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FULL PAPER

Optimisation of coronary angiography exposures requires a multifactorial approach and careful procedural definition

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Objective: This study investigates the factors associated with higher doses for both single-plane and biplane procedures and establishes centre-specific 75th percentile levels.

Methods: 602 patients undergoing coronary angiography in a large hospital at Sydney were recruited to the study, and causal agents for high radiation doses were investigated: gender, procedural complexity, severity of coronary artery disease, presence of coronary bypass grafts, entry approach (radial or femoral), level of operator experience; and a single-plane or a biplane imaging system was employed.

Results: The 75th percentile levels were calculated. The results demonstrated that, for both systems, higher exposures were associated with patients who were male ($p < 0.001$), had coronary vessel disease ($p < 0.001$) and had a history of coronary bypass grafts ($p < 0.001$). In addition, for biplane systems, procedural complexity ($p < 0.001$), types of entry approach ($p < 0.001$) and levels

of operator experience ($p < 0.001$) significantly impacted upon the dose. Biplane examinations recorded higher doses than single-plane procedures ($p < 0.001$) and the inclusion of left-sided ventriculography contributed to the overall dose by up to 10%.

Conclusion: The 75th percentile levels in this study represent the tentative reference levels and are 48.9, 44.2 and 56 Gy cm² for all exposures, single-plane- and biplane-specific exposures, respectively, and compare favourably with the diagnostic reference level values established elsewhere internationally, with only the UK and Irish data being lower.

Advances in knowledge: Specific agents have been identified for dose-reducing strategies and the importance of operator training is highlighted. The assumption that biplane procedures may reduce the patient dose should be treated with caution.

Diagnostic coronary angiography is regarded as an essential imaging and therapeutic tool, given the high incidence of cardiovascular disease in Australia, with 18% of Australians having chronic cardiovascular disease [1,2]. It is the most common invasive cardiac procedure and is used for both the initial diagnosis of coronary artery disease (CAD) and the follow-up examinations of patients after coronary interventional procedures, coronary bypass surgery or cardiac transplantation [3,4]. It is a standardised procedure that involves several cine-fluorographic series of the right and left coronary artery systems, with or without a left ventriculogram [5].

Recently, the rapid increase in the frequency of diagnostic coronary angiography procedures has prompted radiation protection concerns [6], and studies have been performed to determine patient radiation doses in a number of countries [1,3,5,7]. The radiation dose of diagnostic coronary angiography is often presented in the form of a diagnostic reference level (DRL) [8], which is established at the 75th percentile dose-area

product (DAP) value of the distributions of doses observed for a particular examination [9]. The main purpose of DRLs is to facilitate the optimisation of the radiation dose for a particular type of examination by identifying practices with unnecessarily high patient doses [8] and serving as a benchmark for the comparison of radiation dose among countries [10].

Diagnostic coronary angiography can be performed using single-plane and biplane imaging systems. Biplane diagnostic coronary angiography enables two cine-angiography runs to be recorded simultaneously from two orthogonal planes during a single injection of contrast medium [11]. Single-plane diagnostic coronary angiography views the individual in one plane (with one X-ray tube) and acquires patient depth information by altering the tube position between X-ray exposures [11].

In terms of clinical usage, biplane diagnostic coronary angiography has been reported to be more efficient than

single-plane diagnostic coronary angiography [11]. Biplane imaging should be faster, employ reduced fluoroscopy time, require fewer cine-angiography runs and therefore involve lower average radiation dose to the patient than that of single-plane imaging, prompting recommendations for its use in paediatric examinations [11]. Despite these advantages, other researchers have suggested that biplane diagnostic coronary angiography is complicated and requires longer set-ups that can result in increased radiation exposure to both the operator and the patients [7,12–14].

The aim of this study is to address the current biplane imaging debate by examining radiation doses in a large metropolitan teaching hospital in Sydney, NSW, Australia. It will also explore the impact that a number of patients and procedural factors have on dose, such as gender, procedural complexity, severity of CAD, presence of coronary artery bypass grafts, types of entry approach and levels of operator experience. The baseline radiation dose for diagnostic coronary angiography will be provided and compared with published DRLs.

