Impact of biplane versus single-plane imaging on radiation dose, contrast load and procedural time in coronary angioplasty

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ABSTRACT. Coronary angioplasties can be performed with either single-plane or biplane imaging techniques. The aim of this study was to determine whether biplane imaging, in comparison to single-plane imaging, reduces radiation dose and contrast load and shortens procedural time during (i) primary and elective coronary angioplasty procedures, (ii) angioplasty to the main vascular territories and (iii) procedures performed by operators with various levels of experience. This prospective observational study included a total of 504 primary and elective single-vessel coronary angioplasty procedures utilising either biplane or single-plane imaging. Radiographic and clinical parameters were collected from clinical reports and examination protocols. Radiation dose was measured by a dose–area–product (DAP) meter intrinsic to the angiography system. Our results showed that biplane imaging delivered a significantly greater radiation dose (181.4 ± 121.0 Gy cm^2) than single-plane imaging (133.6 ± 92.8 Gy cm^2 , $p < 0.0001$). The difference was independent of case type (primary or elective) ($p = 0.862$), vascular territory ($p = 0.519$) and operator experience ($p = 0.903$). No significant difference was found in contrast load between biplane (166.8 ± 62.9 ml) and single-plane imaging (176.8 ± 66.0 ml) ($p = 0.302$). This non-significant difference was independent of case type ($p = 0.551$), vascular territory ($p = 0.308$) and operator experience ($p = 0.304$). Procedures performed with biplane imaging were significantly longer (55.3 ± 27.8 min) than those with single-plane (48.9 ± 24.2 min, $p = 0.010$) and, similarly, were not dependent on case type ($p = 0.226$), vascular territory ($p = 0.642$) or operator experience ($p = 0.094$). Biplane imaging resulted in a greater radiation dose and a longer procedural time and delivered a non-significant reduction in contrast load than single-plane imaging. These findings did not support the commonly perceived advantages of using biplane imaging in single-vessel coronary interventional procedures.

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The use of biplane imaging during diagnostic coronary angiography and coronary interventions has been reported to reduce the total contrast load to the patient compared with single-plane imaging [1–8]. Additionally, acquiring two simultaneous images from two orthogonal planes has been reported to be more efficient than single-plane imaging [2, 8–11]. However, there are conflicting reports as to whether the radiation dose to the patient differs between biplane and single-plane imaging during coronary studies [3, 10, 11].

Biplane imaging allows two cineangiography runs to be recorded simultaneously with a single injection of contrast. With single-plane imaging, however, the same information can be acquired only by carrying out the two cineangiography runs serially with two separate injections of contrast [1, 2, 8, 10]. Biplane imaging enables the operator to visualise the target lesion in orthogonal

planes simultaneously and was presumed to be more efficient than single-plane imaging, particularly in difficult procedures [1, 4, 9, 12]. Accordingly, examinations would become faster, use of fluoroscopy would be reduced, fewer cineangiography runs would be required and the average radiation dose to the patient would be comparatively lower than in the case of procedures performed with single-plane imaging. The contrast load with biplane imaging was also expected to be significantly reduced [3, 4, 11].

These perceived advantages of biplane imaging have led to recommendations for its use in paediatric and adult cardiac catheter laboratories [1, 4, 5, 10, 12, 13]. A previous study comparing biplane and single-plane imaging in 1156 diagnostic coronary angiography procedures found a small, but notable, reduction in contrast load accompanied by significantly longer table times and screening times with biplane imaging, although radiation dose was not examined [14].

Contrast-induced nephropathy (CIN) is a complication associated with prolonged hospitalisation and

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development of end-stage renal failure [15]. Patients with pre-existing renal disease, diabetes, congestive heart failure or older age are at the greatest risk in developing CIN [16–18]. These high-risk patients have a calculated incidence of CIN ranging from 10% to 30% [4, 18–20]. Pre-hydration is the primary intervention for preventing contrast nephropathy [18], but is not possible in the setting of emergency (primary) angioplasty procedures. The total contrast load during interventional procedures has been established as an independent predictor of CIN and could be effectively controlled by the operator during primary angioplasty cases [18, 21, 22]. Biplane imaging is commonly employed to minimise the contrast load, especially in patients with renal impairment and those who require primary coronary angioplasty procedures [1, 6, 7, 18, 23].

Numerous studies have found that the radiation dose varies significantly according to tube angulations, particularly in the combination of steep left anterior oblique (LAO) with cranial or caudal angulations [24–27]. However, there are no published data on whether the radiation dose with biplane or single-plane imaging during coronary angioplasty differs between the three vascular territories: right coronary artery (RCA), left anterior descending (LAD) and left circumflex/intermediate (LCX). Furthermore, interventional cardiac procedures are operator dependent [28–30]. Hence, it was postulated that senior cardiologists would be more familiar with biplane equipment and thereby more able to reduce radiation dose, contrast load and procedural time than less experienced operators. To our knowledge, no studies have been published that compare the impact of biplane and single-plane imaging in coronary angioplasty procedures.

The aims of this study were to determine whether biplane imaging reduces both contrast load and radiation dosage and shortens procedural time in patients undergoing primary or elective coronary angioplasty compared with single-plane imaging. We also investigated if there was a significant difference in radiation dose, contrast load and procedural time between biplane and single-plane imaging during coronary angioplasty in the three main vascular territories (RCA, LAD and LCX) and in procedures performed by operators with various levels of experience.

Methods

Patient population

From 1 December 2007 to 31 August 2008, 504 patients who required either primary or elective single-vessel coronary angioplasty of the RCA, LAD or LCX were consecutively enrolled into the study. The study was undertaken at a major Sydney metropolitan teaching hospital in two cardiac catheter laboratories utilising either biplane or single-plane imaging. Patients who required multivessel or coronary bypass graft angioplasty were excluded; these cases varied greatly in morphology and technical complexity and it would therefore be difficult to draw any meaningful results from these patients for this study.

