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FULL PAPER

Bi-plane and single plane angiography: a study to compare contrast usage and radiation doses for adult cardiac patients in diagnostic studies

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Objective: This study compares the performance of bi-plane coronary angiography against single plane angiography in terms of the volume of contrast used (ml) and the total dose-area product (DAP) (μGym^2) to the patient measured directly via flat panel detectors.

Methods: A total of 5176 adult diagnostic cardiac angiograms from a hospital in Brisbane, Australia were retrospectively studied. Patients with aortograms, iliac or femoral artery imaging, and stenting or graft interventions were excluded. Student's *t*-tests were used to compare means, and confounding variables were compared using multivariate regression. This quantified the effects of bi-plane system use holding constant other factors (e.g.) body mass index (BMI), age, room, sex, number of digital acquisitions and fluoro time.

Results: Bi-plane imaging had an average difference in mean contrast use of -15.1 ml [15.5% 95% confidence interval (CI) $(-13.2, -17.0)$ $p < 0.001$], multivariate regression demonstrated a -27.0 ml reduction in contrast use [28% 95% CI $(-29.0, -24.83)$ $p < 0.0001$] when the significant effects of fluoro time, number of digital acquisitions,

BMI and sex were held constant. Bi-plane imaging had an average difference in mean DAP of $+887.1 \mu\text{Gym}^2$ [23% 95% CI $(+1110.7, +663.4)$ $p < 0.001$], whilst multivariate regression found a $+628.3 \text{Gym}^2$ increase in DAP [16% 95% CI $(+467.5, +789.3)$ $p < 0.001$] when the significant effects of fluoro time, number of digital acquisitions, BMI and sex were held constant.

Conclusion: These results demonstrate that bi-plane imaging uses less contrast media than single-plane imaging for coronary angiography at the expense of more radiation. Bi-plane imaging may be preferable in patients with renal impairment, however single plane imaging may be preferable in those without renal impairment.

Advances in knowledge: This is a large cohort and statistically comprehensive study comparing bi-plane and single plane coronary angiography. Other studies 4, 5, 6, 12 have used Student's *t*-tests to measure the difference between means, however this provides no causative information on the differences found. This study provides a view of the causative impact of bi-plane usage on DAP and contrast use via multivariate regression modelling.

INTRODUCTION

Coronary angiography is considered to be the gold-standard for assessing coronary artery disease.^{1,2} This common procedure is performed using X-rays and an intravenously injected X-ray opaque contrast dye (contrast media).^{3,4}

X-rays are known to have stochastic and deterministic cancer-causing effects^{1,3,5-7} and concern has been growing regarding radiation doses and adverse radiation effects in procedures.^{8,9} Reduced radiation doses are also important in reducing the scattered radiation exposure risk to staff.^{1,2,7,9} Contrast usage has also been linked to contrast-induced

nephropathy (CIN)^{1,3,5,6,10} and renal failure.¹¹ For these reasons, radiation dose and volume of contrast used are sought to be minimized in cardiac angiography.^{2,4-6}

Standard cardiac imaging approaches utilize either single or bi-plane (dual) acquisitions. Single-plane acquisitions visualize the coronary arteries in two orthogonal planes via a single X-ray source and detector in a sequential manner, via two separate X-ray exposures and contrast injections.⁴⁻⁶ Conversely, bi-plane acquisitions utilize two identical X-ray sources and detectors (typically named A Plane and B Plane) and use a sequence of pre-defined angulations to

visualize each coronary artery in orthogonal planes using only one contrast injection⁴⁻⁶ per coronary artery.

The first aim of this study was to determine whether any differences in radiation dose and contrast use was evident between bi-plane and single plane imaging for non-complex adult diagnostic angiograms. The second aim was to determine if there are other factors that contribute to patient dose and contrast use, *e.g.* body mass index (BMI), sex, age and entry approach (radial or femoral artery).

Previously published studies^{2,4-6,12} have compared bi-plane and single plane systems and used Student's *t*-tests to compare means of bi-plane and single plane patient groups in coronary angiography. This study reproduces this approach using data from a previously unreported hospital site. Additionally, this study provides new research using multivariate regression modelling to investigate the contribution of the imaging method chosen (*i.e.* Bi-plane *vs* single plane) on the contrast volume used and radiation dose, whilst allowing for other factors.

