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Radiation dose reference card for interventional radiology procedures: Experience in a tertiary referral centre

Anna Varghese, Shyamkumar N Keshava, Vinu Moses, George Koshy, Suraj Mammen, Munawwar Ahmed, Roshan S Livingstone

Department of Radiology, Christian Medical College and Hospital, Vellore, Tamil Nadu, India

Correspondence: Dr. Roshan S Livingstone, Department of Radiology, Christian Medical College, Vellore - 632 004, Tamil Nadu, India.
E-mail: roshanlivingstone@gmail.com

Abstract

Background: Fluoroscopy-guided interventions can potentially increase radiation risk to patients, if awareness on angiographic imaging technique and radiation dose is neglected. **Aim:** To develop patient radiation dose reference card from standardized imaging techniques for various radiology interventions performed using flat detector based angiography system. **Materials and Methods:** Real-time monitoring of angiographic exposure parameters and radiation dose were performed for 16 types of radiological interventions. Effective dose (ED) was estimated from dose area product (DAP) using PCXMC Monte Carlo simulation software. Radiation risk levels were estimated based on Biological Effects of Ionising radiation (BEIR) report VII predictive models for an Asian population. **Results:** Pulse rates of 7.5 pps and 0.6 mm Copper filtration during fluoroscopy and 4 frames per second (fps) and 0.1-0.3 mm Cu filtration during image acquisitions were found to reduce radiation dose. Owing to increased number of image acquisitions, DAP was highest during diagnostic spinal angiography 186.7 Gycm^2 (44.0–377.5). This resulted in highest ED of 59.4 mSv with moderate risk levels (1 in 1000 to 1 in 500). Most of the radiological interventions had low radiation risk levels (1 in 10,000 to 1 in 1000). **Conclusion:** The patient radiation dose reference card is valuable to the medical community and can aid in patient counselling on radiation induced risk from radiological interventions.

Key words: Flat detector; interventional radiology; radiation dose reference card

Introduction

The number of interventional radiological procedures performed using angiographic systems is increasing over the recent years due to its diagnostic and therapeutic value. Complex radiological interventions performed using either flat detector (FD) systems or image intensifier (II) systems can impart significant radiation dose to patients when not adhered to standard clinical practices. Recently, FD systems with improved image quality have found to be advantageous over the II systems.[1-5] The new FD systems with structured dose reporting, real-time skin dose mapping are often expensive, however, these features are valuable to the interventional community.[6] The radiation dose protocols involving the choice of pulse rates (pps), frame rates (fps), copper (Cu) filtration should be fine-tuned to patient size

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and type of interventions without compromising image quality. Knowledge on appropriate exposure parameters for different interventions would be valuable for operators using the FD systems.

Often, physicians and interventionists require prior knowledge in radiation dose from complex interventions as it would be beneficial for patient management. Though measurement of radiation dose from interventional procedures is a challenge due to varying imaging parameters, dose area product (DAP) and air kinetic energy released per unit mass (KERMA) denoted as Ka, r have been established as reliable real-time dose indicators in fluoroscopy to assess stochastic and deterministic risks.[7,8] In modern angiography suites, these parameters are recorded and displayed in the control console monitors. However, effective dose (ED) values are not readily available but can be calculated retrospectively using Monte Carlo simulation. The ED provides an estimate of radiation risk to patients from radiological examinations and also enables comparison of radiation risk between different procedures or procedures performed using different modalities. Since ED is directly proportional to stochastic risk, it can be converted to estimate relative or absolute examination risk.[9]

Estimation of fatal cancer risk to a specific population should account for age, gender and demographic factors.[10] Furthermore, it is of greater concern to the paediatric community undergoing diagnostic and therapeutic examinations since they have a longer life expectancy and hence higher risk to radiation-induced cancer risk.[11] Though estimation of radiation-induced cancer risk from radiological examinations is reported to be a flawed concept,[12] knowledge of risk could guide in the optimization process and enable the use of radiation for diagnosis and treatment with utmost caution. Based on the large radiation-related cancer risk estimate of 1 in 1000 corresponding to an ED of 10 mSv according to BEIR VII report, patients' desire to be informed on the radiation-related risk of cancer incidence by interventional radiologist and referring physicians is vital.[13-15] Radiation safety training is part of the curriculum for radiologists. There could be variable awareness regarding the radiation safety among the referring colleagues. This study intends to evaluate optimized angiographic exposure parameters, radiation dose and estimated risk and develop a patient radiation dose reference card for different type of radiological interventions.