The study was performed by three groups of trainees (three first year registrars, three second year registrars and three cardiology fellows) under the supervision of 15 cardiologists assigned randomly to be the supervisor.

Ethics approval

Ethics approval was granted from the Human Research Ethics Committee (HREC) at the University of Sydney and written consent was obtained from all operators.

Imaging system

The two cardiac catheter laboratories were equipped with the Siemens Axiom Artis dBC flat panel (biplane) angiography system. Under the direction of the cardiologists, these systems can also be used as a single-plane system by switching off the corresponding lateral c-arm. The choice of biplane or single-plane imaging was at the discretion of the supervising cardiologists. The Siemens angiography systems in this centre have pre-programmed the tube angles commonly used for each vascular territory for biplane imaging (Table 1). The tube angles were not pre-programmed when single-plane imaging was used.

The X-ray tubes within the Siemens c-arm have an X-ray tube with a 100 kW rating and a focal spot of 0.3, 0.6 and 1 mm. All coronary angioplasty procedures in the hospital were performed with automatic exposure control (AEC) and routinely use a 20 cm diagonal input phosphor field. The Siemens imaging systems are configured to operate at a default setting of 15 frames/s for both digital cineangiography and fluoroscopy screening.

The Siemens Axiom Artis dBC (biplane) systems are equipped with PTW dose-area product (DAP) meters mounted within the diaphragm housing of the X-ray tube. The calibration of the DAP involved measuring the dose with a dose meter during fluoroscopy (70 kV, 200 mA) with no additional filter in the beam, a certain source-to-image distance and collimator opening. The irradiated area of the image intensifier was calculated in cm². The measured dose was multiplied by the irradiated area and compared with the reading from the DAP in the display. All Siemens measurements were done following international standards EN 60601-2-43: 2000. The half value layer (HVL) at 81 kVp was 3.8 mm Al. Calibration was performed annually on the DAP meters, as recommended by the manufacturers and to ensure that relevant safety regulations and standards are met.

The displayed skin dose on the Siemens workstation corresponded to the international reference point. The international reference point is representative of the patient's skin, defined in the International Electrotechnical Commission's (IEC) standard 60601-2-43. For the Siemens Axiom Artis dBC flat panel (biplane) angiography systems utilised in this study, the international reference point is located at 15 cm in front of the isocentre. The displayed skin dose (also called cumulative air kerma = C_{dose}) is calibrated free-in-air and does not include backscatter, table-top attenuation and the conversion of air to tissue kerma.

Table 1. Siemens biplane standard preset angulations for coronary angioplasty procedures

Vessel	Frontal plane	Lateral plane
Proximal LAD and circumflex bifurcation	LAO 40 CRAN 30 Field size 20 cm	RAO 30 CAUD 30 Field size 20 cm
LAD	LAO 45 Field size 20 cm	RAO 30 Field size 20 cm
LM	LAO 90 CRAN 20 Field size 20 cm	LAO 5 Field size 16 cm
RCA	LAO 45 Field size 25 cm	RAO 30 Field size 25 cm
LM, LAD and circumflex bifurcation (spider view)	LAO 45 CAUD 30 Field size 20 cm	RAO 30 CRAN 30 Field size 20 cm

LAD, left anterior descending; LM, left main; LCX, left circumflex; RCA, right coronary artery. LAO, left anterior oblique; CAUD, caudal; CRAN, cranial; RAO, right anterior oblique

Data collection

Patient characteristics, such as height, weight and age, timing of procedure, on/off table time and total contrast volume, were routinely recorded by the radiographers in the cardiology analysis database system (CARDS). The clinical reports were comprised information such as type of case (primary or elective), the degree of coronary artery disease and the details of each lesion targeted for angioplasty. The examination protocols were directly printed out from the angiography system and included the number of cineangiography runs acquired, total cineangiography and fluoroscopy time, cineangiography and fluoroscopy DAP and the corresponding skin dose.

All cases with their corresponding clinical reports, examination protocols and relevant clinical information from CARDS had patient identification details removed and were numerically coded. The data were presented to researchers in a de-identified format by the senior radiographer of the cardiac catheter laboratory. In addition, the operators were coded according to level of experience: first year registrar, second year registrar and cardiology fellow/consultant cardiologist.

Data analysis

The radiographic and clinical parameters were entered into a database in Microsoft Excel. Each procedure was grouped according to whether the case was performed with biplane or single-plane imaging, primary or elective cases and the vascular territory (RCA, LAD and LCX) in which angioplasty was performed.

Data analysis was performed with SPSS statistical software version 15. Categorical clinical variables were compared using the χ^2 test for independence. Simple two-group comparisons of continuous variables were made with independent sample *t*-tests if the data were normally distributed, and Mann-Whitney *U*-tests if they were not. A series of 2×2 between-group univariate analyses of variance were used to explore the relationships between the independent variables of single-plane-biplane and primary-elective surgery with the dependent variables DAP (Gycm²), displayed skin dose (mGy), fluoroscopy time (min), cineangiography time (s),

number of cineangiography runs, total contrast load (ml), and procedural time (min). Two series of 2×3 ANOVAs examined the relationships between the same dependent variables and the independent variables single-plane-biplane and vascular territory (RCA, LAD and LCX), and single plane-biplane and level of operator experience (year 1 registrars, year 2 registrars, cardiology fellow or consultant cardiologist).