METHODS AND MATERIALS

Imaging system

Two identical Siemens Axiom Artis dBC (Siemens healthcare GmbH, Erlangen, Germany) units of near same physical age (within 3 months of each other) were installed in adjacent cardiac catheter laboratory rooms (labelled Room1, Room2) at the hospital for the duration of this study. Both units had identical flat panel detector technology, with identical Dose Area Product (DAP) meters mounted in the X-ray tube housings calibrated annually. There were manufacturer system upgrades made to the software of both machines, as is normal practice during the study timeframe, but these did not affect the image acquisition aspects of the machines. There were no complete system upgrades during the study period.

Frame rates for cardiac angiography are routinely set to 10 pulses per second for fluoroscopy and 15 frames per second for digital acquisition on both systems.

Imaging procedure

Diagnostic coronary angiograms are generally performed using standardized sequences at the hospital for both bi-plane and single plane studies. The c-arm geometry and collimators were operated by trained registered cardiac radiographers who were regularly rostered between each room. The catheterization, fluoroscopy operation and digital acquisition operation was performed by trained and licensed cardiologists. The table was also moved into position by the cardiologist. The dicom image file for each examination includes a record of the specific angle used for each projection.

Studies generally follow the following angulation sequences:

Single plane studies

LAO (left anterior oblique) cranial, RAO (right anterior oblique) caudal, RAO cranial, AP cranial and LAO caudal angulations for the left coronary artery, and LAO, LAO cranial and RAO for

the right coronary artery. Left ventriculography is performed for the assessment of left ventricular function and is performed in the RAO projection for single plane studies where clinically necessary.

Bi-plane studies

For the left coronary artery, three views are performed: (1) LAO cranial-A plane, RAO caudal-B plane; (2) left lateral-B plane, AP cranial-A plane; (3) RAO cranial-A plane, LAO caudal-B plane. For the right coronary artery, two views are performed: (1) RAO-A plane; LAO-B plane; (2) left lateral-B plane, AP cranial-A plane. The left ventriculogram is performed in two views: LAO-B plane and RAO-A plane where clinically required.

Data sources

This was a single centre study performed in a tertiary cardiac hospital in Queensland Australia, using angiography data obtained from a prospective cardiac catheter laboratory database. It included all diagnostic coronary angiograms performed between 2010 and 2015. The data entries were de-identified and accessed by the researchers as a database of measured values for each diagnostic coronary angiography study that met the inclusion criteria.

Study size & design

Inclusion and exclusion criteria were chosen to obtain a set of examinations for analysis that were similar to each other, achievable by all operators, and non-complex in nature. These examinations were routinely performed in both rooms, with the operators and radiographers changing between rooms on a daily basis, with no pre-selection of any kind. The choice between bi-plane and single plane was chosen on the day of each procedure by the cardiologist. The inclusion criteria was: Adult patients (≥ 18 years) who had a diagnostic study of both coronary arteries and left ventriculography. Studies that included right ventriculography, aortograms, femoral or iliac artery angiography, radial artery angiography, coronary artery bypass graft imaging, interventional procedures (*e.g.* stenting) and paediatric cases (< 18 years) were excluded. Studies with incomplete or missing data fields, or that were performed on non-identical machines were also excluded, as were studies that were a mixture of bi-plane and single plane imaging.

Variables

The variables used in this study were: study date, sex (M/F), contrast volume (ml), DAP($\mu\text{Gy m}^2$), fluoroscopy time (min), number of digital acquisitions (termed "runs"), access (right femoral, right radial, left femoral, left radial, right brachial), plane (single plane, bi-plane), room (1, 2), age (years), height (cm), weight (kg). Patient BMI was subsequently calculated post-hoc for each patient for use in the analysis.

DAP was used as the primary measure of radiation exposure in accordance with guidelines published by the International Commission on Radiological Protection.¹³

Statistical methods

Independent samples *t*-tests were performed to compare means between various characteristics for bi-plane vs single plane, and also for Room 1 vs Room 2. The Student's *t*-test was used in comparable published studies^{2,4-6,12} and is said to be robust to variability in data normality in large public health datasets.¹⁴ A *p* value of 0.05 was used to determine statistical significance.