METHODS AND MATERIALS

Patient population

Over an 8-month period, 602 patients, who required diagnostic coronary angiography, were enrolled into the study and randomly assigned to undergo a single-plane or a biplane angiogram according to wait lists and room availability. The study was performed at a major Sydney metropolitan teaching hospital with two cardiac catheterisation laboratories.

Description of the imaging system

The Siemens® Axiom Artis DBC flat panel biplane angiography system (Siemens Healthcare, Forchheim, Germany) with a 100-kW rating and a focal spot of 0.3, 0.6 and 1.0 mm was used in both cardiac catheterisation laboratories. This system can also utilise a single-plane imaging approach by deactivating the corresponding lateral c-arm. All diagnostic coronary angiography procedures were carried out with automatic exposure control (AEC) and a default frame speed of 15 frames per second for both digital cine-angiography and fluoroscopy screening. Calibrated DAP meters (PTW Inc., Freiburg, Germany) mounted within the diaphragm housing of the X-ray tubes were used for all radiation dose recordings and were calibrated according to the international standard EN 60601-2-43:2000 before and at regular intervals during the study.

Ethics approval

Ethics approval was obtained from the Human Research Ethics Committees of Sydney West Area Health Service and the University of Sydney.

Patient and procedural data collection

All 602 procedures of diagnostic coronary angiography were categorised using the following variables: imaging approach used (single plane or biplane); patient gender; procedural complexity—non-complicated (involving ≤ 3 catheter changes) or complicated (involving ≥ 4 catheter changes); severity of CAD (normal cases, minor CAD or CAD affecting one or more vessel); the presence of coronary artery bypass grafts or not; the entry approach used (femoral or radial); and the operator's

experience level (registrars, fellows and consultant cardiologists). All variables are presented in Table 1.

The median and standard deviation for patient age was 62 (13) and 63 (12) years and the median and standard deviation for weight was 83 (20) and 77 (19) kg for single-plane and biplane techniques, respectively.

Data analysis

A four-stage analysis was performed:

- (1) assessment of the impact of the variables described in the previous section for all patients and for patients examined with a specific plane (single plane or biplane)
- (2) comparison of single-plane vs biplane imaging for each of the categories mentioned above
- (3) 75th percentile level calculations
- (4) assessment of the contribution of left ventriculography to radiation doses.

In the first and second stages of the analysis, radiation doses were not normally distributed and were demonstrated using the median values with the 25th and 75th percentiles. Groups were

Table 1. The number of patients belonging to each variable for both single-plane and biplane techniques

Category	Single-plane imaging (N=341)	Biplane imaging (N=261)
<i>Gender</i>		
Male	215	159
Female	126	102
<i>Procedural complexity</i>		
No catheter record	5	7
Non-complicated	291	214
Complicated	45	40
<i>Severity of CAD</i>		
Normal cases	101	67
Minor	101	80
One vessel or more	139	114
<i>Presence of coronary artery bypass grafts</i>		
No graft	305	224
Graft	36	37
<i>Entry approach</i>		
Femoral	271	252
Radial	70	9
<i>Operator experience</i>		
Registrar (n=5)	142	117
Fellow (n=4)	82	80
Consultant (n=16)	117	64

CAD, coronary artery disease.

