: 1.9–10.0), 6.9 (range: 3.1–10.0), 7.0 (range: 3.4–10.0), 7.1 (range: 3.3–9.8), 7.2 (range: 2.9–10.0), and 4.4 (range: 3.1–9.0) msec respectively and the total number of cine images are 6707, 920, 429, 386, 7929 and 52 respectively. We observed that the total fluoroscopy time is a good indicator of radiation exposure and correlated well with total fluoroscopy KAP and $K_{a,r}$. Data from this study indicate that the complex PCI procedures have the highest mean KAP (137.8 Gy-cm²), $K_{a,r}$ (2,541.0 mGy) and fluoroscopy time (29.6 mins) and the LH procedure had the least KAP (50.5 Gy-cm²) and fluoroscopy time (4.9 mins). The CRT-pacemaker procedure had the least $K_{a,r}$ (533.9 mGy). These

results agree with other studies^{6,9,30,37,43,45} addressing the radiation doses of such procedures in other centers (Table 2).

The overall patients median age was 67.0 (range: 26.0–97.0) years and the BMI was 28.8 (range: 15.9–61.7) kg/m². There was no significant difference in the age and BMI distributions when stratified into the various procedures. We further investigated the influence of patient BMI on tube potential used for both fluoroscopy and cine, KAP and $K_{a,r}$. The KAP and $K_{a,r}$ stratified by different BMI classifications for all patients is shown in Table 3 and Figure 4 shows the median tube potential for the fluoroscopy and cine procedures stratified by the various BMI categories. We categorized the BMI according the World Health Organization classifications of 18.5, 18.5–24.9, 25.0–29.9, 30.0–34.9, 35.0–39.9 and ≥ 40 kg/m² to represent underweight, normal weight, pre-obesity, obesity class I, obesity class II and obesity class III respectively.⁵⁰ We observed a significant correlation between the tube potential, KAP and $K_{a,r}$ and an increased patient

Figure 2. Fluoroscopy time stratified by the various procedures. Results are expressed as median, 25th percentile, 75th percentile, minimum and maximum values of the distribution. CRT, cardiac resynchronization therapy; LH, leftheart catheterization; PCI, percutaneous coronary intervention.

BMI. Patients with BMI more than 30 kg/m^2 required about 1.5–2.2 times more radiation compared to patients with normal BMI which agrees with similar findings by Shah et al.⁵¹ These data suggest that operators and other cardiac catheterization

laboratory staff should take patient's BMI into account when making choices regarding technique parameters used in the laboratory with the goal to minimize the radiation dose required to perform a procedure.

Figure 3. Scatter plot of fluoroscopy KAP and fluoroscopy air-kerma at the interventional reference point ($K_{a,r}$) (Figure 3a) and cine KAP and cine air-kerma at the interventional reference point ($K_{a,r}$) (Figure 3b). KAP, kerma-area-product.

The ICRP report-120⁴⁸ and the National Council on Radiation Protection and Measurements (NCRP) report-168⁵² recommend that in situations where a procedure dose exceeds one of the trigger level points for a potential skin injury (e.g. air kerma at interventional reference point of 5 Gy (5000 mGy) and/or KAP of 500 Gy-cm²), clinical follow-up at 4 weeks is recommended to early detect and manage potential radiation injuries. In this study, although, marked differences were observed regarding the patients KAP from various procedures, all KAP values were significantly lower than the trigger level with the closest KAP to the trigger level being 426.0 Gy-cm² obtained for LH with PCI. However, when the $K_{a,r}$ trigger level was also applied, it was observed that six patients (0.6%) (five patients had LH with PCI procedure and one patient had complex PCI procedure) obtained $K_{a,r}$ values that were above the 5000 mGy trigger level. The suggested benchmark dose levels are shown in Table 2 which compared well with similar data in the literature. With the establishment of these initial benchmark dose levels, radiation dose monitoring protocols will be developed to monitor patient radiation doses during the procedure and to flag attending physician when level is being approached. This will help ensure that patient radiation dose is optimized without compromising the clinical purpose of the procedure.

CONCLUSION

Relatively high values of radiation exposure have been considered a necessary consequence of cardiac catheterization procedures. With increasing complexity of these procedures, there will continue to be growing concern regarding the magnitude of the exposure to patients. Therefore, establishing local benchmark radiation data are essential for assessing the impact of any quality improvement initiatives for radiation safety and dose optimization. We have analyzed patient radiation doses from

Table 2. Comparison of estimated median fluoroscopy time (mins), the total kerma-area-product (KAP) and air-kerma at the interventional reference point ($K_{a,r}$) benchmark data stratified by procedure with typical published values