Materials and Methods

The study was approved by the institutional review board (IRB minute No. 8805, 2013). Angiographic techniques and radiation doses were acquired from 16 types of radiological interventions which spanned for a study period of 6 months. Interventional radiological procedures were audited for paediatric patients aged 1–17 years and adults aged 18-79 years. The diagnostic procedures include cerebral angiography (n = 45), transjugular liver biopsy (TJLB) (n = 24), abdominal angiography (n = 6), spinal angiography (n = 7), peripheral venogram (n = 4). The therapeutic interventions included sclerotherapy (n = 81), cerebral embolization (n = 14), bronchial artery embolization (BAE) (n = 18), abdominal embolization (n = 17), transarterial chemoembolization (TACE) (n = 13), trans intraheptic porto systemic shunt (TIPSS) (n = 3), direct intrahepatic porto systemic shunt (DIPSS) (n = 3), inferior vena cava plasty (IVC) (n = 12), percutaneous transhepatic biliary drainage (PTBD) (n = 19), percutaneous nephrostomy (PCN) (n = 32), and peripheral embolization (n = 8). These procedures were performed by a team of experienced interventionists and trainees.

Equipment

All radiological interventions were performed using Siemens Artis Zee biplane angiography suite with FD system (Erlangen Germany). The 48 cm detector had pixel dimensions of 154 × 154 μm with detective quantum efficiency (DQE) of 74% at low spatial frequencies and the 25 cm detector had pixel dimensions of 184 × 184 μm with a DQE of 75% at low spatial frequencies. The angiography system was incorporated with dose protocols that could be customized for neuro, body and peripheral imaging. The fluoroscopy pulsed modes invariably selected were 7.5 pps for all procedures and 0.5 or 1 pps while positioning the patient table or selecting the appropriate views. While 4 fps was the default image acquisition frame rate used for most procedures, 7.5 fps was used for some high flow angiography procedures and this was at the discretion of the interventionists. The system incorporated an inherent filtration of 2.5 mm Al with five-level adaptive copper pre-filtration for reduced skin dose. The Combined Application to Reduce Exposure (CARE) filters (0.1, 0.2, 0.3, 0.6, 0.9 mm Cu) were automatically selected during the procedures depending on the patient anatomy and the region that was intervened. The use of filters ranging from 0.2 to 0.9 mm Cu at 70 kV could result in 50% radiation dose reduction. The source to image detector distance (SID) ranged from 94 to 124 cm and varied depending on the steepness of the angiographic projection.

Dosimetry

The fluoroscopic screening time (FT), DAP and reference air kerma (Ka, r) were obtained from the structured dose reports produced by the angiography system. The PC based Monte Carlo simulation software (PCXMC) was used to estimate ED from the DAP values.[16] ED for sclerotherapy and peripheral interventions involving upper limb were not estimated due to unavailability of information in the PCXMC software. The dose descriptors with ED and its comparison with equivalent period of exposure from background radiation were used to prepare a radiation dose reference card for interventional radiology procedures. The risk levels were assessed for Asian population for number of persons exposed to 0.1 Gy for all types of cancer reported in BEIR VII report.[15]

Results

The angiographic techniques adopted for radiological interventions in adults and paediatrics are shown in Table 1. During fluoroscopic screening, 7.5 pps and 0.6 mm Cu filter was invariably selected in adults and paediatrics. The tube potentials ranged from 65 to 70 kV while the tube current varied between 81 and 217 mA. The fluoroscopic mA was 14% and 23% higher in thorax and abdomen interventions compared to cerebral interventions. In children, though the tube potentials were similar to those in adults and the tube current varied between 83.5 and 110.1 mA. The standardized low dose image acquisition technique combined the use of site-specific protocol with 4fps and maximum filtration of 0.3 mm Cu. The tube potentials for image acquisitions varied between 63 and 86 kVp and the tube current modulated between 144 and 576 mA in children and adults. A maximum of 48 image acquisitions were acquired during cerebral embolization and 43 during spinal angiography [Table 1].

