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Factors contributing to radiation dose for patients and operators during diagnostic cardiac angiography

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Abstract

Introduction: Diagnostic coronary angiography (CA) uses ionising radiation with relatively high doses, which impact on both patients and staff. This study sought to identify which patient and procedural factors impact patient and operator dose the most during CA. **Methods:** Patient and procedure related variables impacting on Kerma area product (P_{KA}) and operator dose (OD) were collected for 16 months. Procedures were separated into 10 different procedure categories. P_{KA} was used for patient dose and OD was measured with an instantly downloadable dosimeter (IDD) – downloaded at the end of each procedure. High and low radiation dose was defined by binary variables based on the 75th percentile of the continuous measures. Univariate and multivariate regression were used to identify predictors. **Results:** Of 3860 patients included, the IDD was worn for 2591 (61.7%). Obesity (BMI > 30 compared to BMI < 25) was the strongest predictor for both a P_{KA} (odds ratio (OR) = 19.1 (95% CI 13.5–26.9) $P < 0.001$) and OD (OR = 3.3 (2.4–4.4) $P < 0.001$) above the 75th percentile. Male gender, biplane imaging, the X-ray unit used, operator experience and procedure type also predicted a high P_{KA}. Radial access, male gender, biplane imaging and procedure type also predicted a high OD. **Conclusion:** Radiation dose during CA is multifactorial and is dependent on patient and procedure related variables. Many factors impact on both P_{KA} and OD but obesity is the strongest predictor for both patients and operators to receive a high radiation dose.

Introduction

Cardiovascular disease is Australia's most common chronic disease and coronary artery disease is the leading cause of mortality.[1] Coronary artery disease can be diagnosed and treated in the same setting with invasive cardiac angiography (CA). CA uses X-ray fluoroscopy and carries risks to the patient undergoing these procedures.[2] The side effects of radiation are both stochastic (neoplasm and heritable abnormalities) and tissue injury (deterministic).[2] The associated radiation dose and relative risk of malignancy may not be conclusive[3] but the deterministic effects of fluoroscopy procedures, presenting as skin injury have been reported many times[4–6] and have been compiled into case review reports and recommendation documents.[2,7] The cardiologist who is closest to the X-ray source and patient is exposed to the harmful effects of low energy scattered radiation during CA which has been highlighted in numerous studies and reports.[8–10]

The International Commission on Radiological Protection recommends that dosimeters should be available for all staff working in fluoroscopic laboratories. In addition, a quality assurance (QA) program should ensure the use of dosimeters with a review of abnormal dose values.[11] Dosimeters, using thermo-luminescent or more recently optically stimulated luminescent dosimetry techniques are required to be worn by catheter laboratory personnel. These are submitted for evaluation on a monthly basis. However, these do not demonstrate how radiation dose is received on a case by case basis and which factors increase a staff members' radiation exposure more than others.

Patient and operator dose have been investigated before, such as the REVERE trial[12] and the RAD-MATRIX trial,[13] which investigated the impact of vascular access site on radiation dose. However, there is a paucity of data on this subject where all variables that may impact on operator dose are assessed together, and which variables are predictive of high doses.

This study aimed to supplement the QA program and perform a more detailed investigation of radiation exposure to both patients and operators during contemporary diagnostic cardiac angiography procedures. This study sought to identify patient and procedural factors that may impact on patient and operator dose in addition to identifying which variables are predictive of a high patient and operator radiation dose.

Method

The study was a retrospective analysis of prospectively collected data for consecutive patients presenting to the cardiac catheterisation laboratories in this single, tertiary, teaching hospital that had diagnostic procedures performed. Data were collected from mid-August 2014 through to mid December 2015. Approval for this study was granted by the facility human research ethics committee.

Radiation protection for operators

The examination table had lead drapes fitted to the tableside. Operators also had a lead acrylic, ceiling suspended shield. Operators all wore a protective apron of at least 0.5 mm lead equivalent at the front, thyroid shields, lead shin guards, lead eye glasses and some wore lead equivalent protective hats.

