Original Studies

A Comparison Between Dual Axis Rotational Coronary Angiography and Conventional Coronary Angiography

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Background: Coronary angiography remains the gold standard for the investigation of coronary artery disease, and is carried out in multiple, predefined stationary views, at different angulations around the patient, for both left and right coronary arteries. Dual axis rotational coronary angiography (DARA) is an alternative technique wherein the c-arm rotates around the patient in a preprogrammed single acquisition, exposing the entire coronary artery at different angulations. The DARA system has been recently installed in the Cardiac Catheterisation Suite at Mater Dei Hospital, Malta, where a monoplane and a biplane machine are available. This study was carried out in order to compare DARA with conventional single and biplane coronary imaging, with respect to radiation dose, contrast loads, and procedure time. Methods: This study was carried out over the period from September to December 2010. Four hundred sixty-three patients were studied. Patients referred for the investigation of native coronary anatomy, for whatever indication, were consented and included, and randomly assigned to one of four groups depending on which machine and modality was used: monoplane conventional, monoplane DARA, biplane conventional, and biplane DARA. Results: DARA was statistically significantly superior in dose area product, fluoroscopy time, amount of contrast used, and procedure time. These reductions ranged between 12 (contrast used) and 71% (procedure time). Conclusions: The advantages of such systems are obvious to both patient and healthcare provider, and DARA may prove to be an important and useful tool in the refinement of diagnostic coronary angiography by reducing patient contrast and radiation doses and reducing procedure time. © 2011 Wiley Periodicals, Inc.

Key words: adult; coronary artery disease; coronary angiography; image processing; computer-assisted; whole-body irradiation; radiation dosage; prospective studies; fluoroscopy

INTRODUCTION

Monoplane and biplane coronary angiography remain the gold standard for the investigation of coronary artery disease. These techniques utilize X-ray radiation and iodine, which should be kept to the minimum possible dosages while ensuring diagnostic accuracy. Angiography of the coronary arteries is conventionally carried out in multiple, predefined stationary views, at different angulations around the patient, for both left and right coronary arteries and an X-ray acquisition is performed with a contrast injection at each angulation. This ensures that the coronary arteries are visualized in their entirety with no portion of the arteries seen only end-on, as such views may mask areas of narrowing.

Rotational angiography is an alternative technique wherein the c-arm rotates around the patient in a

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preprogrammed single acquisition, such that the entire coronary artery is exposed at different angulations, for a fixed period of time [1,2]. This method was shown to provide a significant reduction in contrast and radiation dosages (up to 30%) without compromising diagnostic accuracy, but being a single axis rotation, required two

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Conflict of interest: None.

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Received 12 April 2011; Revision accepted 2 October 2011

DOI 10.1002/ccd.23415 Published online in Wiley Online Library (wileyonlinelibrary.com)



Fig. 1. DARA trajectories for left (top) and right (bottom) coronary angiography.

runs for the complete acquisition of the left coronary artery and one more run for the right coronary artery [3]. A new technique of dual axis rotational coronary angiography (DARA) has recently developed wherein the c-arm is preprogrammed to rotate with a curved trajectory around the patient, thereby acquiring all of the desired anatomical views in a single run (Fig. 1) while operating within safe parameters in order to avoid collisions with patient, staff, and equipment. This is carried out in one run each for both left and right coronary arteries. Left and right coronary cycles last 5.3 and 3.7 sec, respectively. DARA is a combined movement of two axes: propeller (rotating movement around the axis) and roll (movement in the sleeve) carm movements. The speed of the c-arm changes throughout the whole DARA cycle depending on the projection/angulation (view) at any particular period of time. The maximum propeller c-arm speed reached is 55 deg/sec and the maximum roll rate is 30 deg/sec.

The DARA (XperSwing, Philips Healthcare) system has been recently installed in the Cardiac Catheterisation Suite at Mater Dei Hospital, Malta. The hospital is teaching center as well as a regional center providing all of the national cardiology services for the archipelago, which has a total population of $\sim 400,000$. The Suite has two laboratories, one monoplane (Philips Allura Xper FD10), and one biplane (Philips Allura Xper FD10/10), and carries out \sim 185 coronary angiograms and 56 percutaneous coronary interventions monthly. The contrast used is Omnipaque R 350 (GE Healthcare).

This study was carried out in order to investigate whether DARA differs significantly in radiation, contrast loads, and procedure time, when compared with conventional single and biplane coronary angiography.