Table 2 shows the radiation dose as a result of the angiographic practices adopted in the study. The diagnostic interventions recorded a maximum FT of 33.2 min during spinal angiography while the therapeutic interventions recorded a maximum of 90.8 min during TIPSS intervention. The highest mean DAP was 186.7 Gycm^2 (44.0–377.5) during spinal angiography compared to all radiological interventions. The Ka, r was maximum for cerebral embolization and spinal angiography as shown in Table 2. The estimated ED was 3.3 and 6.8 mSv for cerebral angiography and cerebral embolization respectively. The highest ED was estimated to be 59.4 mSv for spinal angiography intervention followed by 28.6 mSv for TACE intervention. In children, the estimated ED was 12.7 mSv for abdominal embolization while it was 2.8 mSv for cerebral angiography. Radiation dose reference card as shown in Table 2, indicates a risk of low level (1 in 10,000 to 1 in 1000) for major fraction of the radiological interventions. The increase in estimated ED for spinal angiography and TACE indicated a moderate risk level (1 in 1000 to 1 in 500) in

Table 1: Exposure factors for radiological interventions from Siemens Artis Zee biplane angiography system

Radiological interventions	Fluoroscopic screening		Image acquisitions			
	Mean kVp (range)	Mean mA (range)	fps (Cu mm)	Mean kVp (range)	Mean mA (range)	Mean No. of image acquisitions (range)
Adults						
Sclerotherapy#	68 (66-71)	97 (13-220)	-	-	-	-
Cerebral angiography	66 (65-69)	93 (81-200)	4, 30 (0.1-0.3)	70 (69-75)	301 (283-361)	9.8 (4-20)
Cerebral embolization	67 (65-69)	124 (91-194)	4, 30 (0.1-0.3)	74 (71-84)	286 (273-307)	21.1 (8-48)
BAE	67 (66-68)	124 (94-189)	4 (0.1-0.3)	67 (63-70)	378 (323-407)	13.9 (5-26)
Abdominal angiography*	66 (65-68)	124 (105-148)	4 (0.1-0.3)	69 (67-70)	390 (288-576)	8.8 (3-14)
Abdominal embolization	67 (65-70)	136 (98-198)	4 (0.1-0.3)	73 (66-86)	371 (272-493)	13.3 (3-23)
TJLB	65 (65-68)	127 (93-217)	4, 5, 7.5 (0.1-0.3)	74 (67-81)	331 (173-383)	1.2 (1-2)
TACE	67 (66-69)	149 (118-209)	4 (0.1-0.3)	70 (66-74)	376 (280-571)	7.8 (3-16)
IVC Plasty	65 (65-70)	128 (98-209)	4 (0.1-0.3)	72 (70-76)	396 (335-556)	8.8 (3-20)
TIPSS*	67 (65-69)	162 (140-183)	4, 7.5 (0.1-0.3)	75 (73-79)	342 (321-352)	10.6 (7-16)
DIPSS*	66 (65-68)	115 (97-134)	4 (0.1-0.3)	70 (69-71)	382 (380-384)	11.3 (9-14)
PTBD	65 (65-67)	129 (89-210)	1,4 (0.1-0.3)	71 (66-83)	398 (363-428)	2.5 (1-8)
PCN	65 (65-67)	110 (92-225)	1, 4 (0.1-0.3)	72 (67-85)	332 (220-356)	1.2 (1-2)
Spinal angiography*	66 (65-68)	141 (92-203)	4 (0.1-0.3)	72 (68-74)	453 (346-599)	28.4 (12-43)
Peripheral venogram *	66 (65-68)	112 (94-145)	4 (0.1-0.3)	76 (66-97)	338 (232-399)	3.3 (2-5)
Peripheral embolization*	66 (65-68)	80 (19-200)	4 (0.1-0.3)	65 (61-73)	199 (131-404)	8.6 (2-22)
Paediatrics						
Sclerotherapy# (extremities)	67.2 (66-71)	50.3 (10.2-142.7)	-	-	-	-
Sclerotherapy# (face, neck, and tongue)	67.4 (66-71)	105.6 (38.6-170)	-	-	-	-
Cerebral angiography*	65.1 (65-66)	87.6 (83.5-95.9)	4 (0.1-0.3)	70 (69-71)	319.6 (292.8-381)	11.5 (6-18)
TJLB*	65	95.2 (95.1-97.6)	7.5 (0.3)	76	165.3 (144-177)	1.7 (1-2)
Abdominal Embolization*	69 (67.7-68)	95.3 (85.1-110.1)	4 (0.3)	67 (66-70)	420 (392-475)	12.6 (6-25)
Peripheral embolization*	66	84.5 (72.4-96.5)	4 (0.3)	66	151 (150-152)	13.5 (5-22)