Post hoc comparisons in the 2×3 ANOVAs were carried out with the Tukey honestly significant difference (HSD) procedure to determine where differences among the groups occurred. The Tukey method was chosen because it offers good protection against type I errors without unduly risking type II errors [31, 32]. All *p*-values were two-tailed; α was set at 0.05 for all comparisons. With α at this level, power set at 80% and a sample size of 504 (see Table 2), power tables supplied by Murphy and Myers [33] and their effect size conversion formulae indicate that the 2×2 ANOVAs could be expected to detect interaction effect sizes of approximately $d=0.25$ (percentage of variance =1.5%); 2×3 ANOVAs could be expected to detect interaction effect sizes of approximately $d=0.28$ (percentage of variance =1.9%). These equate to conventionally small effects. Lesser effects would be clinically uninteresting.

Results

In the nine month period, 504 single-vessel coronary angioplasty procedures of LAD, RCA and LCX were performed. A total of 234 procedures were done with single-plane and 270 procedures with biplane imaging. The baseline characteristics are summarised in Table 2. Out of the 504 procedures, weight was not recorded in 94 cases. There were no significant differences in age, gender or weight between the group treated with single-plane imaging and the group treated with biplane imaging. Similarly, there were no significant differences in the target vessels treated, the number of primary or elective angioplasty cases, the timing of the cases, number of comorbidities, the level of operator experience, number of lesions treated and the number of stents deployed between the two imaging groups.

Table 2. Baseline patient characteristics (n=504)

Characteristic	Single-plane imaging	Biplane imaging	P-value
No. of patients (n)	234	270	
Age (years)	61.7 ± 11.7 ^a	61.1 ± 11.4 ^a	0.602 ^c
Weight (kg) ^b	83.1 ± 17.2 ^a	82.9 ± 20.4 ^a	0.939 ^c
Gender			0.210 ^d
Male	167 (71.4%)	207 (76.7%)	
Female	67 (28.6%)	63 (23.3%)	
Vascular territory			0.618 ^e
RCA	88 (37.6%)	108 (40%)	
LAD and left main	101 (43.2%)	105 (38.9%)	
LCX and intermediate	45 (19.2%)	57 (21.2%)	
Case type			0.747 ^d
Primary	98 (41.9%)	118 (43.7%)	
Elective	136 (58.1%)	152 (56.3%)	
Time of procedure			0.600 ^d
In working hours	179 (76.5%)	200 (74.1%)	
Out of hours	55 (23.5%)	70 (25.9%)	
No. of cardiac comorbidities acquired			0.203 ^e
0	122 (52.1%)	123 (45.6%)	
1	37 (15.8%)	55 (20.4%)	
2	24 (10.3%)	22 (8.1%)	
≥3	15 (6.4%)	25 (9.3%)	
Renal impairment/diabetes	7 (3.0%)	12 (4.4%)	
Cardiac co-morbidities and renal impairment/diabetes	22 (9.4%)	17 (6.3%)	
≥3 Cardiac co-morbidities and renal impairment/diabetes	7 (3.0%)	16 (5.9%)	
Operator experience			0.996 ^e
Year one registrars	35 (15.0%)	51 (18.9%)	
Year two registrars	37 (15.8%)	32 (11.9%)	
Cardiology fellow/consultant cardiologists	162 (69.2%)	187 (69.3%)	
No. of lesions treated			0.630 ^e
1	186 (79.5%)	1–219 (81.1%)	
2	43 (18.4%)	2–47 (17.4%)	
3	5 (2.1%)	3–3 (1.1%)	
4	0 (0%)	4–1 (0.4%)	
No. of stents deployed			0.362 ^e
0	16 (6.8%)	0–15 (5.6%)	
1	161 (68.8%)	1–178 (65.9%)	
2	36 (15.4%)	2–60 (22.2%)	
3	8 (7.7%)	3–12 (4.4%)	
4	3 (1.3%)	4–5 (1.9%)	

Categorical variables presented in numerical (number of coronary angioplasty procedures) and percentage values.

^aMean ± 1 standard deviation (SD).

^bWeight record was available in 183 procedures with single-plane and 227 procedures with biplane imaging.

^cIndependent samples *t*-test.

^d χ^2 test for independence.

^eMann–Whitney *U*-test.

DAP: radiation dose

The 270 coronary angioplasty procedures performed with biplane (BP) imaging resulted in a 36% increase in the average DAP compared with the 234 procedures performed with single-plane (SP) imaging (BP: 181.4 ± 121.0 Gy cm^2 vs SP: 133.6 ± 92.8 Gy cm^2 , $p < 0.0001$). The difference was independent of case type (primary or elective) ($p = 0.862$), vascular territory ($p = 0.519$) and operator experience ($p = 0.903$).

Biplane versus single-plane imaging in primary and elective angioplasty procedures

In the subgroup who had primary angioplasty, biplane imaging had a 38.5% increase in the mean DAP (BP: 186.4 ± 128.0 Gy cm^2 vs SP: 134.6 ± 103.8 Gy cm^2 , $p < 0.0001$)

(Figure 1a). There was a similar 37.5% increase in DAP recorded in patients undergoing elective angioplasty (BP: 177.6 ± 115.6 Gy cm^2 vs SP: 129.2 ± 84.3 Gy cm^2 , $p < 0.0001$).

There were no significant differences in the DAP between primary (P) and elective (E) angioplasty with single-plane imaging ($p = 0.664$) or with biplane imaging ($p = 0.556$) (Figure 1a).

Biplane versus single-plane imaging in the three vascular territories

The 504 procedures, 196 were angioplasty to the RCA, 206 were to the LAD and 102 were for the LCX. In all three vascular territories, biplane imaging delivered a significantly greater radiation exposure than single-plane imaging ($p < 0.0001$): RCA angioplasty procedures (BP:

Figure 1. Comparison of mean ($\bar{x}$) radiation dose in with ± 1 standard deviation biplane and single-plane imaging systems. (a) Radiation dose (with ± 1 standard deviation DAP) in primary and elective coronary angioplasty. (b) Radiation dose (DAP) for angioplasty in the three vascular territories. (c) Radiation dose (DAP) with level of operator experience. RCA, right coronary artery; LAD, left anterior descending; LCX, left circumflex.