METHODS

This study was carried out over the period from September to December 2010. Ethics approval was obtained from the University of Malta Research Ethics Committee, and patients were verbally consented with regard to the study and an information sheet was also made available. Patients referred for the investigation of native coronary anatomy, for whatever indication (including acute coronary syndromes) were included in the study. The following were excluded: graft studies, angiography related to valvular heart disease, emergency primary percutaneous coronary interventions, sheath shots, and right and left heart studies.

Patients were randomly assigned to one of four groups depending on which machine and modality was used: monoplane conventional (MC), monoplane DARA (MD), biplane conventional (BC), and biplane DARA (BD)—see with regard to the latter group explanation below.

Operators could not be blinded as to which technique would be carried out. All operators knew about the study, but were not influenced in any way to modify their technique/s so as to reduce procedure time. The same set of six operators were involved throughout the study. The minimum experience in angiography was 4 years and the maximum was 30 years.

The shielding used was the same for all procedures and included ceiling suspended lead-acrylic and lead skirt, and two table-mounted lead skirts with lead equivalence of 2-mm lead. For the DARA procedures, the lead suspended had to be moved further away from the patient in order to avoid collisions with the image intensifier.

Collimation was used for standard angiography procedures but could not be used for DARA since during DARA, the collimators are programmed to be fully open during the trajectory.

Collimator distance from tube to patient was the same in all cases since the patient always remained in the isocenter. The flat detector distance to patient was minimized in conventional procedures, as is the norm, but DARA programs the distance to the maximum distance from patient as default. Automatic tube adjustments for KvP/mA were used for all procedures.

Catheterization and Cardiovascular Interventions DOI 10.1002/ccd.

Published on behalf of The Society for Cardiovascular Angiography and Interventions (SCAI).

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TABLE I.	Age and B	AI Summary	y Statistics b	by Gender
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	Male		Female	
	Age (yrs)	BMI (kg/m ²)	Age (yrs)	BMI (kg/m ²)
Mean	61.5	29.5	66.1	29.5
SD	10.5	5.0	9.1	5.6
Min	25	19.2	42.0	15.8
Max	91	49.7	83.0	45.5

TABLE II. Coronary Angiography Access Site by Gender

	Femoral	Radial
Male	279	30
Female	143	11
Total	422	41

Roadmapping was available for all procedures. Contrast conservation is the norm in our unit and opened bottles were used for subsequent patients (on the same day).

The following data were collected for each patient in a bespoke Excel spreadsheet: gender, age, body mass index (BMI), fluoroscopy time, levels of fluoroscopy used (low, normal, high), dose area product (DAP), number of runs, total number of images, femoral or radial approach, 4 or 5 Fr catheters, extra views (if any), amount of contrast used, and total procedure time. Procedure time commenced with the first acquisition run and terminated with the end of the last acquisition run. Operator doses were not measured.

For conventional monoplane angiography, the protocol included five standard projections for the left coronary artery (RAO $20^{\circ}/-20^{\circ}$, RAO $10^{\circ}/0^{\circ}$, RAO $10^{\circ}/+20^{\circ}$, LAO $45^{\circ}/+20^{\circ}$, LAO $45^{\circ}/-20^{\circ}$) and two projections for the right coronary artery (LAO $45^{\circ}/0^{\circ}$, RAO $30^{\circ}/0^{\circ}$). Conventional biplane angiography included three biplane, perpendicular projections for the left coronary artery (RAO $20^{\circ}/-20^{\circ}$ LAO $45^{\circ}/+20^{\circ}$, RAO $30^{\circ}/0^{\circ}$ LAO $45^{\circ}/-0^{\circ}$, PA $0^{\circ}/+30^{\circ}$ LAO $45^{\circ}/-30^{\circ}$) and one biplane projection for the right coronary artery (LAO $45^{\circ}/0^{\circ}$, RAO $30^{\circ}/0^{\circ}$). For the dual axis rotation group, one DARA was made for the left and one for the right coronary arteries, and the trajectories are shown in Fig. 1.

A small dose of contrast imaged under fluoroscopy prior to cine imaging was utilized in all studies. It is a standard practice in our laboratories to acquire a ventriculogram, and this is obtained in a single view with the monoplane machine (RAO $30^{\circ}/0^{\circ}$) and in RAO $30^{\circ}/0^{\circ}$ and LAO $45^{\circ}/0^{\circ}$ in the biplane machine. This practice was also applied for rotational coronary angiography. Following left ventriculography, the lateral tube of the biplane machine was parked in order to allow for DARA. This added another 30 sec (timed

	MC	MD	BC	BD
Male	81	73	81	74
Female	48	33	37	36
Total	129	106	118	110
Total		46	53	

MD: monoplane DARA; BD: biplane DARA; MC: conventional monoplane; BC: conventional biplane angiography.

average) to the procedure time and increased the radiation dose as the ventriculogram is obtained using both tubes. Hence, this group was analyzed separately as group BD to allow comparison with the conventional biplane group.