BAE: Bronchial artery embolization; TJLB: Transjugular liver biopsy; TACE: Transarterial chemoembolization; IVC: Inferior vena cava; TIPSS: Trans intrahepatic portosystemic shunt; DIPSS: Direct intrahepatic portosystemic shunt; PTBD: Percutaneous transhepatic biliary drainage; PCN: Percutaneous nephrostomy; pps: Pulse per second; fps: Frames per second; Cu: Copper filter; #DSA image acquisitions were not performed; *Interventions with sample size <10

Table 2: Radiation dose reference card for interventional radiological procedures

Radiological interventions	Mean FT in min (range)	Mean DAP in Gycm^2 (range)	Mean Ka, r in Gy (range)	Mean ED (mSv)	Equivalent period of exposure to natural background radiation (3 mSv)	Level of risk
Adults						
Sclerotherapy#	1.2 (0.2-2.4)	0.6 (0.02-5.2)	0.005 (0-0.03)	-	-	-
Cerebral angiography	5.1 (0.8-23.9)	47.6 (18.2-100.3)	0.4 (0.1-0.7)	3.3	1 year	Low
Cerebral embolization	38.4 (17.3-83.4)	111.1 (57.4-161.7)	1.5 (0.5-2.8)	6.8	2 years	Low
BAE	27.2 (5.7-51.7)	26.8 (2.2-65.2)	0.3 (0.02-0.8)	10.6	4 years	Low
Abdominal angiography*	12.4 (0.8-27.8)	47.0 (31.9-57.9)	0.3 (0.1-0.4)	7.4	2 years	Low
Abdominal embolization	22.7 (4.2-52.9)	69.0 (5.3-154.6)	0.7 (0.07-1.4)	14.9	5 years	Low
TJLB	5.3 (1.7-10.8)	5.2 (0.82-11.3)	0.06 (0.006-0.1)	1.9	1 year	Low
TACE	20.3 (8.5-42.6)	43.7 (8.5-94.8)	0.5 (0.1-1.0)	28.6	10 years	Moderate
IVC Plasty	14.8 (1.8-31.9)	30.4 (9.4-54.6)	0.4 (0.1-0.8)	9.9	3 years	Low
TIPSS*	46.8 (23.9-90.8)	96.0 (40.1-176.4)	0.8 (0.3-1.5)	26.4	9 years	Low
DIPSS*	27.8 (19.7-37.0)	53.3 (40.4-63.7)	0.4 (0.4-0.5)	13.7	5 years	Low
PTBD	5.3 (0.3-20.6)	4.4 (0.2-23.0)	0.08 (0.002-0.005)	1.9	1 year	Very low
PCN	1.3 (0.1 -7.5)	2.3 (0.2-5.7)	0.03 (0.002-0.1)	0.3	0.1 year	Very low
Spinal angiography*	17.5 (10.4-33.2)	186.7 (44.0-377.5)	1.4 (0.5-2.7)	59.4	20 years	Moderate
Peripheral venogram#*	5.7 (0.4-13.9)	12.6 (5.3-25.3)	0.1 (0.06-0.3)	-	-	-
Peripheral embolization#*	5.5 (0.5-10.6)	11.2 (0.1-52.3)	0.09 (0.0007-0.5)	-	-	-
Paediatrics						
Sclerotherapy# (extremities)	1.2 (0-2.3)	0.21 (0.03-1.8)	0.001 (0-0.008)	-	-	-
Sclerotherapy# (face, neck, and tongue)	1.1 (0.5-2.4)	0.5 (0.11-2.1)	0.007 (0.002-0.02)	-	-	-
Cerebral angiography*	3.4 (2.0-6.1)	29.9 (14.8-63.3)	0.2 (0.1-0.5)	2.8	1 year	Low
TJLB*	3.0 (1.6-5.2)	0.9 (0.5-1.9)	0.01 (0.007-0.03)	0.4	0.1 year	Very low
Abdominal embolization*	17.7 (10.0-25.6)	16.3 (4.9-35.1)	0.2 (0.08-0.6)	12.7	4 years	Low