Table 2. Single-plane and biplane radiation doses for the listed variables

Category	Radiation dose (Gy cm ²)		Interplanar significance (<i>p</i> -value)
	Single-plane cases (<i>N</i> =341)	Biplane cases (<i>N</i> =261)	
Overall	28.5 (18.1, 40.5)	33.3 (21.6, 50.1)	<0.001
<i>Gender</i>			
Male	31.9 (22.6, 43.9)	37.7 (24.8, 56.0)	0.005
Female	22.4 (13.0, 32.9)	26.0 (19.3, 41.1)	0.002
Intervariable significance (<i>p</i> -value)	<0.001	<0.001	
<i>Complexity</i>			
Non-complicated	27.7 (17.5, 40.5)	31.5 (21.3, 46.0)	0.003
Complicated	31.7 (24.1, 42.1)	41.4 (29.8, 57.2)	0.024
Intervariable significance (<i>p</i> -value)	0.143	0.02	
<i>Severity of CAD</i>			
Normal cases	21.9 (12.0, 37.1)	26.1 (19.3, 39.7)	0.012
Minor	28.9 (18.5, 40.5)	26.3 (20.1, 40.6)	0.883
One vessel or more	32.0 (23.9, 43.8)	39.4 (29.9, 56.8)	<0.001
Intervariable significance (<i>p</i> -value)	<0.001 ^{a,b}	<0.001 ^{a,b}	
<i>Presence of coronary bypass grafts</i>			
No graft	27.4 (17.0, 39.4)	30.4 (20.5, 44.3)	0.003
Graft	40.8 (28.6, 56.0)	49.0 (37.5, 65.9)	0.101
Intervariable significance (<i>p</i> -value)	<0.001	<0.001	
<i>Entry approach</i>			
Femoral	28.3 (17.7, 40.6)	32.1 (21.5, 48.7)	0.001
Arm	30.6 (18.5, 40.5)	60.8 (36.5, 67.6)	0.004
Intervariable significance (<i>p</i> -value)	0.744	0.004	
<i>Operator experience</i>			
Registrar	31.1 (19.5, 44.3)	38.1 (23.7, 56.1)	0.003
Fellow	28.4 (16.9, 41.9)	26.6 (19.8, 38.7)	0.454
Consultant	26.8 (17.8, 37.6)	31.6 (20.3, 52.5)	0.015
Intervariable significance (<i>p</i> -value)	0.077	0.004 ^a	

CAD, coronary artery disease.

Median values are provided, and the 25th and 75th percentiles are shown in parentheses.

^aSignificant difference between the first and second categories within a variable.

^bSignificant difference between the first and third categories within a variable.

evaluated using either the Mann–Whitney rank sum test (two groups) or the Kruskal–Wallis comparison (three groups). As left ventriculography was performed in only 461 of 602 procedures, the dose component of left ventriculography was removed for these stages of the analyses.

The third analyses involved the calculation of the 75th percentile of the total dose distributions for all patients and those belonging to either the single-plane or biplane groups. The minimum, maximum, 25th percentile and median values were also calculated. The last element of the analyses compared the contribution of left ventriculography with the overall dose and the 75th percentile level for each imaging plane.

RESULTS

In total, this study included 602 procedures, of which 341 and 261 were performed with single-plane and biplane imaging, respectively. As described in the Methods and materials section, there were four stages to the analysis, and results for each are considered individually.

Intravariation differences

The intravariation comparisons demonstrated that, for both single-plane and biplane imaging, males, along with patients with one vessel or more CAD, and patients with coronary artery bypass grafts received a significantly higher radiation dose than female patients, patients with minor CAD or normal vessels and patients

Table 3. Distribution of radiation doses of both single-plane and biplane imaging

Imaging plane	Number	Dose–area product (Gy cm ²)					
		Range	Maximum	Minimum	Median	25th percentile	75th percentile
Single plane and biplane	602	152.6	156.4	3.7	33.3	22.2	48.9
Single plane	341	103.5	109.1	5.6	30.4	19.3	44.2
Biplane	261	152.6	156.4	3.7	38.4	26.2	56.0

without grafts, respectively (Table 2). Procedural complexity, types of entry approach used and levels of operator experience had a significant influence on the radiation dose for biplane imaging only (Table 2). All significant results were identified at $p < 0.05$, with specific values specified in Table 2.

Comparison of single-plane with biplane imaging for each of the categories

The interplane comparison in Table 2 demonstrates that biplane imaging had a 17% higher radiation dose than single-plane imaging when all examinations were grouped into one of the two groups ($p < 0.001$). Higher doses for biplane compared with single-plane imaging were also evident for each variable ($p < 0.001$) (Table 2), except for examinations involving minor CAD, grafts and cardiology fellows.

Calculation of procedural radiation levels

The 75th percentile levels of patient doses are shown in Table 3 along with the minimum, maximum, 25th percentile and median values for all patients combined and then separately for those undergoing single-plane and biplane imaging.

Contribution of left ventriculography to radiation doses for each plane

Left ventriculography was responsible for 8.4% and 10.7% of the total dose recorded for single-plane and biplane imaging, respectively (Table 4). Contributions to the 75th percentile level are shown in Table 4.