Workflow and equipment protocols

All procedures were performed in one of two identical biplane cardiac catheterisation laboratories (Siemens Axiom Artis dBc, Siemens Healthcare, Erlangen, Germany). Operators positioned (panned) the patient on the floating top tables and activated the fluoroscopy and digital acquisition. Radiographers operated the C-arm, controlled pulse rate, dose per pulse, collimation and wedge filtration from an adjacent control room. Fluoroscopy was typically set to 7.5 pulses per second and the digital acquisition (DA) frame rate was set to 15 frames per second. A standard fluoroscopy and acquisition protocol was typically used for procedures in which the X-ray system automatically adjusted copper filtration, kV and mA to achieve a detector dose that would produce an acceptable image.

Radiation data collected were:Fluoroscopy time (FT), Kerma area product (P_{KA}), skin entrance dose (air kerma – mGy) at the reference point (K_{AR}) and number of DA. These were entered into an oracle database at the end of each procedure (Impax CV, Agfa Healthcare, Netherlands). P_{KA} was the primary measure for patient dose and was calculated using the P_{KA} meter in the X-ray tube housing and is given in $Gycm^2$. Both X-ray systems were checked for accuracy of the P_{KA} meter readings as part of their annual compliance tests.

Individual elements for each procedure were entered into the database using a series of tick boxes and procedures were then grouped into 10 categories:

1 Abdominal/femoral angiogram only (AFA).
2 Coronary angiography only (CORS).
3 Coronary angiography + aortogram/left ventriculogram (CORS-LV/AO).
4 Coronary angiography + left heart catheterisation + right heart catheterisation (CORS-LHC/RHC).
5 Coronary angiography + additional coronary artery lesion assessment with intravascular ultrasound (IVUS), optical coherence tomography (OCT) of fractional flow reserve (FFR) – (CORS-OCT/IVUS/FFR).
6 Coronary angiography + pulmonary angiography (CORS-PA)
7 Coronary angiography + coronary artery bypass graft angiography (CORS-GRAFTS).
8 Pulmonary angiography alone (PA).
9 Right heart catheterisation ± venography (RHC)
10 Work-up for transcatheter aortic valve implant: Includes coronary angiography, aortography, ilio-femoral angiography (TAVI-WU).

The CORS group was used as the reference group for statistical analysis. Other procedural variables that could impact on radiation dose, such as catheter access route and whether biplane angiography was used were also recorded. Patient variables, including age and body mass index (BMI) were collected. BMI was grouped into three categories: <25, 25–30, and >30 kg/m^2.

Operator dose analysis

The primary and secondary operators (where a second operator was present) were monitored using instantly downloadable personal dosimeters (IDD) (Instadose^{TM}, Mirion technologies, Georgia, USA) in addition to their usual TLD monitors. The IDD was worn on the thyroid collar, on the outside of the protective apron for the procedure duration and downloaded at the end of each procedure. The methodology for using these dosimeters has been previously described.[14] The dosimeter is plugged into a personal computer (PC) to be read using the Instadose™ software. The readout from the PC demonstrates the air kerma incident on the dosimeter with a conversion calculation to give the personal dose equivalent $H_p(10)$. $H_p(10)$ (the dose equivalent in soft tissue measured at a depth of 10 mm) is an accepted surrogate measurement of effective dose (E). This is inaccurate in this setting, as the operator wears a lead apron so this value was divided by 21 – in line with the methodology outlined in the NCRP 168 document[15] to give an effective dose (E) whilst wearing a lead apron.

Operators wearing the IDD were all cardiologists with varying experience. For analysis, they were grouped into three experience categories: Group1 = Registrar, Group 2 = Interventional fellow, Group 3 = Consultant.

Data integrity and statistical analysis

Data for procedures where an IDD was worn were compared to those procedures where the IDD was not worn to ensure a comparable data set. The distributions of variables were assessed. Means and standard deviations (SD) or medians and inter-quartile ranges were used to describe continuous variables. Mann–Whitney *U* tests were used to compare continuous variables when there were only two categories and Kruskal–Wallis tests were used to compare continuous variables when there were more than two categories. The continuous outcome measures (OD and P_{KA}) were categorised to form binary measures for use in analysis. For each variable, values below the 75th percentile were included in the reference category and values at or above the 75th percentile were included in the high dose comparison category. Categorical variables were compared using a Chi squared test. Significant categorical variables from the Chi-square analysis with a $P < 0.1$ with univariate analysis were included in multivariate logistic regression modelling. Stepwise removal of variables with the highest *P*-value was performed. In the final model all variables remained significantly associated with the outcome at the 0.05 level.