178.3±131.4 Gy cm^2 vs SP: 132.3±104.7 Gy cm^2); LAD angioplasty procedures (BP: 177.0±111.8 Gy cm^2 vs SP: 134.3±85.9 Gy cm^2); and LCX procedures (BP: 195.5±117.8 Gy cm^2 vs SP: 123.5±83.9 Gy cm^2). No significant difference was found in the DAP among the three vascular territories with single-plane imaging or with biplane imaging (Figure 1b).

Biplane versus single-plane imaging with level of operator experience

All of the 504 angioplasty procedures were performed under the supervision of an attending cardiologist. First year registrars performed 86 procedures, second year registrars performed 69 procedures and cardiology fellows and/or senior cardiologists performed 349 procedures.

In all three groups of operators, biplane imaging delivered a significantly greater radiation dose to the patient than single-plane imaging ($p<0.0001$) (Figure 1c). The angioplasty procedures carried out with first year registrars using biplane imaging delivered a radiation exposure 40.4% greater than with single-plane imaging (BP: 201.8±133.9 Gy cm^2 vs SP: 143.7±97.1 Gy cm^2). With second year registrars, the difference with biplane compared with single-plane imaging was 37.4% (BP: 200.2±115.1 Gy cm^2 vs SP: 145±95.7 Gy cm^2). When cardiology fellows/senior cardiologists carried out procedures with biplane imaging, the radiation exposure was greater than the single-plane group by 37.5% (BP: 172.7±117.9 Gy cm^2 vs SP: 125.6±91.1 Gy cm^2). The radiation dose to the patients was independent of operator experience when angioplasty procedures were performed with single-plane imaging ($p=0.344$) and with biplane imaging ($p=0.204$) (Figure 1c).

The estimated skin dose, cineangiography time and number of cineangiography runs were significantly higher with biplane than with single-plane imaging during primary and elective angioplasty (Table 3), angioplasty of the three main vascular territories (Table 4) and different levels of operator experience (Table 5).

Contrast load

Eight of the 270 angioplasty procedures with biplane and 11 of the 234 procedures with single-plane coronary angioplasty did not have the contrast load recorded. There was a small but non-significant reduction in contrast volume in the 262 procedures with biplane imaging compared with the 223 procedures with single-plane imaging (BP: 166.8±62.9 ml vs SP: 176.8±66.0 ml, $p=0.052$). This non-significant difference was independent of case type ($p=0.068$), vascular territory ($p=0.308$) and operator experience ($p=0.304$).

Biplane versus single-plane imaging in primary and elective angioplasty procedures

There was no significant difference in contrast load between primary and elective angioplasty with single-plane imaging (P: 183.8±66.0 ml vs E: 171.9±65.8 ml, $p=0.188$) or with biplane imaging (P: 161.4±57.5 ml vs E: 171.2±66.9 ml, $p=0.212$) (Figure 2a).

Biplane versus single-plane imaging in the three vascular territories

The contrast load was found to be significantly different among the vascular territories. *Post hoc* comparisons using the Tukey HSD test indicated the average contrast load was significantly higher only in the LAD territory, compared with the RCA territory (LAD: 180.7±62.3 ml vs RCA: 164.6±66.5 ml, $p=0.038$). There was no significant difference in contrast load between biplane and single-plane imaging during angioplasty of the RCA (BP: 160.1±68.4 ml versus SP: 170.2±63.9 ml, $p=0.308$), LAD (BP: 172.5±55.4 ml versus SP: 189.1±68.0 ml, $p=0.060$) and LCX (BP: 169.0±65.1 ml vs SP: 161.4±61.5 ml, $p=0.555$) (Figure 2b).

Biplane versus single-plane imaging with level of operator experience

There was a significant difference in contrast load between the first year registrars and the cardiology fellows/senior cardiologists, but not between first and second year registrars (first year registrars: 186.4±68.7 ml vs cardiology fellow/senior cardiologists: 165.5±58.0 ml, $p=0.021$). In all three operator groups, no significant difference in contrast load was found between biplane and single-plane imaging, first year registrars (BP: 189.1±69.7 ml vs SP: 182.2±68.1 ml, $p=0.652$), second year registrars (BP: 170.5±75.7 vs SP: 195.1±91.1 ml, $p=0.235$) and cardiology fellows/senior cardiologists (BP: 159.9±57.2 ml vs SP: 172.1±58.4 ml, $p=0.055$) (Figure 2c).

Procedural time

The average procedural time with biplane coronary angioplasty was significantly longer than for single-plane angioplasty (BP: 55.3±27.8 min vs SP: 48.9±24.2 min, $p=0.010$). The significant difference was independent of case type ($p=0.226$), vascular territory ($p=0.642$) and operator experience ($p=0.094$).

Biplane versus single-plane imaging in primary and elective angioplasty procedures

Procedural time was not statistically different during primary (P) and elective (E) angioplasty with single-plane imaging (P: 48.5±24.0 min vs E: 49.1±24.4 min, $p=0.835$) or with biplane imaging (P: 51.7±25.3 vs E: 58.1±29.3 min, $p=0.056$) (Figure 3a).

Biplane versus single-plane imaging in the three vascular territories

Biplane angioplasty procedures tended to require a longer procedural time than single-plane in all three vascular territories, but the difference did not reach statistical significance: RCA (BP: 56.5±28.9 min vs SP: 49.5±24.4 min, $p=0.072$); LAD (BP: 54.6±24.4 min vs SP: 50.3±24.6 min, $p=0.216$); LCX (BP: 54.5±31.6 min vs SP: 44.3±22.6 min, $p=0.073$). There was no significant difference in procedural time among the three vascular territories with single-plane imaging ($p=0.367$) or with biplane imaging ($p=0.854$) (Figure 3b).