Two separate multivariate regression models were performed using DAP and contrast volume (ml) as outcome variables. For each regression, a full model was initially produced using all continuous and categorical variables from the extracted database data as explanatory variables. Each model was then refined using backwards-stepwise refinement with all variables and interactions being statistically significant at $\alpha=0.05$. Each model was tested for parsimony and multicollinearity. No multicollinearity was found in either model, and explanatory variables that did not substantially contribute to the R^2 value of the model were removed. The residuals of each model were tested for normality. The contrast volume regression residuals were normally distributed, however the DAP regression showed residuals with increasing variance when plotted. The DAP model was subsequently refined using a square root ($\sqrt{\cdot}$) transformation of the outcome variable (DAP). The residuals of the refined model were normally distributed, with no change in statistical significance or polarity of the explanatory variables compared with the initial un-transformed regressions.

Statistical analysis was performed using IBM SPSS v. 22.

ETHICS APPROVAL

The facility's Human Research Ethics Committee (HREC) approved the research protocol for this research, approval HREC/16/QPCH/82.

RESULTS

Of the 11,800 diagnostic procedures performed in the study timeframe, 5176 met the inclusion criteria. 4554 were single plane (88%) and 622 were bi-plane (12%). There were 3067 male patients (59.25%) and 2109 (40.75%) female patients. Room 1 was used for 2660 (51.4%) procedures and Room 2 was used for 2516 (48.6%).

Differences in means for bi-plane vs single plane

The student's *t*-tests demonstrated that on average the contrast volume used in bi-plane mode was 15.1 ml less (−15.5%) than in single plane mode [$t_{5176} = 15.7$, 95% CI (−13.23, −17.00 ml), $p < 0.001$ (Figure 1)]. DAP was 887.1 higher (+23.1%) in bi-plane mode [$t_{5176} = -7.8$, 95% CI (663.42 1110.70 μGym^2) $p < 0.001$] (Figure 2) than in single plane mode. The number of digital acquisitions was 2.77 higher (+26.6%) in bi-plane mode [$t_{5176} = -27.4$, 95% CI (2.57, 2.97), $p < 0.001$] and the fluoroscopy time was 0.75 min higher (−17%) in bi-plane mode [$t_{5176} = 5.7$, 95% CI (−0.49, −1.01), $p < 0.001$] compared to single plane mode. Patient BMI was on average 1.31 lower in the bi-plane group compare to single plane (29.06 vs 30.37, $p < 0.001$, respectively). The patients in the bi-plane group were on average 3.4 years

Figure 1. Bi-plane ($n = 4554$) and single plane ($n = 622$) mean contrast volumes, bi-plane mean = 82.6 ml (SD = 22.9), single plane mean = 97.7 ml (SD = 22.4), Difference in mean (15.1 ml) significant $p < 0.0001$, 95% CI (13.2,17.0). CI, confidence interval; SD, standard deviation.

older than the single plane group (66.1 vs 62.7 years, $p < 0.001$, respectively), (Table 1).

Differences in means for Room1 vs room 2

There was a statistically significant difference in means using the two samples student's *t*-test for DAP ($t_{5176} = -4.97$, $p < 0.001$)

Figure 2. Bi-plane ($n = 4554$) and single plane ($n = 622$). Mean DAP, bi-plane mean = 4727.0 μGym^2 (SD = 2704.3), single plane mean = 3839.9 μGym^2 (SD=2358.0), Difference in means (887.1 μGym^2) significant $p < 0.000195\%$ CI: 663.4,1110.4. CI, confidence interval; DAP, dose-area product; SD, standard deviation.

Table 1. Difference in means between bi-plane and single plane for various characteristics

