Evaluation of coronary angiographic projections to balance the clinical yield with the radiation risk

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Objective: Radiation safety principles dictate that imaging procedures should minimise the radiation risks involved, without compromising diagnostic performance. This study aims to define a core set of views that maximises clinical information yield for minimum radiation risk. Angiographers would supplement these views as clinically indicated.

Methods: An algorithm was developed to combine published data detailing the quality of information derived for the major coronary artery segments through the use of a common set of views in angiography with data relating to the dose–area product and scatter radiation associated with these views.

Results: The optimum view set for the left coronary system comprised four views: left anterior oblique (LAO) with cranial (Cr) tilt, shallow right anterior oblique (AP-RAO) with caudal (Ca) tilt, RAO with Ca tilt and AP-RAO with Cr tilt. For the right coronary system three views were identified: LAO with Cr tilt, RAO and AP-RAO with Cr tilt. An alternative left coronary view set including a left lateral achieved minimally superior efficiency (<5%), but with an ~8% higher radiation dose to the patient and 40% higher cardiologist dose.

Conclusion: This algorithm identifies a core set of angiographic views that optimises the information yield and minimises radiation risk. This basic data set would be supplemented by additional clinically determined views selected by the angiographer for each case. The decision to use additional views for diagnostic angiography and interventions would be assisted by referencing a table of relative radiation doses for the views being considered.

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In 1977 the International Commission on Radiological Protection (ICRP) put forward three basic guiding principles aimed at minimising the detrimental impact that radiation has on society [1]. Since that time these principles of justification, optimisation and limitation have been developed into the foundation of most state, national and international legislation dealing with radiation protection.

In the medical context, the principle of optimisation requires that all exposures to patients (and staff) arising from imaging procedures be kept as low as reasonably achievable (ALARA). This objective is particularly important in cardiac imaging as, although the absolute radiation dose from an individual coronary angiography procedure might be relatively low, patients with cardiac disease often undergo multiple imaging procedures which can lead to substantial cumulative exposures [2].

Owing to the potential for high cumulative radiation doses, strategies that minimise the radiation contribution at each point in the imaging journey should be pursued [3, 4]. For complex operator-directed imaging procedures such as diagnostic coronary angiography (DCA) and interventions, this approach involves close examination of

not only the technology-related aspects of the procedure (namely the imaging system and its set-up) but also how the equipment is used to achieve the clinical objective.

Numerous papers have been written reviewing the radiation exposures delivered to individuals undergoing cardiac imaging procedures and those involved in the conduct of these procedures [5–9]. What is immediately apparent in reviewing this literature is that there is tremendous variation in clinical practice, technology and technique, with the consequence that the results reported by the various authors regarding the radiation risks for these procedures vary substantially. Information presented by Mettler et al [10], for example, shows that DCA is associated with an average radiation exposure of 7 mSv (with doses ranging from 2 to 15.8 mSv being reported), while Kim and Miller [11] suggest that the average dose to cardiologists performing DCA is of the order of 5 µSv per case (but might vary by as much as three orders of magnitude for the same type of procedure).

The level of exposure received by patients undergoing DCA procedures is substantially greater than that reported by Mettler et al [10] for patients undergoing common medical imaging procedures such as an X-ray of the chest (0.02 mSv), abdomen (0.7 mSv) or thoracic spine (1 mSv). Only patients undergoing complex fluoroscopy (up to 70 mSv) and CT (up to 15 mSv) procedures receive doses rivaling DCA.

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Partridge and Slaughter [12] published work in 1986 that analysed the information gathering process in DCA and proposed a standard set of projections (supplemented by extra views at the discretion of the experienced operator) for the efficient collection of diagnostic information in cardiac angiography. This evaluation was largely based on deriving clinical information and did not balance the clinical information yield with the radiation consequence of the selection of projections. Papers such as the one by Kuon et al [13] have shown that significant dose reduction can be achieved in situations where multiple view options exist by selecting the view with the lowest per unit exposure.

The purpose of this study is to use information from the available literature on clinical information yield for various angiographic projections and merge this with data relating to the radiation consequence of these views to derive a core set of projections that simultaneously optimises clinical information yield for minimum radiation risk. This analysis will encompass consideration of the radiation risk arising from a DCA to both the patient and the cardiologist.