Results

The study population comprised 3860 patients. The mean age for patients was 66 (SD 13) years. P_{KA} measurements were available for all 3860 procedures and the IDD was worn during 2591 (67.1%) of these procedures. Primary operator dose (OD) was measured in this subset. The cut point for the 75th percentile value for P_{KA} was 61.4 $Gycm^2$ (Table 1). Procedures above this were considered High P_{KA}. The cut point for the 75th percentile for Operator 1 dose (OD) was 1.90 μSv, with dosimeter readings above this value categorised as high.

All patient and radiation parameters did not differ significantly between procedures where the IDD was and was not worn. The overall and procedure group comparisons for each of the 10 examination categories are given in Table 1. The CORS-LV/AO category was the most numerous, accounting for 1745 (45%) of the procedures performed. The medians of all variables differed significantly across procedural categories. Patients in the TAVI-WU category were the eldest (median 82 years) but the CORS-PA category demonstrated the highest FT (13 (10.4–17.9) min), K_{AR} (1327 (885–1796) mGy), P_{KA} (99.69 (67.66–160.07) $Gycm^2$) and DA (19 (17–22)). However, this category accounted for only 0.3% of procedures performed. Median OD was 0.95 μSv (Inter quartile range (IQR) 0.00–1.90) and varied significantly across procedure categories ($P = 0.002$) and is demonstrated graphically in Figure 1. Median patient and operator dose for each category within each variable that may impact on radiation dose is given in Table 2.

Factors contributing to a high P_{KA}

Overall, 64% of patients were male, 33% of patients were overweight (BMI 25–30) and 45% were obese (BMI >30). Under univariate analysis, the CORS-PA procedure category demonstrated the highest odds ratio (OR), with these patients having a 16 fold greater chance of receiving a high dose in comparison to the CORS baseline category.

Under multivariate analysis, a BMI > 30 was the strongest predictor for a high P_{KA}, demonstrating that after correcting for all other variables in the model, these patients were 19.1 times more likely to receive a high dose. Males were more likely to be in the highest quartile of radiation dose (OR: 5.3, 95% CI: 4.3–6.7), compared to females and Biplane imaging was also more likely to be associated with a high P_{KA} (OR = 5.2 (95% CI: 4.2–6.5)) (Table 3).

Factors contributing to a high operator 1 dose (OD)

In the subset of 2591 patients where the IDD was worn by operators, patients were predominantly male (64%), 33% were overweight and 46% were obese. Biplane imaging was used in 21% of cases and radial access was used in 69% of procedures. Under univariate analysis, a BMI > 30 was demonstrated to be the strongest predictor of a high OD, with an OR of 3.3 (95% CI: 2.5–4.4). This effect persisted in the multivariate model, where after correcting for all other variables in the model, a BMI > 30 was the strongest

Table 1. Overall patient and radiation data and comparisons across procedure categories.

	Procedure category											
	Overall	AFA	CORS	CORS-LV/AO	CORS-LHC/ RHC	CORS-OCT/ IVUS/FFR	CORS-PA	CORS-GRAFTS	PA	RHC	TAVI - WU	*P*-value
N	3680	11	1019	1745	200	268	10	413	18	55	121	–
Patient measures												
Age (years)	66 ± 13	77 (72–82)	67 (57–75)	65 (56–72)	69 (54–77)	68 (61–75)	64 (59–67)	72 (66–79)	52 (36–67)	59 (41 –72)	82 (78–86)	<0.001
BMI kg/m^2	29.3 (25.5–33.6)	30.5 (25.7–34.8)	29.3 (25.4–33.8)	29.6 (25.7–33.9)	27.9 (24.1–33.3)	29.4 (26.0–33.2)	29.8 (28.3–35.3)	28.9 (25.9–32.9)	25.6 (22.2–30.0)	27.6 (21.2 –31.6)	27.7 (24.9–31.4)	<0.001
Radiation measures												
FT (min)	4.7 (2.9–8.3)	4.5 (1.3–7.7)	3.9 (2.5–6.4)	3.7 (2.6–5.6)	8.1 (5.1–11.9)	9.1 (6.5–12.9)	13.0 (10.4–17.9)	9.8 (6.7–14.4)	10.5 (8.5–14.3)	4.7 (2.0–9.5)	7.5 (4.5–9.7)	<0.001
K_{AR} (mGy)	646 (399–980)	139.0 (32.6–451)	626.0 (398–934)	593.0 (374–872)	613.0 (372–900.5)	841.5 (493.5–1242.5)	1327.0 (885–1796)	1018.0 (665–1476)	391.5 (200–610)	53.8 (19–105)	721.0 (449.0–1124)	<0.001
P_{KA} (Gycm^2)	40.0 (24.8–61.4)	12.93 (3.13–42.70)	37.37 (23.96–56.41)	35.76 (22.89–53.49)	43.25 (26.69–65.28)	49.37 (30.44–72.72)	99.69 (67.66–160.07)	67.11 (43.75–95.58)	34.30 (17.13–57.43)	5.72 (2.24 –13.97)	47.86 (32.09–78.38)	<0.001
DA	10 (9–13)	4 (2–9)	9 (8–11)	10 (10–12)	10 (8–12)	12 (9–14)	19 (17–22)	17 (14–20)	8 (5–9)	0 (0–1)	14 (12–16)	<0.001