Characteristic	Single-plane <i>n</i> = 4554 (88%)	Bi-plane <i>n</i> = 622 (12%)	Difference in means	<i>p</i> -value (independent samples student's <i>t</i> -test)	95% confidence interval
Fluro Time (min)	3.65 (3.06 ^a)	4.40 (3.13 ^a)	-0.75 (-17.0%)	<0.001 ^c	-0.49, -1.01
Contrast Vol (ml)	82.58 (22.90 ^a)	97.69 (22.41 ^a)	-15.11 (-15.5%)	<0.001 ^c	-13.23, -17.00
DAP (μGym ²)	4726.97 (2704.25 ^a)	3839.91 (2358.00)	887.06 (+23.1%)	<0.001 ^c	1010.70, 663.42
Number of digital acquisitions (runs)	13.18 (2.45 ^a)	10.41 (1.61 ^a)	2.77 (+26.6%)	<0.001 ^c	2.97, 2.57
Age (yrs)	66.06 (12.10 ^a)	62.70 (11.71 ^a)	3.38 (+5.4%)	<0.001 ^c	4.37, 2.4
BMI	29.06 (5.41 ^a)	30.37 (6.95 ^a)	-1.31 (-4.3%)	<0.001 ^c	-0.84, -1.78

^aMean (Standard Deviation).^bEqual Variances Assumed. Levene's Test of Equal Variances > 0.05.^cEqual Variances Not Assumed. Levene's Test of Equal Variances < 0.05.

between Room 1 and Room 2. On average, the DAP in Room 2 was 334.1 μGym² higher (+8.1%) than Room 1 [95% CI (465.86, 202.23)]. All other variables had differences between Room 1 and Room 2 that were either not statistically significant, or statistically significant but of negligible impact (Table 2).

Multivariate regression models

The coefficients of determination for the DAP and contrast volume models were 0.677 and 0.412 respectively.

There is evidence ($p < 0.001$) to suggest that using the bi-plane system in diagnostic coronary angiograms in adults at this hospital reduces the amount of contrast used on average by 26.89 ml (-27.9%) [$t = -25.52$, 95% CI (-28.96, -24.83), $p < 0.001$], and increases the average DAP by 628.32 μGym² (+15.9%) [$t = 7.65$, 95% CI (467.34, 789.3), $p < 0.001$], allowing for the effects of time, runs, BMI and sex being held constant.

Comparisons to the literature

Comparisons with the literature are demonstrated in Table 3.

DISCUSSION

This is the largest and most statistically comprehensive study of its kind to compare bi-plane and single plane angiography. Other studies^{4-6,12} have used Student's *t*-tests to identify the presence of a statistical difference between means, however this provides no causative information on the differences found. This study provides a view of the causative impact of bi-plane usage on DAP and contrast use via comprehensive statistical analysis.

There were a number of results in this study that are broadly similar to the findings of other studies.^{2,4-6} The number of males was higher than females; the number of digital acquisitions (runs) with bi-plane use was higher, whilst the total overall fluoroscopy time for bi-plane use was slightly higher. The fluoroscopy time increase has been attributed to more complex set-up procedures for bi-plane imaging⁴⁻⁶ requiring the target vessels to be placed within the iso-centre of the machine.

Other published studies have broadly found an increased DAP and reduced contrast use for bi-plane use.^{2,4-6,12} The results of

Table 2. Difference in means for between Room 1 and Room 2 for various characteristics

Characteristic	Room 1 <i>n</i> = 2660 (51.4%)	Room 2 <i>n</i> = 2516 (48.6%)	Difference in means	<i>p</i> -value (independent samples student's <i>t</i> -test)	95% confidence interval
Fluro time (min)	4.00 (2.97 ^a)	4.62 (3.26 ^a)	-0.62 (-13.4%)	$p < 0.001^c$	-0.79, -0.45
Contrast vol (ml)	95.16 (23.53 ^a)	96.63 (22.41 ^a)	-1.47 (-1.5%)	0.021 ^c	-2.73, -0.22
DAP (μGym ²)	3784.13 (2342.20 ^a)	4118.18 (2487.04 ^a)	-334.05 (-8.1%)	<0.001 ^c	-465.86, -202.23
Number of digital acquisitions (runs)	11.00 (2.05 ^a)	10.48 (1.80 ^a)	0.51 (+5.0%)	<0.001 ^c	0.41, 0.62
Age (yrs)	63.19 (11.91 ^a)	62.98 (11.70 ^a)	0.21 (+0.3%)	0.53 ^b	-0.44, 0.85
BMI	30.07 (6.63 ^a)	30.36 (6.97 ^a)	-0.29 (-1.0%)	0.13 ^b	-0.66, 0.08

BMI, body mass index; DAP, dose-area product;

^aMean (Standard Deviation).^bEqual Variances Assumed. Levene's Test of Equal Variances > 0.05.^cEqual Variances Not Assumed. Levene's Test of Equal Variances < 0.05.