Methods and materials

An algorithm was developed to provide an efficiency score for a combination of radiographic views by integrating published data detailing the clinical image quality of information derived for the major coronary artery segments through use of the common views in angiography with data relating to the dose–area product (DAP), scatter radiation and effective dose (E) for these views.

Image quality information

The information quality yield for each segment delivered by each projection is taken from the work by Di Mario and Sutaria [14] and is shown in Table 1. As this paper deals with the selection of a set of views for standard coronary angiography, analysis involving coronary artery bypass graft studies has not been included. The only enhancement to this data involves the inclusion of a segment weighting score (w_j) that reflects the relative importance of achieving a diagnostic outcome for that segment. Values for w_j of 1.5 were allocated to high-priority segments, while the remaining segments were each assigned a value of 1.

Radiation data

Radiation data reflecting the time-adjusted radiation exposure (DAP rate in $\text{mGy cm}^2 \text{s}^{-1}$) and mean operator radiation exposure (scatter rate in microsieverts per hour) have been derived from the work by Kuon et al [13]. Use of this information allows the DAP and scatter dose to the clinician for each view to be estimated for each projection in Table 1 using interpolation (these data are for uncollimated use of the imaging system). The E contribution for each projection is then derived using conversion factors estimated from the data provided in the work of Stern et al [15]. Rather than use the Stern tables to derive absolute

conversion factors relating DAP to E, for the purposes of the evaluation conducted in this study it was sufficient to derive a relative weighting factor. As a relative conversion factor is used, the resultant effective dose rate estimate does not have the SI unit of sieverts, and instead the term “units” is used. Table 2 details the relative DAP, E and scatter dose contributions from each projection. For ease of calculation and as relative dose contributions are sufficient, the scatter and E factors for each projection used in the calculation have been normalised to the lowest value (referred to in Table 1 as the normalised E or scatter rates).

For the purpose of this study, it has been assumed that the time spent delivering radiation during the fluoroscopy and fluorography components of the study are equally divided between each projection. Although this may not be strictly valid for fluoroscopy, it has been shown that this component of a study accounts for less than 15% of the total radiation dose delivered in a DCA [16] and, as such, variations from the assumption will make little difference to the overall analysis. The use of normalised dose rates in both the analysis of patient dose and clinician scatter dose also assists generalisation of the analysis as it removes dependence of the results on actual dose rates, and hence imaging platform set-up and mode of operation of the equipment (assuming different imaging systems respond in similar manners to changes in radiographic load).

Algorithm description

- (1) For each coronary segment the mean dose-adjusted quality score (V_j) is calculated by averaging the information quality score (q_{ij}) divided by the radiation exposure for each projection (R_i). This is used as a quality “benchmark” for that segment in each subsequent projection combination evaluated.
- (2) For each projection combination, the total dose-adjusted quality score normalised using the quality “benchmark” for each segment (V_j), across all included views, is calculated.
- (3) The total “efficiency” score for each projection combination (Q_{set}) is then adjusted using a weighting factor based on the proportion of contributing segments with the maximum quality score.

The resultant algorithm can be expressed as:

$$Q_{\text{set}} = \frac{n_{\text{max}}}{nv} \sum_{i=1}^{n_v} \frac{1}{R_i} \sum_{j=1}^{n_{\text{seg}}} \frac{w_j q_{ij}}{V_j} \quad (1)$$

with

$$V_j = \frac{1}{N} \sum_{i=1}^N \frac{q_{ij}}{R_i} \quad (2)$$

In these equations terms are defined as follows:

N is the total number of views considered in the algorithm

R_i is the radiation exposure (in terms of DAP) from view i

Table 1. Image quality scores for each coronary anatomical segments by projection