Table shows how the different patient characteristics and radiation measures compare across procedure category. Median and inter-quartile ranges are shown with *P*-values calculated using Kruskal–Wallis tests. BMI, body mass index; CORS, coronary angiogram; DA, digital acquisitions; FT, fluoroscopy time; K_{AR}, air Kerma at the interventional reference point; P_{KA}, Kerma area product; TAVI, transcatheter aortic valve implant; AFA, abdominal/femoral angiogram only; CORS, coronary angiography only; CORS-LV/AO, coronary angiography + aortogram/left ventriculogram; CORS-LHC/RHC, coronary angiography + left heart catheterisation + right heart catheterisation; CORS-OCT/IVUS/FFR, coronary angiography + additional coronary artery lesion assessment with intravascular ultrasound (IVUS), optical coherence tomography (OCT) of fractional flow reserve (FFR); CORS-PA, coronary angiography + pulmonary angiography; CORS-GRAFTS, coronary angiography + coronary artery bypass graft angiography; PA, pulmonary angiography alone; RHC, right heart catheterisation ± venography; TAVI-WU, work-up for transcatheter aortic valve implant.

predictor of a high OD, (OR = 3.3 (95% CI: 2.4–4.4)). Of the 10 procedural categories, TAVI-WU demonstrated the highest OR for predicting a high OD, (OR = 2.7 (95% CI: 1.5–4.8)). Males, biplane imaging and radial access were also associated with a high OD (Table 4).

Discussion

This study is a large and comprehensive analysis of factors that can impact on patient and operator radiation dose during 10 different diagnostic cardiac procedures performed in a tertiary cardiac catheter laboratory over 16 months period. There was no significant difference between the radiation dose variables when an IDD was or was not worn and this is important when establishing results for operator dose and whether they are relevant across the entire cohort.

A local, multicentre diagnostic reference level (DRL) for CA was developed in 2013 and published in 2014.[16] The 75th percentile of 61.4 $Gycm^2$ in this study appears to be similar to that studies' DRL for CA of 58.65 $Gycm^2$ and importantly, the median P_{KA} value appears to be lower than that studies' 75th percentile DRL.[16] This demonstrates ongoing compliance with the local DRL, even with the addition of more complex procedures that were not included in the DRL study of 2014.

Obesity

The multivariate analysis demonstrates that after correcting for all other variables in the model, risk of exposure to high P_{KA} and OD values was highest in obese patients. This is consistent with previous research where obesity was demonstrated to significantly increase the radiation dose used during coronary angiography.[17] However, the present study supplements these findings with the additional information that a high patient BMI is the strongest predictor for both a high patient and operator dose across a range of diagnostic procedures. A high patient BMI means a greater patient thickness which requires more X-ray tube output. The X-ray system boosts exposure automatically but increases patient dose from the increased absorption and scatter of X-rays from the additional thickness. The additional scatter in turn increases OD.