Table 3. Biplane and single-plane imaging in primary and elective cases

	Single plane	Mean $\pm$ 1SD ^a	n	Biplane	Mean $\pm$ 1SD ^a	n	p level
Displayed skin dose (mGy)	Primary	2009.4 $\pm$ 1227.2	97	Primary	2867.0 $\pm$ 2024.1	118	Primary versus elective Interaction effect p=0.874 0.543
	Elective	2077.6 $\pm$ 1389.8	136	Elective	2750.7 $\pm$ 1851.1	152	
	Total	2049.2 $\pm$ 1322.3	233 ^b	Total	2801.5 $\pm$ 1925.8	270	
	Significance level	Biplane versus single plane p<0.0001					
Fluoroscopy time (min)	Primary	15.4 $\pm$ 11.9	98	Primary	16.6 $\pm$ 11.9	118	Primary versus elective Interaction effect p=0.085 0.485
	Elective	16.6 $\pm$ 13.7	136	Elective	19.4 $\pm$ 13.9	152	
	Total	16.1 $\pm$ 13.0	234	Total	18.2 $\pm$ 13.1	270	
	Significance level	Biplane versus single plane p=0.093					
Cineangiography time (s)	Primary	93.0 $\pm$ 38.1	98	Primary	146.0 $\pm$ 49.8	118	Primary versus elective Interaction effect p=0.013 0.828
	Elective	83.7 $\pm$ 33.8	136	Elective	134.8 $\pm$ 55.4	152	
	Total	87.6 $\pm$ 35.9	234	Total	139.7 $\pm$ 53.2	270	
	Significance level	Biplane versus single plane p<0.0001					
No. of cineangiography runs	Primary	26.2 $\pm$ 9.8	98	Primary	39.0 $\pm$ 12.8	118	Primary versus elective Interaction effect p=0.418 0.551
	Elective	24.7 $\pm$ 8.4	136	Elective	38.7 $\pm$ 15.6	152	
	Total	25.3 $\pm$ 9.0	234	Total	38.8 $\pm$ 14.4	270	
	Significance level	Biplane versus single plane p<0.0001					

n, number of procedures.

^aMean $\pm$ 1 standard deviation (SD).^bOne procedure missing displayed skin dose value.**Table 4.** Biplane and single-plane imaging in angioplasty of the RCA, LAD and LCX

	Single plane	Mean $\pm$ 1SD ^a	n	Biplane	Mean $\pm$ 1SD ^a	n	p level
Displayed skin dose (mGy)	RCA	1901.5 $\pm$ 1058.5	88	RCA	2719.2 $\pm$ 2091.8	108	Vascular territory Interaction effect p=0.503 0.306
	LAD	2224.7 $\pm$ 1501.8	101	LAD	2740.4 $\pm$ 1730.6	105	
	LCX	1940.9 $\pm$ 1333.2	45	LCX	3070.1 $\pm$ 1949.1	57	
	Total	2049.2 $\pm$ 1332.3	233 ^b	Total	2801.5 $\pm$ 1925.8	270	
	Significance level	Biplane versus single plane p<0.0001					
Fluoroscopy time (min)	RCA	17.7 $\pm$ 15.7	88	RCA	19.1 $\pm$ 13.8	108	Vascular territory Interaction effect p=0.193 0.648
	LAD	15.9 $\pm$ 11.5	101	LAD	17.5 $\pm$ 11.6	105	
	LCX	13.6 $\pm$ 9.6	45	LCX	17.8 $\pm$ 14.6	57	
	Total	16.1 $\pm$ 13.0	234	Total	18.2 $\pm$ 13.1	270	
	Significance level	Biplane versus single plane p=0.052					
Cineangiography time (s)	RCA	90.3 $\pm$ 37.9	88	RCA	145.0 $\pm$ 60.9	108	Vascular territory Interaction effect p=0.167 0.574
	LAD	89.3 $\pm$ 36.0	101	LAD	136.3 $\pm$ 44.5	105	
	LCX	78.4 $\pm$ 30.7	45	LCX	135.8 $\pm$ 52.3	57	
	Total	87.6 $\pm$ 35.9	234	Total	139.7 $\pm$ 53.2	270	
	Significance level	Biplane versus single plane p<0.0001					
No. of cineangiography runs	RCA	25.1 $\pm$ 10.0	88	RCA	40.3 $\pm$ 15.9	108	Vascular territory Interaction effect p=0.188 0.458
	LAD	26.3 $\pm$ 8.7	101	LAD	38.5 $\pm$ 12.9	105	
	LCX	23.5 $\pm$ 7.3	45	LCX	36.7 $\pm$ 14.2	57	
	Total	25.3 $\pm$ 9.0	234	Total	38.8 $\pm$ 14.4	270	
	Significance level	Biplane versus single plane p<0.0001					

n, number of procedures.

^aMean $\pm$ 1 standard deviation (SD).^bOne procedure missing displayed skin dose value.