Angulation	Priority	Projection							
		LAO/Ca	AP-RAO/Ca	RAO/Ca	AP-RAO/Cr	LAO/Cr	LL	LAO	RAO
LAO (+)/RAO (-)		45	-15	-37	-15	37	90	50	-37
Cr (+)/Ca (-)		-30	-30	-35	40	30	0	0	0
Segment									
LM ostium	1.5	2	1	1	3	3	0	0	0
LM bifurcation	1.5	3	3	2	0	0	0	0	0
LAD proximal	1.5	2	2	3	2	2	1	0	0
LAD mid	1	0	1	1	3	2	2	0	0
LAD distal	1	1	1	3	1	0	3	0	2
LAD diagonal	1	2	1	0	2	3	0	0	0
LCX proximal	1	1	3	3	0	0	0	0	0
LCX distal	1	1	1	2	3	2	1	2	0
OM bifurcation	1	2	3	2	0	0	0	1	0
RCA proximal	1.5	0	0	0	1	3	0	2	0
RCA mid	1	0	0	0	0	1	3	2	3
RCA distal/crux	1	0	0	0	3	3	0	2	0
PDA	1	0	0	0	3	2	0	1	2
PLV	1	1	0	0	3	2	1	1	0

AP, anteroposterior; AP-RAO, between AP and 20° RAO; Ca, caudal; Cr, cranial; LAD, left anterior descending; LAO, left anterior oblique; LCX, left circumflex; LL, left lateral; LM, left main; OM, obtuse marginal; PDA, posterior descending artery; PLV, posterior left ventricular; RAO, right anterior oblique; RCA, right coronary artery.

These data are drawn from the work of Di Mario and Sutaria [14]. The system used by Di Mario and Sutaria translates to the classification of a view that is not recommended as 0, occasionally useful as 1 and very useful as 2. The ideal view is rated as 3.

q_{ij} is the information quality score of information on segment j from view i

w_j is the relative importance of segment j

n_{seg} is the number of segments being evaluated

n_{max} is the number of segments recording a maximum quality factor

n_v is the number of views involved.

The algorithm was designed to derive an overall quality score for a set of projections (Q_{set}) by summing together the quality-weighted radiation scores for each vessel segment. The individual quality scores for each vessel segment is derived by dividing the quality score provided by a particular view (q_{ij}/R_i) by the average quality-weighted radiation score provided for all views of that segment (V_j). This aspect of the algorithm delivers scores greater than one for a particular view of a segment that delivers a quality score greater than the average quality score of all views for a segment, while a score of less than one results when the view “performs” more

poorly than the average. The addition of the weighting factor n_{max}/n_v enhances the algorithm’s bias towards ensuring that a view set that achieves ideal visualisation in all relevant segments is identified. In addition, view combinations were eliminated entirely if any individual coronary segment failed to achieve a score greater than 0.

To test the validity of the algorithm in combining measures of radiation (ratio scale) and quality (ordinal scale), a sensitivity analysis was performed to assess the impact on view selection that would result through the application of different weighting mechanisms for the q_{ij} values (one using the square, the other using the square root of q_{ij}).

Results

The overall effect of the proposed algorithm is to bias the Q_{set} score to deliver the optimum compromise between the number of views used, the quality of

Table 2. Radiation weighting factors by projection

Radiation factor	Projection							
	LAO/Ca	AP-RAO/Ca	RAO/Ca	AP-RAO/Cr	LAO/Cr	LL	LAO	RAO
DAP rate (mGy cm ² s ⁻¹)	46.5	20.0	44.8	45.5	60.7	28.0	30.0	15.1
Relative E weight/DAP	2.0	2.1	2.1	1.5	1.7	0.9	2.2	2.1
E (units)	93.0	42.0	94.0	68.3	103.2	25.2	66.0	31.7
Normalised E rate	3.69	1.67	3.73	2.71	4.09	1.00	2.62	1.26
Scatter rate (μSv h ⁻¹)	680	160	306.5	440	671	630	600	94
Normalised scatter rate	7.23	1.70	3.26	4.68	7.14	6.70	6.38	1.00

AP, anteroposterior; AP-RAO, between AP and 20° RAO; Ca, caudal; Cr, cranial; DAP, dose–area product; E, effective dose; LAO, left anterior oblique; LL, left lateral; RAO, right anterior oblique.

Data for the time-adjusted radiation exposure (DAP rate in mGy cm² s⁻¹) and mean operator radiation exposure (scatter rate in μSv h⁻¹) have been derived from the work of Kuon et al [13] using linear interpolation. Data for the relative weights converting DAP rate to E (units) have been derived from the work of Stern et al [15].

information derived using those views and the radiation dose delivered in obtaining this information. All possible view combinations for the left and right coronary systems were evaluated separately and the Q_{set} score for each view set was plotted against radiation dose measures for visual interpretation. Graphs relating to the evaluation of patient E and scatter dose to the cardiologist for the left and right coronary systems are shown in Figures 1 and 2, respectively. Table 3 provides the top five ranked view set combinations in order of decreasing efficiency (Q_{set} score) for both patient E and scatter dose to the cardiologist for imaging of the left and right coronary systems. In addition to the Q_{set} score for each combination of views, this table includes an index of the total dose (patient E and scatter), as well as the number of segments visualised with an "ideal" rating (out of eight for the left and five for the right).