Catheter access route

Radial arterial access has previously been demonstrated to be a procedural factor that increases P_{KA}[18–20] and operator dose.[21,22] However, in the present study, under multivariate analysis, access route did not remain significantly associated with a high P_{KA} at the 5% level. However, radial artery access was associated with a high OD. This is important as radial artery access is now the access route of choice, with lower vascular complication rates[23,24] and a higher patient preference.[24] This study shows a predominantly radial approach and operators are familiar with the technique. The reason for a higher OD with radial access is likely due to the operator standing closer to the radiation source and this observation has previously been highlighted as a possible reason for a higher OD.[12,18]

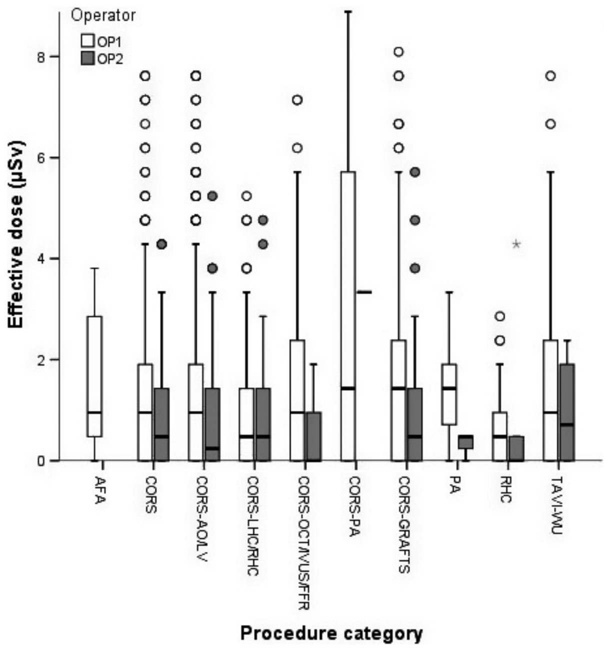

Figure 1. Median radiation dose to operators by procedure category. This graph demonstrates the differences in operator dose across procedure categories. AFA, abdominal/femoral angiogram only; BMI, body mass index; CORS, coronary angiography only; CORS-LV/AO, coronary angiography + aortogram/left ventriculogram; CORS-LHC/RHC, coronary angiography + left heart catheterisation + right heart catheterisation; CORS-OCT/IVUS/FFR, coronary angiography + additional coronary artery lesion assessment with intravascular ultrasound (IVUS), optical coherence tomography (OCT) of fractional flow reserve (FFR); CORS-PA, coronary angiography + pulmonary angiography; CORS-GRAFTS, coronary angiography + coronary artery bypass graft angiography; OP1, operator 1; OP2, operator 2; PA, pulmonary angiography alone; RHC, right heart catheterisation ± venography; TAVI-WU, work-up for transcatheter aortic valve implant: Includes coronary angiography, aortography, ilio-femoral angiography.

Biplane imaging

Unsurprisingly, biplane imaging was demonstrated to significantly increase high P_{KA} and OD rates. Biplane imaging uses an additional C-arm and X-ray source to acquire images and it has previously been demonstrated to increase FT, DA[25] and P_{KA}.[26] The study by Lin et al.[26]

Table 2. Median radiation dose for patients and operators within variable categories.

Item	P_{KA} (Gycm^2) Median (IQR)	*P*-value	OD (μSv) Median (IQR)	*P*-value
N	3860	<0.001	2591	0.002
Access				
Radial access	38.37 (24.55–57.24)		0.95 (0.00–1.90)	
Femoral access	46.04 (26.17– 72.57)		0.95 (0.00–1.90)	
Jugular access	2.86 (1.43–6.06)		0.72 (0.24–1.19)	
Gender		<0.001		<0.001
Female	27.52 (16.65–44.57)		0.95 (0.00–1.43)	
Male	47.45 (32.22–70.71)		0.95 (0.00–2.38)	
Imaging technique		<0.001		<0.001
Biplane Imaging	58.16 (35.55–89.74)		1.43 (0.00–2.38)	
Single plane	36.44 (22.88–55.27)		0.95 (0.00–1.90)	
Cath lab used		<0.001		0.372
Cath lab 1	37.40 (23.29–59.83)		0.95 (0.00–1.90)	
Cath lab 2	42.49 (26.40–63.97)		0.95 (0.00–1.90)	
BMI category		<0.001		<0.001
BMI >30	53.63 (37.52–76.01)		1.43 (0.00–2.38)	
BMI 25–30	35.96 (24.29–53.02)		0.95 (0.00–1.90)	
BMI <25	21.73 (13.43–33.83)		0.48 (0.00–1.43)	
Operator 1 experience		0.001		0.380
OP1 exp. (Consultant)	38.06 (23.91–60.40)		0.95 (0.00–1.90)	
OP1 exp. (Fellow)	41.11 (25.07–61.37)		0.95 (0.00–1.90)	
OP1 exp. (Registrar)	44.60 (28.38–65.41)		0.95 (0.00–1.90)	
Operator 2 experience		0.825		0.056
OP2 exp. (Consultant)	46.74 (30.65–71.07)		0.95 (0.00–2.38)	
OP2 exp. (Fellow)	45.68 (26.77–67.13)		0.95 (0.00–1.90)	
OP2 exp. (Registrar)	44.76 (29.50–69.86)		1.43 (0.48–2.86)	