BAE: Bronchial artery embolization; TJLB: Transjugular liver biopsy; TACE: Transarterial chemoembolization; IVC: Inferior vena cava; TIPSS: Trans intrahepatic portosystemic shunt; DIPSS: Direct intrahepatic portosystemic shunt; PTBD: Percutaneous transhepatic biliary drainage; PCN: Percutaneous nephrostomy; FT: Fluoroscopy time; DAP: Dose area product; Ka: r: Reference air kerma; ED: Effective dose; #ED were not estimated for extremities in PCXMC; *Interventions with sample size <10

Risk level	Negligible	Minimal	Very low	Low	Moderate
Estimated additional risk of developing fatal cancer	< 1 in 1,000,000	1 in 1,000,000 to 1 in 100,000	1 in 100,000 to 1 in 10,000	1 in 10,000 to 1 in 1000	1 in 1000 to 1 in 500

adults. Very low-risk levels (1 in 100,000 to 1 in 10,000) were demonstrated for PCN and PTBD interventions in adult and TJLB intervention in children.

Discussion

Interventional radiological procedures whether diagnostic or therapeutic in nature tend to impart high radiation dose to the patients depending upon complexities of the procedure. Although several studies focus on the radiation dose imparted to patients, it is also important to understand the angiographic exposure parameters which influence the radiation dose. Angiographic exposure parameters such as kVp, mA, pulse rates, frame rates, dose protocols, number of image acquisitions has a direct influence in increasing or decreasing radiation dose. The selection of these parameters depends on the type of equipment and operator experience.[17-20] In the present study, interventionists adhered to safe radiation practices by adopting low-dose customized protocol in Siemens Artis Zee biplane system as shown in Table 1. Our imaging protocol involved use of 7.5 pps and 0.6 mm Cu filtration during fluoroscopic screening and 4fps and 0.3 mm Cu filtration during image acquisitions. Intervention such as PCN required only 0.5 pps during fluoroscopy for the placement of the tube. These customized parameters rendered appreciable image quality for adult and paediatric patients of Indian origin. The use of lower pulse rate and increased filtration is crucial during paediatric imaging in order to achieve lower radiation dose.[21] The optimized imaging practice involved constant tube potentials with varying tube current as shown in Table 1. The degree of variation of tube current was attributed to varying patient size, use of large focus, three–dimensional (3D) rotational angiography, choice of dose protocols, road mapping technique and increased detector to patient distance.

In the study reported by Varghese *et al*., a doubling of tube current showed a doubling effect on the DAP values.[22] A maximum tube current of 599 mA and an exposure time of 51 ms were selected for diagnostic spinal angiography owing to the selection of large focus compared to the fine focus selected for other interventions. Similar findings have been reported in II systems.[23] A maximum of 43 image acquisitions were performed using large and fine focus during diagnostic spinal angiography, thus resulting in increased radiation dose.