Table 5. Operator experience with biplane and single-plane imaging in coronary angioplasty

	Single plane	Mean $\pm$ 1SD ^a	n	Biplane	Mean $\pm$ 1SD ^a	n	p level	
Displayed skin dose (mGy)	Reg (year 1)	2341.9 $\pm$ 1710.2	35	Reg (year 1)	3156.4 $\pm$ 2153.3	51	Operator experience	p=0.040
	Reg (year 2)	2251.7 $\pm$ 1569.2	37	Reg (year 2)	3068.4 $\pm$ 1768.6	32		
	Fellow/cardiologists	1939.1 $\pm$ 1148.5	161	Fellow/cardiologists	2659.1 $\pm$ 1878.5	187		
	Total	2049.2 $\pm$ 1322.3	233 ^b	Total	2801.5 $\pm$ 1925.8	270		
	Significance level	Biplane versus single plane, p<0.0001					Interaction effect	0.958
Fluoroscopy time (min)	Reg (year 1)	18.3 $\pm$ 11.3	35	Reg (year 1)	24.3 $\pm$ 16.0	51	Operator experience	p=0.001
	Reg (year 2)	17.3 $\pm$ 13.3	37	Reg (year 2)	20.0 $\pm$ 11.2	32		
	Fellow/cardiologists	15.4 $\pm$ 13.2	162	Fellow/cardiologists	16.2 $\pm$ 12.1	187		
	Total	16.1 $\pm$ 13.0	234	Total	18.2 $\pm$ 13.1	270		
	Significance level	Biplane versus single plane, p=0.032					Interaction effect	0.257
Cineangiography time (s)	Reg (year 1)	94.1 $\pm$ 40.0	35	Reg (year 1)	148.8 $\pm$ 43.4	51	Operator experience	p=0.029
	Reg (year 2)	97.4 $\pm$ 42.8	37	Reg (year 2)	147.2 $\pm$ 48.4	32		
	Fellow/cardiologists	83.9 $\pm$ 32.8	162	Fellow/cardiologists	135.9 $\pm$ 56.1	187		
	Total	87.6 $\pm$ 35.9	234	Total	139.7 $\pm$ 53.2	270		
	Significance level	Biplane versus single plane, p<0.0001					Interaction effect	0.946
No. of cineangiography runs	Reg (year 1)	27.7 $\pm$ 11.0	35	Reg (year 1)	40.0 $\pm$ 12.0	51	Operator experience	p=0.297
	Reg (year 2)	25.2 $\pm$ 9.7	37	Reg (year 2)	39.9 $\pm$ 15.7	32		
	Fellow/cardiologists	24.8 $\pm$ 8.4	162	Fellow/cardiologists	38.3 $\pm$ 14.9	187		
	Total	25.3 $\pm$ 9.0	234	Total	38.8 $\pm$ 14.4	270		
	Significance level	Biplane versus single plane, p<0.0001					Interaction effect	0.836

n, number of procedures.

^aMean $\pm$ 1 standard deviation (SD).^bOne procedure missing displayed skin dose value.

Figure 2. Comparison of mean ($\bar{x}$) contrast load with ± 1 standard deviation in biplane and single-plane imaging systems. (a) Contrast volume in primary and elective coronary angioplasty. (b) Contrast load for angioplasty in the three vascular territories. (c) Contrast load with level of operator experience. RCA, right coronary artery; LAD, left anterior descending; LCX, left circumflex.

Figure 3. Comparison of mean ($\bar{x}$) procedural times in biplane and single-plane imaging systems. (a) Procedural time in primary and elective coronary angioplasty. (b) Procedural time for angioplasty in the three vascular territories. (c) Procedural time with level of operator experience. RCA, right coronary artery; LAD, left anterior descending; LCX, left circumflex.

Biplane versus single-plane imaging with level of operator experience

The difference in procedural time among the group of operators was found to be significant ($p=0.001$), with *post hoc* comparisons using the Tukey HSD test indicating a significantly longer procedural time with attending first year registrars than with cardiology fellows/senior cardiologists (first year registrars: 62.2 ± 31.1 min *vs* cardiology fellow/senior cardiologist: 49.5 ± 24.5 min, $p < 0.0001$).

In all three subgroups of operators, biplane imaging required a significantly longer procedural time than compared with single-plane imaging ($p=0.003$) (Figure 3c). Of the coronary angioplasty procedures performed with an attending first year registrar, the biplane subgroup required a procedural time 33.5% longer than the corresponding single-plane subgroup (BP: 69.3 ± 34.7 min *vs* SP: 51.9 ± 21.6 min, $p=0.005$). With second year registrars, the difference between biplane and single-plane was 9.2% (BP: 57.1 ± 26.5 min *vs* SP: 52.3 ± 25.6 min, $p=0.445$). When cardiology fellows/senior cardiologists carried out procedures with biplane imaging, the procedural time was 8.0% longer than procedures performed with single-plane imaging (BP: 51.2 ± 24.6 min *vs* SP: 47.4 ± 24.3 min, $p=0.151$). Although the first year registrars appeared to have a proportionately greater procedural time on biplane relative to single-plane than the other operator groups, the absence of an interaction effect between operator type and the method of imaging ($p=0.094$) suggests that the interaction pattern seen in the sample cannot be safely generalised to the population. The absence of an interaction may be due to the large standard deviation.

Discussion

The use of biplane imaging during single-vessel coronary angioplasty resulted in a 36% increase in radiation dose, a longer procedural time and a small but non-significant reduction in contrast load compared with single-plane imaging. The larger DAP with biplane imaging was due to the greater number of cineangiography runs and their longer duration, as fluoroscopy time was not significantly different between the two imaging modalities.

To the best of our knowledge, this study is the first to document that there is no significant difference in radiation dose and contrast load between biplane and single-plane imaging with the type of angioplasty (primary and elective) and the vascular territory (RCA, LAD or LCX) in which angioplasty was performed. These results did not support the widely presumed advantages of using biplane imaging in single-vessel coronary angioplasty procedures.