This table demonstrates the differences in median (inter-quartile range (IQR)) radiation dose values for the patient (Gycm^2) and operator (uSv) between categories within each variable measured. BMI, body mass index; OD, primary operator dose; OP1, operator 1; OP2, operator 2.

also demonstrated that imaging of saphenous vein grafts and patient gender impact on P_{KA}, a finding that is has been replicated in this study, where the CORS-GRAFTS procedure category was demonstrated to be associated with a high P_{KA} and OD under univariate and multivariate analysis. Biplane imaging takes more images and may increase magnification, as it requires the anatomy to be placed in the isocentre of the image in both planes, positioning the patient closer to the X-ray source, which will increase skin dose. In addition, biplane imaging may increase the air-gap between the patient and the detector, increasing the incident air Kerma. These factors will also impact on OD and the ceiling suspended lead shield may be more difficult to position in order to protect the operator from the additional radiation from the two C-arms.

X-ray system used

It is interesting that one X-ray system delivered more P_{KA} than the other and that this was a significant predictor under multivariate analysis for a high P_{KA}. This did not, however, equate to a high OD. Both systems were identical models of the same age and used the same imaging protocols and exposure parameters. One explanation for this finding may be a difference in dose area product meter (DAP meter) readings between the two systems. Median P_{KA} varied only slightly between the systems. Both systems were tested on a regular basis for dose outputs and the accuracy of the DAP meter, and there are acceptable error ranges for DAP meters. Others studies suggest that an error of ±25% is usually deemed acceptable,[27,28] which is far greater than the difference seen here.

Procedural categories

Coronary angiography (CORS) was used as the baseline/reference procedure category for this study and the other categories were compared against this. CORS is seen as the baseline procedure of cardiac angiography, with most other procedure categories building on it. CORS and CORS-AO/LV account for 71.6% of procedures in this study. Only AFA, PA and RHC procedures did not include coronary angiography.

It is unsurprising therefore that those procedure categories that is built on the CORS reference procedure, demonstrated a higher P_{KA}. Of the procedure categories,

Table 3. Regression analysis for variables that impact on P_{KA} for diagnostic cardiac angiography procedures.