In addition to two-dimensional (2D) image acquisitions, cerebral interventions involving aneurysms required 3D imaging (30 fps) which selected tube potentials of 70-73 kVp and tube current of 311-375 mA using a 42 cm field of view. In depth analysis showed that the number of image frames (973.3 frames) acquired during cerebral embolization (arterial venous malformation [AVM] were higher compared to aneurysmal interventions (796.1 frames). These observations were similar to those reported by Hassan and Amelot, where the number of image frames was 706 frames for AVM embolization and 300 frames for aneurysmal interventions.[24] It was reported that the advantage of the rotational angiography in treating aneurysms provide a better understanding of the vasculature without the need for increased number of 2D image acquisitions compared to AVM interventions.[25] However, the number of 2D images acquired is at the discretion of the interventionists. Experienced interventionists with knowledge on radiation safety acquired 18% lower image frames during paediatric imaging compared to adults. In children, sclerotherapy was commonly performed to extremities and other regions face, neck and tongue using road maps instead of image acquisitions. Geryes *et al.* reported similar practice of using 7.5 pps for fluoroscopy with 1 or 2 fps for image acquisition.[26]

Information on FT and radiation dose from radiological interventions would be valuable for radiation safety purpose and as part of clinical reporting for future reference or for designing any study involving ionizing radiation. In our study, a patient radiation dose reference card was developed for 16 interventions based on the standardized angiographic techniques [Table 2]. The reference card has information on mean DAP, Ka, r, ED, equivalent exposure to background radiation and the level of risk for each procedure. These dose descriptors are available in the angiographic suites and may be documented for radiation safety purposes. However, prior knowledge of an estimate of FT and radiation dose would be vital to plan any procedures, hence, a reference card would be a valuable tool.

Interventional radiology personnel may also record Ka, r dose rates (mGy/min) displayed on the viewing monitor to calculate the trigger time reaching threshold doses of 2 or 5 Gy for probable tissue reactions from lengthy fluoroscopic time.[27] This method also enables the interventionist to plan and adopt radiation safe practices prior to the intervention and initiate clinical follow-up in patients following lengthy procedures.

The estimated mean ED using Monte Carlo simulations for the interventional procedures studied were varying from 1.9 to 59.4 mSv as shown in Table 2. Using the mean DAP and ED from Table 2, the conversion coefficients derived in the present study were 0.07 mSv/Gycm^2, 0.39 mSv/Gycm^2 and 0.33 mSv/Gycm^2 for cerebral, thorax and abdominal/spinal interventions respectively and was found to be similar to those reported in literature.[28,29] Falco *et al*. reported conversion coefficients ranging from 0.07 to 0.25 mSv/Gycm^2 with ED values of 5.4–66.9 mSv depending on the type of intervention.[30] In children, the conversion coefficients were 0.01 and 0.6 mSv/Gycm^2 for cerebral and abdominal interventions respectively. Though there may be uncertainties in conversion from DAP to ED, this method is useful for comparison of radiation dose from different modalities and procedures.

The reference card [Table 2] includes risk levels described as moderate, low, very low, minimal and negligible similar to the dose reference card developed by the American College of Radiology (ACR) for few radiography and CT procedures.[31,32] In this context, a reference patient is not an individual but a reference hermaphrodite patient for whom risks have been assessed based on the average for a whole population. Hence, the actual numerical value for risk of cancer incidence in an individual may be far greater.Therefore, the best indicator for individual risk is to estimate mean dose from all radiosensitive organs combined with appropriate age, sex and organ-specific risk coefficient for radiation-induced stochastic effects according to ICRP.[31,33] The risk in females was greater than males due to the additional tissue weighting factor given for breast tissues. Children have 2–5 times higher risk of developing cancer compared to adults exposed to the same magnitude of radiation dose.[34]

In our study, most of the radiology interventions involved low-risk levels, however, interventions with higher ED values such as spinal angiography and TACE had moderate risk levels. It should be noted that level of risk for some of the interventions may vary among various centres due to sample sizes, operator experience, technique of procedure and equipment. A similar study involving larger sample sizes from multiple centres and different equipment will provide a more standardized dose reference.

Conclusion

This study highlights the use of low-dose protocols and develops a radiation dose reference card for 16 radiological interventions performed using a FD-based angiographic suite. The patient radiation dose reference card with simplified radiation dose information would be valuable for explaining radiation-related information to patients by the clinicians and the interventional community. The reference card also enables to identify interventions involving lengthy FT and high radiation dose. This study limits to a radiation dose reference card from a single tertiary referral centre and single angiography equipment forming a local reference level. However, similar information from other angiography systems can add value to such dose reference cards to maintain radiation safety standards in medicine.

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Conflicts of interest
There are no conflicts of interest.

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