The use of biplane equipment involves aligning two planes to position the area of interest within the isocentre of both imaging tubes [4, 34]. However, attempting to align two c-arms to acquire optimal diagnostic images in both planes for every cineangiography run can be cumbersome, particularly in a stressful environment. To facilitate operators, this centre pre-programmed the tube angles commonly used for each vascular territory in the Siemens biplane angiography system. However,

from the researcher's anecdotal observations, the pre-programmed angles did not appear to be ideal for all clinical situations, depending on patient size, pathology and the anatomy of the coronary circulation. The proceduralist often would begin with the pre-programmed angles, perform test injections and then correct the angiographic projection to demonstrate the particular coronary lesion with minimal geometric distortion and with the least overlap of other vessels. Acquiring optimal diagnostic cineangiography runs with biplane imaging may have been more arduous because of restrictions in the proximity of the two X-ray tubes, table height, patient size, surrounding medical equipment and ceiling-mounted monitors [34]. These factors were seen to be particularly relevant in critically ill, intubated or obese patients, and thus perhaps contributed to the larger number of cineangiography runs with accompanying increase in contrast load required with biplane angioplasty procedures. The potential impact of these factors in the choice of single or biplane imaging would warrant further study.

Furthermore, if operators were not completely at ease with the use of biplane equipment, procedural time was further prolonged. Conversely, operators who elected to use single-plane (with no pre-programmed angles) appeared to find it easier to manoeuvre a single c-arm during coronary angioplasty procedures.

A common dose reduction technique reported in the literature for both patients and operators is the avoidance of steep LAO with cranial-caudal angulations whenever possible, as large exposure factors are selected for oblique angulations [27, 35]. Kuon and colleagues [25, 26] reported a 2.5-fold increase in DAP with the typical cranial LAO $60^\circ/20^\circ$ angulation for visualisation of the bifurcation into LAD and diagonal compared with the cranial posterior-anterior (PA) $0^\circ/30^\circ$. Kuon et al [25] suggested substituting the PA caudal LAO projection for the cranial PA for the proximal LAD region and the caudal PA for the distal left main stem bifurcation. Implementing these into clinical routine may not be as effective or possible with biplane equipment, as the corresponding lateral plane would always be set in an orthogonal projection from the less radio-intensive tube angle. Conversely, single-plane imaging would avoid this predicament. The difficulty in avoiding steep tube angulations may further clarify why biplane imaging delivered a greater radiation exposure than single-plane irrespective of vascular territory, case type and operator experience.

The average DAP of 158.2 Gy cm^2 found in this study is within the range reported in the literature ($28.5\text{--}370.6 \text{ Gy cm}^2$) [24, 36–41], but higher than the reference dose level of 75 Gy cm^2 established by the European Cardiology research programme DIMOND [37]. A 300 Gy cm^2 threshold has also been set for probable induction of skin injury by the European DIMOND research programme. Several factors may have contributed to the greater DAP recorded in this study. Of the 504 coronary angioplasty procedures, 92% were performed with a cardiology trainee present, which would have a tendency to increase the procedural time (Figure 3c). The average DAP reported in this study included results from procedures carried out with biplane imaging, delivering a radiation exposure 36%

greater than single-plane angioplasty. The range of reported DAP values in the literature often did not specify whether biplane or single-plane imaging was used or report the level of operator experience. Therefore, comparison of DAP measurements with other reported studies is not possible. Several studies also report DAP values from angiography systems with image intensifiers [27, 38–40, 42, 43], as opposed to the flat-panel detector technology utilised in this study. The introduction of flat-panel technology has been promoted to eliminate veiling glare and to improve spatial resolution [44, 45]; however, its effect on radiation dose has been controversial. Flat-panel detectors are purported to have better detector quantum efficiency (DQE), and are therefore able to reduce radiation dose to the patient [46, 47]. Clinical studies have shown that digital flat-panel systems produce images at similar or higher quality than conventional imaging intensifiers, although some studies reported no significant difference in the radiation exposure delivered between flat-panel detectors and conventional image intensifiers [47, 48]. However, Prasan et al [49] and Tsapaki et al [50] found a greater radiation exposure with flat-panel detectors: Prasan and colleagues [49] reported a 35% difference when compared with image intensifiers.

Recommendations to reduce the contrast load in coronary angioplasty include minimising the number and length of cineangiography runs, avoiding ventriculograms, using smaller sized catheters and staging diagnostic and interventional procedures [7, 21]. In practice, these guidelines may be difficult to follow, as these interventional procedures are highly dependent on the operator and the clinical condition of the patient [28, 34]. On the other hand, the use of biplane equipment was assumed to be a practical measure to significantly reduce contrast load when compared with single-plane equipment [1, 5–7, 12, 18, 23]. The study by Sadick et al [14] reported a small but significant reduction in contrast load with biplane imaging, compared with single-plane imaging, in a much larger group of patients undergoing diagnostic coronary angiography. This study showed that there was a small but non-significant reduction in contrast load with biplane imaging (BP: 166.8 ± 62.9 ml *vs* SP: 176.8 ± 66.0 ml, $p=0.052$). This result may have reached statistical significance with a larger sample size. The non-significant difference in contrast load found between the two imaging techniques was independent of vascular territory and case type (primary or elective). This is of significant concern, as there are very limited innovative prophylactic therapies established for CIN in patients undergoing primary coronary angioplasty [22, 51].

The ICRP (International Commission on Radiological Protection) that has stated “it is particularly important that individuals performing these procedures are adequately trained in both clinical techniques and knowledge of radiation protection” [52]. Justino [34] also raised the concern that adequate training in the proper use of the equipment is vital so that radiation safety strategies in biplane imaging can effectively reduce radiation dose to the patient. No significant difference was found in the DAP between procedures performed by first year registrars and those performed by the more senior cardiologists within the subgroup of single-plane and biplane angioplasty procedures. The first and second

year registrars often required the assistance of the supervising cardiologists in performing the procedure. The radiation dose record would therefore be biased towards a lower dose and unlikely to reflect the dose incurred if the procedure had been done solely by the registrars themselves. The differences between the three groups would therefore be more difficult to detect. Furthermore, there may have been variations in the training of the senior cardiologists, whereas at other centres, radiation exposure may or may not be under their control. Arthur et al [30] proposed that, without adequate training to control radiation exposure, cardiologists in training may progress to the consultant stage and bypass the learning curve necessary to reduce radiation doses.