Operator-controlled manual injections were used for all angiograms. In all patients, 35 ml of contrast was used for all left ventricular angiograms. In all four groups, if the diagnostic information was deemed insufficient, additional (extra) view/s were obtained at the discretion of the operating cardiologist in monoplane.

The above data were analyzed using two unpaired two-tailed *t*-tests (assuming unequal variance) comparing MD and BD with conventional monoplane and conventional biplane angiography. A *P* value ≤ 0.05 was considered a statistically significant result.

RESULTS

A total of 463 patients were included in the study. There were 309 males and 154 females. Summary statistics for age and BMI are shown in Table I. The access site used is shown in Table II, while the modality used is shown in Table III. One patient in the dual axis rotational angiography group suffered from transient myocardial ischemia during the procedure with no associated ECG changes and this resolved spontaneously.

Summary statistics for fluoroscopy time, DAP, number of runs, extra views, amount of contrast used, and total procedure time are shown in Table IV. Overall, DARA had lower levels of all values except for extra views.

The results of *t*-tests comparing MD and BD with conventional monoplane (MC) and conventional biplane (BC) angiography are shown in Table V. DARA was significantly superior in almost all values measured, including timings and doses. Percentage reductions in variables are also shown in the same table and these ranged from a minimum of 12% (contrast used) to a maximum of 71% (procedure time) for all variables studied.

There was no significant learning curve for any of the operators involved in this study.

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		DAP (mGy cm ²)	Fluoroscopy time (min)	Runs (n)	Extra views (<i>n</i>)	Contrast used (ml)	Procedure time (min)
MC	Mean	32.7	03:01	8.3	0.6	38.1	07:35
	SD	17.8	02:57	1.2	1.1	11.3	04:09
	Min	7.8	00:35	3.0	0.0	20.0	03:02
	Max	94.3	20:41	12.0	5.0	73.0	27:25
MD	Mean	22.0	01:53	3.0	0.9	22.5	05:27
	SD	16.3	01:12	0.2	1.2	9.2	02:20
	Min	7.8	00:42	3.0	0.0	5.0	02:00
	Max	143.0	06:38	5.0	6.0	64.0	19:39
BC	Mean	56.7	02:33	9.7	1.2	27.8	06:19
	SD	28.6	02:38	0.7	1.6	10.8	03:35
	Min	20.7	00:38	8.0	0.0	6.0	01:45
	Max	208.0	21:15	10.0	8.0	81.0	21:18
BD	Mean	30.9	01:57	4.0	0.6	24.4	05:21
	SD	18.5	01:28	0.4	1.0	7.7	03:11
	Min	7.1	00:36	4.0	0.0	9.0	02:03
	Max	156.7	07:55	8.0	4.0	53.0	24:08

TABLE IV. Summary Statistics for Radiation, Contrast, and Timings

DAP: dose area product; MD: monoplane DARA; BD: biplane DARA; MC: conventional monoplane; BC: conventional biplane angiography.

TABLE V. T-Tests and	Percentage	Reduction f	for Radiation,	Contrast,	and	Timings
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	DAP (mGy cm ²)	Fluoroscopy time (min)	Runs (n)	Extra views (n)	Contrast used (ml)	Procedure time (min)
MD vs. MC (P)	< 0.0001	< 0.0001	< 0.0001	0.130	< 0.0001	< 0.0001
Reduction (%)	32.7	37.7	63.6	ns	41.0	28.1
MD vs. BC (P)	< 0.0001	0.014	< 0.0001	0.124	< 0.0001	0.033
Reduction (%)	61.2	26.3	68.7	ns	19.2	13.6
BD vs. MC (P)	0.433	< 0.0001	< 0.0001	0.750	< 0.0001	< 0.0001
Reduction (%)	ns	35.2	51.4	ns	36.1	70.6
BD vs. BC (P)	< 0.0001	0.035	< 0.0001	0.002	0.006	0.034
Reduction (%)	45.6	23.3	58.2	49.1	12.4	15.2

DAP: dose area product; MD: monoplane DARA; BD: biplane DARA; MC: conventional monoplane; BC: conventional biplane angiography.