Table 3. Table comparing results against other relevant studies

Dose area product					
Year	Author	Study Size (n=)	Change in DAP for Bi-plane usage	Statistical method used	Significance level
2012	Gretch et al ²	463	+73.4%	None stated	None stated
2010	Sadick et al ⁶	504	+35.8%	Student's <i>t</i> -test	$p < 0.001$
2013	Lin et al. ⁴	602	+16.8%	Student's <i>t</i> -test	$p < 0.001$
2018	This study	5176	+15.9%	Multivariate Regression Model	$p < 0.001$
2012	Ho-Ping et al ⁵	147	-1.3%	Student's <i>t</i> -test	None stated
Contrast use					
Year	Author	Study Size (n=)	Change in contrast vol for Bi-plane usage	Statistical method used	Significance level
2008	Sadick et al ⁵	1156	-5.5%	Student's <i>t</i> -test	$p < 0.001$
2010	Sadick et al ⁶	504	-5.6%	Student's <i>t</i> -test	$p = 0.052$
2012	Gretch et al ²	463	-27.0%	None stated	None stated
2018	This study	5176	-28.0%	Multivariate Regression Model	$p < 0.001$
2012	Ho-Ping et al ¹²	147	-39.8%	Student's <i>t</i> -test	$p < 0.001$

this study concur with these findings. Table 3 places the results of this study in the context of the findings of other studies. A recent study¹⁵ has supplemented these findings by also demonstrating an increase in radiation dose to the operator when using bi-plane angiography.

Contributing to the higher DAP result for bi-plane studies could be the three extra digital acquisitions routinely performed within the standard protocol in use at the Hospital. These extra digital acquisitions contribute to an extra radiation dose. The lower contrast usage for bi-plane use suggests that the theoretical benefits of the bi-plane system itself are achievable in practice. On average bi-plane studies used 28% less contrast than single plane studies, taking into account the effect of other variables (fluoroscopy time, number of runs, age, sex). This result confirms that bi-plane system use is justified where reduced contrast load to the patient is important, as is the case for patients with reduced renal function.

The radiation dose to males compared to females has been reported to be higher in published literature⁴ and this study confirmed an average increase of 1536 μGym^2 in DAP for male patients compared to female patients. Lin et al³ suggests that this is likely due to increased patient size in males. Analysis of the data identified that males were on average 12.95 kg heavier than females in this study ($p < 0.001$) which supports this suggestion. Male BMI, however, was lower when compared to females (male 30.0 vs female 30.5, $p < 0.02$).

Entry approach (surgical site) and patient age were found to be non-significant to radiation dose and contrast use while performing the multivariate regression analysis. However, other variables were found to be significant including number of digital acquisitions, fluoroscopy time, BMI, sex and plane (bi-plane vs single plane).

An 8.1% difference in DAP between Room 1 and Room 2 was identified. This is likely to be a result of calibration tolerances for each unit. Room utilisation (Room 1, Room 2) was not significant in the multivariate regression model for DAP ($p = 0.237$) and contributed only 0.005 to the R^2 value of the model.

Creatinine levels post-angiography procedures were not recorded in this study. This did not allow the incidence of CIN to be determined, and made it difficult to directly assess the impact of contrast administration during angiography to patient mortality. Renal failure can increase the likelihood of death from pre-existing non-renal conditions, or alternatively increase the chance of non-renal conditions developing if they are not already present.¹¹ Acute renal injury is however vitally important to consider in coronary examinations, and other structural interventions eg. Transcatheter Aortic Valve Implantation.

Bi-plane and single plane systems are commonly used for diagnostic and interventional cases in a wide range of procedures including neurological, hepatobiliary, renal and vascular cases, with variations in DAP existing within these examination types.^{8,9} In the specific area of neuroangiography interventions

(as a whole category), Johnson *et al*⁸ found bi-plane systems had a lower (−37.5%) mean DAP for interventional cases, whilst conversely for the specific case of endovascular stroke treatment, DAP for bi-plane use was almost 80% *higher* than of single plane.¹⁶ Friedrich *et al*¹⁶ pointed to the possibility of this increase being due to long periods of biplane screening during neurology interventions. Diagnostic cardiac angiography in comparison does not usually involve long periods of biplane screening, as the image acquisition sequences are relatively short (typically 10 s maximum), with biplane screening only occurring for short periods to place the target vessels in the iso-centre of the machine. Understanding the performance of bi-plane technology in the broader clinical realms is important, however, making cross comparisons around DAP between realms should be done with caution, as the same technology is often used in fundamentally different procedural methods.