	Univariate			Multivariate		
	OR	95% CI	P value	OR	95% CI	P value
Gender			<0.001			<0.001
Female	Ref.Cat.			Ref.Cat.		
Male	4.39	3.61–5.32	<0.001	5.34	4.26–6.68	<0.001
Access			<0.001			
Femoral	Ref.Cat.					
Jugular	0.13	0.02–1.00	0.05			
Radial	0.53	0.46–0.62	<0.001			
Cath lab used			<0.001			<0.001
Cath lab 1 used	Ref.Cat.			Ref.Cat.		
Cath lab 2 used	1.20	1.04–1.39	0.01	1.37	1.14–1.64	0.002
Imaging technique			<0.001			<0.001
Single plane	Ref.Cat.			Ref.Cat		
Bi-plane	3.93	3.34–4.62	<0.001	5.17	4.14–6.47	<0.001
BMI			<0.001			<0.001
BMI <25	Ref.Cat.			Ref.Cat		
BMI 25-30	3.58	2.61–4.90	<0.001	3.88	2.74–5.50	<0.001
BMI >30	9.59	7.13–12.90	<0.001	19.08	13.52–26.94	<0.001
Procedure type			<0.001			<0.001
CORS	Ref.Cat.			Ref.Cat		
AFA	0.40	0.05–3.12	0.386	0.25	0.03–2.26	0.215
CORS-LV/AO	0.85	0.70–1.03	0.102	0.88	0.70–1.10	0.254
CORS-OCT/IVUS/FFR	2.55	1.91–3.41	<0.001	3.47	2.46–4.89	<0.001
CORS-PA	16.08	3.39–76.29	<0.001	10.36	1.96–54.77	0.006
CORS-RHC	1.64	1.17–2.31	0.004	2.51	1.66–3.79	<0.001
CORS-GRAFTS	5.15	4.02–6.60	<0.001	3.66	2.70–4.96	<0.001
PA	1.15	0.37–3.53	0.809	1.51	0.40–5.67	0.542
RHC	0.32	0.11–0.88	0.028	0.45	0.15–1.37	0.157
TAVI-WU	2.55	1.72–3.80	<0.001	1.85	1.13–3.01	0.014
Operator 1 Experience			0.077			0.010
Consultant	Ref.Cat.			Ref.Cat.		
Fellow	1.06	0.90–1.24	0.480	1.06	0.87–1.28	0.588
Registrar	1.29	1.04–1.61	0.024	1.51	1.15–1.98	0.003
Operator 2 Experience			0.72			
Consultant	Ref.Cat.					
Fellow	0.97	0.55–1.73	0.923			
Registrar	0.81	0.46–1.42	0.455			

This table demonstrates the odds ratio and significance for all variables that impact on a high P_{KA} in the study under univariate and multivariate logistic regression. AFA, abdominal/femoral angiogram only; BMI, body mass index; CORS, coronary angiography only; CORS-LV/AO, coronary angiography + aortogram/left ventriculogram; CORS-LHC/RHC, coronary angiography + left heart catheterisation + right heart catheterisation; CORS-OCT/IVUS/FFR, coronary angiography + additional coronary artery lesion assessment with intravascular ultrasound (IVUS), optical coherence tomography (OCT) of fractional flow reserve (FFR); CORS-PA, coronary angiography + pulmonary angiography; CORS-GRAFTS, coronary angiography + coronary artery bypass graft angiography; OP1, operator 1; OP2, operator 2; OR, odds ratio; PA, pulmonary angiography alone; Ref.Cat., reference category; RHC, Right heart catheterisation ± venography; TAVI-WU, work-up for transcatheter aortic valve implant: Includes coronary angiography, aortography, ilio-femoral angiography.

CORS with pulmonary angiography (CORS-PA) was the strongest procedural predictor for a high P_{KA}. CORS-PA had the highest median P_{KA} and DA count. CORS-PA routinely uses bi-plane angiography, in which the planes are used in the posterior-anterior projection and lateral projection for the PA component. The lateral projection is very steep and steep or more extreme angles have been shown to increase P_{KA}.[29]

Intra coronary assessment of coronary artery disease with the use of pressure wires (FFR) and intra-vascular imaging with OCT or IVUS is also shown to impact on P_{KA}, although it did not reach significance for a high OD. The results here show that these additional assessment tools increase the FT, P_{KA} and DA for diagnostic procedures. FFR is recommended in the assessment of intermediate lesions prior to revascularisation[30] and the

Table 4. Regression analysis for variables that impact on operator dose for diagnostic cardiac angiography procedures.