DISCUSSION

The data provided in this work demonstrate the multifactorial nature of radiation doses delivered to patients undergoing coronary angiography. Three variables, namely gender, severity of CAD and the presence of coronary artery bypass grafts, had a significant influence on the radiation dose for both single-plane and biplane techniques. The finding that male patients received significantly higher radiation doses than female patients, most likely owing to

increased patient size, is well documented [15] but highlights the potential difficulty of grouping all patients when establishing a single representative value such as a DRL, in which doses for one gender can be 45% higher (biplane) than the other. The higher doses associated with severe CAD or bypass grafts reflect the level of procedural difficulty in these situations and most probably the increased time required to successfully complete the examinations.

Three other categories—procedural complexity, types of entry approach and levels of operator experience—significantly influenced biplane exposures. These results and the higher doses shown with biplane imaging are most likely to be associated with increased technical difficulty and the higher level of expertise required compared with single-plane procedures. The complex adjustment of the two X-ray tubes and attached detectors required for accurate representation of patient anatomy while managing all other concurrent activities such as patient care and contrast administration is often overlooked, and the opinion of the authors of this paper is that greater attention should be directed to educational programmes in cardiology, especially for biplane imaging.

The simultaneous acquisition and viewing of two patient planes presents the potential for reducing the procedural duration, cine-fluoroscopy exposures, contrast load and patient radiation doses; however, regardless of this potential, it is important that proper training is available to and taken up by operators of complex angiographic facilities, or the variables of procedural duration, cine-fluoroscopic exposures, contrast load and radiation doses will not be optimised [11]. It is tempting to suggest that this training should be focused on junior operators, but the results shown here suggest that all operators may benefit. The surprising increased dose shown for more senior colleagues compared with their junior counterparts may be the result of more experienced operators taking responsibility for procedures with a higher level of complexity or difficulty and/or junior colleagues performing a greater number of cases and hence gaining additional practice.

Table 4. Contribution of left ventriculography to the 75th percentile level of diagnostic coronary angiography for either imaging plane

Imaging plane	75th percentile level (Gy cm ²)		Dose contribution of left ventriculography to the 75th percentile level (Gy cm ²)	Percentage contribution of left ventriculography to the 75th percentile level
	Without left ventriculography	With left ventriculography		
Single plane and biplane	43.1	49.2	6.4	13.0
Single plane	40.5	45.4	3.7	8.4
Biplane	50	55.5	6.0	10.7

Although few data on DRLs or 75th percentiles are available in Australia, the 75th percentile levels presented here can be added to the increasing database in Australia of 75th percentiles. So, until DRLs are adopted in Australia, this will be the metric for comparison with reference values being reported worldwide [1,3,5,7,16]. In Table 5, we have collated currently existing DRLs and compared these with our data, and it is reassuring to note that our combined single-plane and biplane value is comparable to those levels established elsewhere, with only the Irish and the UK data being lower [1,16]. However, the reliance of DRL values on the method of image acquisition as highlighted in our work suggests that a single DRL for all diagnostic coronary angiography procedures may not adequately represent single-plane- and biplane-specific exposures. If meaningful international comparisons are to be made and appropriate dose-reducing methodologies identified, the image acquisition details must be carefully defined. The contribution of ventriculography to the overall patient dose reinforces this recommendation.

In summary, this study provides some new insights into the complexities of attempting to optimise coronary arteriography. Although our study only involved a single imaging centre and widespread application of conclusions is unwise, the data presented would suggest that a careful and multifactorial approach is required if patient doses are to be lowered and described in a meaningful way.

Table 5. Comparison of the 75th percentile dose values from the current study with diagnostic reference levels (DRLs) established elsewhere

Study	Dose value (Gy cm ²)
<i>Previous studies (DRL)</i>	
D'Helft et al [1]	42.0
Balter et al [5]	50.0
Neofotistou et al [3]	57.0
Bogaert et al [7]	71.3
Hart et al [16]	36.0
<i>Current study (75th percentile level)</i>	
Single-plane and biplane imaging	48.9
Single-plane imaging	44.2
Biplane imaging	56.0

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