Analysis of the optimum view combinations for imaging of the two coronary systems for both E and scatter reveals that when scatter to the operator and E are separately considered, slightly different view combinations are identified in each system. When patient E was considered, the optimum view set identified by the algorithm for the left coronary system comprised five views: left lateral (LL), left anterior oblique (LAO) with cranial (Cr) tilt, shallow right anterior oblique (AP-RAO) with caudal (Ca) tilt, RAO with Ca tilt and AP-RAO with Cr tilt. The set of views ranked second in this analysis comprised four views, omitting the LAO with Cr. Closer inspection of these two view sets shows that the higher-ranked set achieves ideal ratings for all eight vessel segments, while the second-ranked set achieves only seven ideal ratings, with visualisation of the left anterior descending (LAD) diagonal being rated as very useful. When operator scatter dose is considered, the optimum set of views comprises only three views, omitting the LL view from the set of views ranked second in the patient E analysis. The set of views ranked second in the scatter analysis is similar to the

view set ranked first in the patient E analysis, with omission of the LL. This view set ranks third in the patient E analysis. In reviewing the results of the scatter and E analysis simultaneously, the set combining an LAO/Cr, shallow RAO/Cr, RAO/Ca and shallow RAO/Ca ranks third on the list for E (5% less efficient and 8% less dose when compared with the set ranked first) and second on the list for scatter dose (5% less efficient but 40% more dose when compared with the set ranked first).

Applying a similar review of the projection sets for the right coronary system identified a three-view set (LAO with Cr tilt, RAO and AP-RAO with Cr tilt) as being the optimum combination when scatter to the operator is balanced with clinical information yield. However, when clinical information yield is traded against patient dose, a four-view set, comprising the same three views found in the scatter set with a LL projection, is identified. This set of views ranks third when scatter dose is considered (20% less efficient at 50% higher scatter dose), while the optimum scatter biased view ranks fourth when E to the patient is considered (3% less efficient at 11% lower E).

When the impact of alternative weighting mechanisms for the q_{ij} scores was assessed it resulted in negligible change in the evaluation of left and right system views. For scatter dose to the clinicians, this aspect of the analysis demonstrated no meaningful change to the ranking of the sets of views. For E to the patient, however, when greater emphasis was placed on the quality of information (through squaring the Q_{set} scores), the view combinations we have recommended for imaging both the left and right systems moved up the rankings (from three to two for the left and four to two for the right).

Discussion

Application of the ALARA principle to DCA procedures requires the striking of a balance between the

Figure 1. Graphs of Q_{set} score against E score (a measure related to effective dose) for the left and right coronary systems. Highlighted is the view set recommended as being optimal for imaging of the left and right coronary systems (corresponds respectively to the asterisk and plus sets in Table 3).

Figure 2. Graphs of Q_{set} score against scatter score (a measure related to operator scatter dose) for the left and right coronary systems. Highlighted is the view set recommended as being optimal for imaging of the left and right coronary systems (corresponds respectively to the asterisk and plus sets in Table 3).

competing needs of effectively obtaining accurate and reliable information about coronary anatomy and disease state, on the one hand, and low radiation risk to the patient on the other. Owing to the operator-directed nature of cardiac angiography, this goal is achieved by ensuring that the technical performance of the imaging

platform is appropriate for the purpose (image quality is appropriate for the clinical needs) and through optimisation of the clinical information-gathering process. This also highlights an added complexity of this type of procedure where the radiation risk is not solely incurred by the patient but, in part, is shared (through scattered

Table 3. Table summarising the top five ranked view set combinations in order of decreasing efficiency (Q_{set} score) for patient effective dose and cardiologist scatter dose for imaging of the left and right coronary systems