	Univariate			Multivariate		
	OR	95% CI	P value	OR	95% CI	P value
Gender			<0.001			<0.001
Female	Ref.Cat.			Ref.Cat.		
Male	1.77	1.44–2.17	<0.001	1.66	1.33–2.06	<0.001
Access			0.053			<0.001
Femoral	Ref.Cat.			Ref.Cat.		
Jugular	0.83	0.18–3.84	0.815	1.79	0.26–12.16	0.565
Radial	1.29	1.05–1.58	0.017	2.34	1.69–3.17	<0.001
Cath lab used			0.793			
Cath lab 1 used	Ref.Cat					
Cath lab 2 used	0.98	0.81–1.17	0.793			
Imaging technique			<0.001			<0.001
Single plane	Ref.Cat.			Ref.Cat.		
Bi-plane	1.73	1.40–2.14	<0.001	2.18	1.68–2.84	<0.001
BMI			<0.001			<0.001
BMI <25	Ref.Cat.			Ref.Cat.		
BMI 25–30	1.66	1.22–2.27	0.001	1.51	1.09–2.08	0.011
BMI >30	3.31	2.49–4.41	<0.001	3.25	2.42–4.37	<0.001
Procedure type			0.011			0.014
CORS	Ref.Cat.			Ref.Cat.		
AFA	1.94	0.35–10.68	0.448	3.13	0.50–19.57	0.223
CORS-LV/AO	1.03	0.82–1.30	0.793	0.97	0.77–1.24	0.818
CORS-OCT/IVUS/FFR	1.41	0.97–2.05	0.069	1.44	0.98–2.12	0.067
CORS-PA	1.94	0.48–7.84	0.354	1.87	0.43–8.03	0.404
CORS-RHC	0.83	0.50–1.36	0.454	1.28	0.74–2.20	0.376
CORS-GRAFTS	1.53	1.11–2.12	0.010	1.86	1.24–2.79	0.003
PA	0.86	0.18–4.03	0.849	1.49	0.28–7.88	0.641
RHC	0.52	0.18–1.49	0.222	0.91	0.24–3.36	0.882
TAVI-WU	2.05	1.24–3.39	0.005	2.68	1.50–4.76	0.001
Operator 1 Experience			0.094			
Consultant	Ref.Cat					
Fellow	1.23	0.92–1.65	0.168			
Registrar	1.00	0.74–1.34	1.000			
Operator 2 Experience			0.190			
Consultant	Ref.Cat					
Fellow	1.35	0.76–2.40	0.310			
Registrar	0.76	0.41–1.42	0.391			

This table demonstrates the odds ratio and significance for all variables that impact on a high OD in the study under univariate and multivariate logistic regression. AFA, abdominal/femoral angiogram only, BMI, body mass index; CORS, coronary angiography only; CORS-LV/AO, coronary angiography + aortogram/left ventriculogram; CORS-LHC/RHC, coronary angiography + left heart catheterisation + right heart catheterisation; CORS-OCT/IVUS/FFR, coronary angiography + additional coronary artery lesion assessment with intravascular ultrasound (IVUS), optical coherence tomography (OCT) of fractional flow reserve (FFR); CORS-PA, coronary angiography + pulmonary angiography; CORS-GRAFTS, coronary angiography + coronary artery bypass graft angiography; OP1, operator 1; OP2, operator 2; OR, odds ratio; PA, pulmonary angiography alone; Ref.Cat., reference category; RHC, right heart catheterisation ± venography; TAVI-WU, work-up for transcatheter aortic valve implant: Includes coronary angiography, aortography, ilio-femoral angiography.

use of these additional tools may increase over time so it is important to measure their impact on radiation dose.

Operator experience

Operator experience is shown to impact on P_{KA} during CA under multivariate analysis. After correcting for other variables, the least experienced operators (registrars) were statistically more likely to deliver high P_{KA} values and these findings complement those of the REVERE trial where less experienced radial access operators delivered a higher P_{KA}.[12] The higher P_{KA} seen is possibly due to increased fluoroscopy times when manipulating guide wires and catheters, and possibly a higher number of repeat DA from catheters disengaging mid-acquisition. A higher number of DA and FT for inexperienced operators was also noted in the REVERE trial.[12] Other studies have demonstrated a difference between individual operators in terms of FT, K_{AR} and P_{KA} delivered, though this was not attributed to experience level.[20,31] Operator experience did not appear to impact on OD in this study but all operators had training in the use of radiation and the effective use of protection measures, supplemented through annual refresher training.

Limitations

While not measured in this study, the effective use of the ceiling suspended shield would make a significant impact on OD and this should be analysed in future studies. Beam kV, mAs and beam geometry were not collected for each procedure, given the cohort size and this could have impacted on dose for different procedures.

Conclusions

This study demonstrates that radiation dose to patients and the operator performing the procedure is multifactorial and is affected by both patient and procedure related variables. Some variables impact on radiation dose more than others and some variables are predictive of a high P_{KA}, some predictive of a high OD, and some both. Overall, a high patient BMI is the strongest predictor for both a high patient and operator radiation dose.

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Conflict of Interest

The authors declare no conflict of interest.

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