Alternatively, more complicated procedures, such as primary angioplasty procedures, might have been assigned to the more senior cardiologists in this study. The American Association of Physicists in Medicine (AAPM) reported that an angioplasty of a totally occluded artery results in a 50% increase in fluoroscopy time compared with an angioplasty of a subtotal stenosis [53]. Either way, in evaluating the procedural time in the subgroup of single-plane angioplasty procedures, there was a tendency for operators to take a longer time to become proficient with biplane imaging (Figure 3c). Furthermore, the greater radiation exposure delivered with biplane imaging was independent of operator experience.

Clinical implications

The presumed advantages of biplane imaging have led to more widespread use among many cardiac catheter laboratories, with operators assuming that the use of biplane will reduce radiation dose and contrast load and shorten procedures. As a result, operators frequently prefer to use biplane imaging for patients with pre-existing renal impairment, those who are more radio-sensitive, such as children, or in critically ill patients during primary angioplasty procedures [13, 23]. The findings in this study emphasise the need for an increased awareness of radiation dose and contrast load during coronary angioplasty procedures. The results in this study suggest that the preferred imaging modality should be single-plane rather than biplane imaging for single-vessel coronary angioplasty procedures. Our findings, however, should not be extended to more complex interventional procedures, such as multivessel/vein-graft angioplasty or radiofrequency ablations, for cardiac arrhythmias.

Limitations

The actual recording of the data was not monitored at all times by the researchers. Therefore, the results are based on the assumption that information was accurately recorded in CARDS and the clinical reports. All procedures were performed with a senior cardiologist, although the procedures by classified according to the least experienced operator present. The degree of assistance from the senior cardiologists in each procedure was variable. Moreover, operators were not

randomised in the use of biplane or single-plane imaging, and this could also have biased the results. Finally, this study investigated single-vessel coronary angioplasty procedures undertaken at a single large teaching hospital, and the findings cannot be generalised across all interventional cardiac procedures and other cardiac catheter laboratories.

The radiation measurements presented on the examination protocols (dose rate, skin dose and DAP) were not corrected for table-top attenuation. Consequently, the correct DAP and skin dose to the patient may be lower than the values reported in this study (Appendix 1).

Conclusion

This study found the use of biplane imaging to impart a significantly greater radiation exposure to the patient and to require a longer procedural time. The contrast load between biplane and single-plane angioplasty procedures was not found to be significantly different. These results were independent of whether the procedure was a primary or elective case, whether the angioplasty was performed in the RCA, LAD or LCX territory or on the level of operator experience. The findings of this study illustrate that biplane may not be as effective as previously assumed in reducing radiation dose, contrast load and procedural time in single-vessel coronary angioplasty procedures.

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Appendix 1

Measurement of table attenuation — Siemens Axiom Artis dBC

As interventional cardiology procedures are performed in a posteroanterior projection, it is important to acknowledge the degree of table attenuation with the radiation measurements provided on the Siemens Axiom Artis dBC angiography system. Dose-area product (DAP) meters are a common, readily available method of providing a patient dose index and are commonly harnessed within the X-ray unit. The cumulated DAP for a procedure is a surrogate measurement for the total amount of X-ray energy delivered to the patient.

Frequently, DAP meters were not found to account for table attenuation [48, 54], consequently the correct DAP and skin dose to the patient may be lower than the values reported in this study. A solid-state detector was used to determine the table-top attenuation at various tube angulations.

Method

The degree of table attenuation was measured with an Unfors Xi (solid-state detector) taped on 1 mm of copper on the front of the flat-panel detector. Focus to flat-panel detector distance was set at 100 cm.

The dose rate was firstly measured in air, noting the kilovolts, milliamperes and autotest filtration. The table was then repositioned within the c-arm, and the dose rates were remeasured at 0°, 30° and 60° with similar kilovolts and milliamperes as the first measured dose rate in air (Table A1).

Results and conclusion

The tube angulation of 0° measured an average of 11% degree of table attenuation, LAO and RAO 30° measured an average degree of table-top attenuation of 11% and LAO and RAO 60° found an average 23% degree of table attenuation (Table A1).

Not all clinical angles used during coronary angioplasty were incorporated, and thus further investigation may be warranted.

Table A1

Angulation (degrees)	Table IN/OUT	kVp	mA	HVL	Dose rate (μGy s ⁻¹)	Average		Normalised ^b		Table attenuation
						mA	Dose rate (μGy s ⁻¹)	Dose rate (μGy s ⁻¹)	Dose rate (μGy s ⁻¹)	
0	Table OUT	66	74	6.09	14.45	74	14.5	19.5	11%	
	Table IN ^a	66	85	6.02	14.74	84.5	14.7	17.4		
LAO 30	Table OUT	66	84	6.03	14.72					
		66	72	5.92	13.63	72	13.8	19.1	12%	
	Table IN ^a	66	72	5.91	13.88					
		66	85	6.16	14.29	84.5	14.2	16.8		
RAO 30	Table OUT	66	74	5.92	14.13					
	Table IN ^a	66	74	5.92	14.08	74	14.1	19.0	10%	
LAO 60	Table OUT	66	86	5.97	14.71	86	14.7	17.1		
	Table IN ^a	66	71	5.87	13.63	71	13.6	19.2	24%	
RAO 60	Table OUT	66	92	6.32	13.5	92	13.5	14.7		
	Table IN ^a	66	73	5.86	14.2	73	14.2	19.5	22%	
		66	94	6.01	14.26	94	14.3	15.2		

^aThe mattress was not included when the dose was measured. Separate measurements indicate an approximate 10% attenuation by the mattress in addition to the table using vertical beam projection.

^bNormalised to 66 kVp 100 mA.

HVL, half-value layer; RAO, right anterior oblique; LAO, left anterior oblique.