Procedure	Fluoroscopy time (min)		Total KAP (Gy-cm ²)		$K_{a,r}$ (mGy)	
	This work median (Range)	Reported median (Range)	This work median (Range)	Reported median (Range)	This work median (Range)	Reported median (Range)
LH	3.7 (0.8–41.6)	4.1 (0.3–57) ⁶ 3.5 ⁹ 3.7 (0.1–77.0) ³⁰ 14* (1–70 37] 3.5* (0.4–21.7) ⁴⁰ 5.1* (0.57–3) ⁴⁰ 10.8* (1.6–57.0) ⁴⁰	44.4 (4.1–203.2)	39.08 ⁹ 27.2 (0.1–610.8) ³⁰ 70* (5–193 37] 33.0* (1.4–105.5) ⁴⁰ 494.5* (66.2–1409.1) ⁴⁰ 32.6* (7.3–147.0) ⁴⁰	701.0 (35.3–3794.0)	** (49–711 6] 581 ⁹ 732* (90–3146) ³⁷
LH with PCI	12.0 (3.5–65.1)	11.8 (1.7–70.3) ⁴⁵ ** (2.5–86) ⁶	91.7 (5.7–426.0)	67 (6–1003) ⁴⁵	1589.3 (100.2–7237.4)	1244 (207–4927) ⁴⁵
LH with Complex PCI	13.0 (7.3–46.9)	-	83.7 (48.0–246.1)	-	1607.0 (883.5–4448.3)	-
PCI	12.7 (2.2–33.6)	11.1 (1.4–172) ⁶ 11 ⁴³ 11.2 ⁹ 10.3 (0.7–124.9) ³⁰ 20* (2–87 37] 4.4* (0.9–22.4) ⁴⁰ 7.4* (1.25–20.1) ⁴⁰ 12.4* (10.1–33.31) ⁴⁰	80.2 (18.9–208.5)	74.3 ⁴³ 87.36 ⁹ 56.8 (1–293) ³⁰ 720* (48–2120) ³⁷ 44.0* (6.1–329.3) ⁴⁰ 673.8* (135.0–2215.0) 40] 61.7* (7.3–142.5) ⁴⁰	1384.7 (291.7–4021.8)	** (170–1660) ⁶ 1830 ⁴³ 1501 ⁹ 1034* (132–3008) ³⁷
Complex PCI	26.3 (12.8–50.9)	-	113.8 (60.9–284.5)	-	2260.2 (867.4–5311.9)	-
CRT pacemaker	11.8 (5.1–28.2)	10* ^{1–20,37} 10.6* (5.7–18.4) ⁴⁰ 4.52* (0.2–15.1) ⁴⁰ 20.9* (0.6–45.2) ⁴⁰	51.1 (7.0–175.9)	31* (7–77 37] 32.1* (15.9–47.4) ⁴⁰ 223.8* (28.6–1050.8) ⁴⁰ 31.5* (7.2–75.4) ⁴⁰	463.8 (67.7–1695.9)	255* (60–623 37]

CRT, Cardiac Resynchronization Therapy (CRT) pacemaker.; LHC, Left Heart Catheterization; PCI, Percutaneous Coronary Intervention.

^avalue quoted is the mean value.

^bmedian value is not available.

Table 3. KAP and air-kerma at the interventional reference point ($K_{a,r}$) stratified by different BMI classifications

BMI (kg/m ²)	Mean ± SD	Range(min-max)	Median	Q1-Q3
Total Kerma Area Product (KAP) (Gy-cm ²)				
<18.5	21.1 ± 15.6	7.1–60.9	15.7	10.9–22.3
18.5 < 24.9	49.2 ± 39.9	5.2–313.5	37.4	23.5–66.2
25 < 29.9	65.2 ± 44.6	4.2–284.5	54.7	35.3–80.9
30 < 34.9	75.2 ± 44.1	7.8–256.2	62.4	44.5–94.6
35 < 39.9	94.4 ± 53.9	4.1–268.1	78.3	55.9–124.8
≥40	107.6 ± 71.7	19.9–426.0	92.42	60.7–130.4
Air-kerma at the interventional reference point ($K_{a,r}$) (mGy)				
<18.5	299.4 ± 213.3	97.3–867.4	253.6	166.7–326.3
18.5 < 24.9	828.8 ± 685.8	75.0–3922.8	586.4	380.4–1050.9
25 < 29.9	1100.5 ± 856.6	49.0–5647.5	849.2	553.2–1326.0
30 < 34.9	1276.6 ± 845.3	75.6–5301.5	1035.2	717.1–1608.8
35 < 39.9	1598.3 ± 1000.2	35.3–4867.6	1249.3	874.0–2255.2
≥40	1843.3 ± 1237.2	328.4–7237.4	1516.7	1012.1–2358.9

BMI, body mass index; KAP, kerma-area-product; SD, standard deviation.

Data are reported as mean, range (minimum–maximum), median and interquartile range (lower quartile (Q1)–upper quartile (Q3)).

six commonly used procedures in our cardiac catheterization laboratories and suggest possible initial values for benchmarks for patient radiation dose from these procedures. These benchmark dose data will be used to monitor patient radiation dose during each procedure. Attending physicians will be flag when these values are being approached during a procedure to ensure doses are optimized without compromising the clinical purpose of the procedure. These benchmark dose data will be considered

Figure 4. Bar plot of the median tube potential used for fluoroscopy and cine procedures stratified by the different categories of BMI. BMI, body mass index.

as supplements to professional judgement and will not provide a dividing line between good and bad practice and will form our initial facility data.

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This study was granted ethics approval by the Tri-Hospital Research Ethics Board (THREB)

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