DISCUSSION

This study has shown that DARA is superior to conventional angiography in both monoplane and biplane machines with a reduction in the variables measured ranging from a minimum of 12% (contrast used) to a maximum of 71% (procedure time) for all variables studied. The information obtained is very similar with both modalities, as shown by the similar number of extra views that the cardiologists decided to obtain. Indeed, in the biplane comparisons, DARA resulted in significantly fewer extra views than in conventional biplane angiography. An advantage noted by the operators using the DARA is that because of the continuous rotation of the tube, the best viewing position could be noted prior to acquiring the extra run/s.

DARA is particularly effective, because the coronaries are filled with contrast throughout the trajectory and in every single image. Moreover, each image is unique, unlike the static views generated by conventional angiography that only generates replications of the same image and projection. It was also observed that the longer DARA right coronary injection (when compared with shorter injections for conventional right coronary angiography) occasionally caused the catheter to flick out of the coronary ostium, and this was counted as an extra view. However, with experience, the cardiologists began to rescreen the catheter just before commencing the acquisition in order to ensure that the right coronary catheter was firmly in position, thus reducing the instances of this occurrence.

There was a preponderance of males over females, with high BMIs, and with a higher mean age for females undergoing coronary angiography. Most invasive cardiologists practice the femoral approach as opposed to the radial approach in our center.

Patient benefits are obvious, with significantly lower doses of radiation and contrast and a shorter procedure time. The DAP was high in our study in the biplane acquisitions (including DARA) due to the unit's practice of obtaining biplane ventriculography. Some units have abandoned this and instead obtain this information from echocardiography, thereby also saving 35 ml

Catheterization and Cardiovascular Interventions DOI 10.1002/ccd.

Published on behalf of The Society for Cardiovascular Angiography and Interventions (SCAI).

TABLE VI. Savings in Contrast and Time Assuming 20 Patients Undergoing Coronary Angiography (contrast excluding the ventriculogram)

		Each	Sav	ings
		(mean)	One patient	20 patients
Contrast (ml)	MC	38.1	15.6	312.6
	MD	22.5		
	BC	27.8	3.5	69.2
	BD	24.4		
Procedure time (min)	MC	07:35	02:08	42:40
	MD	05:27		
	BC	06:19	00:58	36:35
	BD	05:21		

DAP: dose area product; MD: monoplane DARA; BD: biplane DARA; MC: conventional monoplane; BC: conventional biplane angiography.

of contrast per patient. Moreover, omitting the ventriculogram in biplane laboratories would save an additional 30 sec that were used, in our study, to park the lateral tube prior to the DARA rotation.

It is worth noting that the longer runs associated with DARA may, theoretically cause ischemia, but in this study, only one patient suffered from transient ischemia during the procedure, which was not associated with ECG changes and resolved spontaneously.

The benefits to the health provider are obvious in that contrast is expensive, as is theatre time. Table VI quantifies savings assuming a throughput of 20 patients daily through a catheterization laboratory. Significant daily savings for both time and contrast are clearly seen, which could be utilized to fit in more patients, a welcome possibility in the ubiquitous waiting list scenario that faces the healthcare services of almost all developed countries. Moreover, the reduced radiation dosage with the resultant decrease in scatter would be beneficial to staff working in catheterization laboratories.

It should be noted that reduction in doses in both contrast and radiation are the common pursuits of all imaging modalities, with the radiation dose of a normal diagnostic coronary angiogram at typically 5–10 mS, while coronary CT angiography is typically associated with a dose of 5–15 mS [4].

The DARA system may benefit through additional enhancements, such as a setting allowing some adjustment between thinner and fatter patients as the default distance between the flat detector and the patient is such as to allow even obese patients to undertake DARA angiography without any changes of settings. Another possibility is that of utilizing both tubes in biplane machines, theoretically shortening procedure time and utilizing smaller doses of contrast, an intricate series of movements that would require more complex programming.

CONCLUSION

Since the introduction of cardiac catheterization [5], advances have included contrast injection, fluoroscopy [6], coronary cine angiography [7], biplane angiography [8], digital acquisition and more recently, CT angiography [9]. DARA may prove to be an important and useful tool in the refinement of diagnostic coronary angiography by reducing patient contrast and radiation doses and reducing procedure time.

ACKNOWLEDGEMENTS

The authors acknowledge their consultant colleagues, and their patients who were utilized in this study along with their colleagues (radiographers, nurses, and ECG technologists) in the Cath. Suite who helped with data collection, patient organization, patient care, and general advice. These include C. Borg, D. Demicoli, L. Smith, J. Vella, J. Tomren, and A. Balguid (Philips Healthcare). They also thank patients for participating in this study.

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