Consideration must also be given to the cost of bi-plane systems from a value/benefit standpoint, as they are often 20% higher in price than single plane systems, with their benefits often only being derived from the perceptions of clinicians and other staff¹⁷ in the absence of a large body of direct clinical research into the technology. Bi-plane systems have been suggested to be more difficult to use, due to complex adjustments required of both X-ray tubes,^{4–6} and additional training in biplane imaging specific for cardiology has been suggested.⁴ This will add to their effective organisational costs. There is a paucity of studies that have directly measured the performance of biplane systems in the cardiology setting, and this study has aimed to improve knowledge in this area.

Clinical implications

CIN is a potential complication of angiogram studies^{1,5,6} and it is important to reduce this risk where possible. This study has shown that using bi-plane imaging has the potential to reduce patient contrast load by 28%, which would be of benefit to patients with renal impairment. However, this benefit has been shown to come at a cost of increased radiation dose (+16% DAP).

Radiation exposure has cumulative stochastic adverse effects including cancer risks^{1,4,7} and minimising the radiation exposure of patients and staff is a high priority in angiography procedures.^{1,2,4–7}

Bi-plane angiography can be beneficial in many other types of cardiac procedures, including electrophysiology, percutaneous coronary intervention of complex lesions, particularly chronic total occlusions and also structural cardiac intervention, and complex procedures.¹⁵ However, for patients with no identified renal impairment this study demonstrates that for diagnostic coronary angiography, it may be preferable to perform diagnostic angiogram studies in single-plane mode to reduce the overall radiation dose to the patient and staff. Bi-plane angiography should be utilised where renal insufficiency suggests a lower contrast burden for the patient is prudent to reduce the risk of CIN, with outcome data continuing to be collected to optimise clinical protocols and radiation dose as suggested by Bellemare *et al*.¹⁸

Limitations

A limitation of this study is that it was performed at one site only. The study size was very large, however, and the results of this study are likely to be valid for other sites that follow similar imaging sequences for bi-plane and single plane studies.

Another limitation is that the R^2 values on the multivariate regression models were low ($R^2 = 0.41$ for contrast volume, $R^2 = 0.68$ for DAP) which suggests that additional factors may be present that are unaccounted for in the models. Other variables studied in the literature which are not included in this study are clinician experience^{4,6} and procedural complexity (measured in number of catheters used).^{2,4,7} There were a variety of users between rooms 1 and 2 over the duration of the study, with varying amounts of experience. Unfortunately, no specific data were available to take different users into account on this study. The effect of user experience is mitigated to an extent by the choice of study for inclusion being simple diagnostic angiogram studies that were expected to be readily achievable by all operators.

Clinician experience would have varied around an average in the 5-year duration of this retrospective study, with a core set of experienced clinicians providing the foundation of clinical skill at the site. Being unable to take into account different users in this study also meant that we were unable to analyse whether particular operators (and/or their experience level) changes the likelihood of bi-plane being used for a procedure. This is a potential confounder to the results of this study.

Another limitation is that the study was retrospective in nature, and therefore had no randomization of participants.

CONCLUSIONS

This study has used multivariate regression to show that bi-plane imaging can reduce patient contrast loads on average by 28%. This study has shown the contrast load reduction occurs at a cost of +16% increase in DAP, when other statistically significant factors in the models are held constant [*i.e.* fluoroscopy time, number of digital acquisitions (runs), BMI and sex]. Bi-plane imaging would therefore be of benefit in the management of patients with renal impairment to help avoid contrast-induced nephropathy. Radiation dose however does have stochastic and deterministic harmful effects, and single plane imaging reduced patient dose by 16% compared to bi-plane imaging and should be preferred where patient renal function does not suggest a reduced contrast load is necessary. This would also reduce scattered radiation doses to operators and other staff in the room.

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