Factor (system)	Rank	Q_{set} score	Dose score	V_{max}	Projection combination
Effective dose					
(Left)	1 (7)	6.31	13.20	8	LL, LAO/Cr, AP-RAO/Cr, RAO/Ca, AP-RAO/Ca
	2 (8)	6.13	9.10	7	LL, AP-RAO/Cr, RAO/Ca, AP-RAO/Ca
	3 (2) ^a	6.02	12.20	8	LAO/Cr, AP-RAO/Cr, RAO/Ca, AP-RAO/Ca
	4 (1)	5.98	8.10	7	AP-RAO/Cr, RAO/Ca, AP-RAO/Ca
	5 (13)	5.96	16.89	8	LL, LAO/Cr, AP-RAO/Cr, RAO/Ca, AP-RAO/Ca, LAO/Ca
(Right)	1 (3)	2.33	9.06	5	LL, LAO/Cr, AP-RAO/Cr, RAO
	2 (8)	2.29	11.68	5	LL, LAO/Cr, LAO, AP-RAO/Cr, RAO
	3 (36)	2.28	7.80	5	LL, LAO/Cr, AP-RAO/Cr
	4 (1) ^b	2.27	8.06	5	LAO/Cr, AP-RAO/Cr, RAO
	5 (40)	2.24	10.42	5	LL, LAO, LAO/Cr, AP-RAO/Cr
Scatter dose					
(Left)	1 (4)	5.38	9.64	7	AP-RAO/Cr, RAO/Ca, AP-RAO/Ca
	2 (3) ^a	5.12	16.78	8	LAO/Cr, AP-RAO/Cr, RAO/Ca, AP-RAO/Ca
	3 (8)	4.52	24.02	7	LAO/Cr, AP-RAO/Cr, RAO/Ca, AP-RAO/Ca, LAO/Ca
	4 (12)	4.50	16.88	8	AP-RAO/Cr, RAO/Ca, AP-RAO/Ca, LAO/Ca
	5 (19)	4.50	17.78	7	LAO/Cr, AP-RAO/Cr, RAO/Ca, AP-RAO/Ca
(Right)	1 (4) ^b	1.87	12.82	5	LAO/Cr, AP-RAO/Cr, RAO
	2 (6)	1.63	19.20	5	LAO/Cr, LAO, AP-RAO/Cr, RAO
	3 (1)	1.50	19.52	5	LL, LAO/Cr, AP-RAO/Cr, RAO
	4 (13)	1.44	12.06	5	LAO, AP-RAO/Cr, RAO
	5 (23)	1.43	20.05	5	LAO/Cr, LAO/Ca, AP-RAO/Cr, RAO

AP, antero-posterior; AP-RAO, between AP and 20° RAO; Ca, caudal; Cr, cranial; LAO, left anterior oblique; LL, left lateral; RAO, right anterior oblique.

The number in brackets after the rank shows the ranking of that view set in the list for the alternative radiation measure. V_{max} represents the number of segments visualised with at least one view rated as ideal (out of eight for the left and five for the right).

^aThe core set of views recommended for the left coronary system.

^bThe core set of views recommended for the right coronary system.

radiation) by those directly involved in the conduct of the procedure.

As a feature of the analysis performed is to bias heavily in favour of projection combinations that provide sound visualisation of each major vessel segment of the left and right coronary systems, comparison of the top-ranked views in each category largely comes down to a comparison of the radiation dose-weighted efficiency of each combination and the radiation dose concerned (scatter dose to the clinician and E to the patient). In undertaking this analysis, it has been assumed that although more than one view is usually required to perform quantification on a stenosis, in many instances only one view is required to determine whether a stenosis is clinically significant [12]. Additional review of each set of views will therefore focus on the ability of the combination to provide identification of disease only in all major vessel segments.

Analysis of projection combinations for imaging the right coronary system depicted in the graphs of Figures 1b and 2b comes down to a choice between performing the procedure at minimum scatter dose to the operator and minimum E to the patient. Of the two view sets ranked highest for these two measures, the resulting analysis shows that the optimum scatter-biased combination (which includes the LAO/Cr, RAO and AP-RAO/Cr projections) ranks fourth on the Q-ordered list of E-biased projections. However, when the scatter-biased list is reviewed, the optimum E projection set (comprising the same three views and an LL) ranks third, delivering in excess of 50% more scatter radiation to the operator. It is this factor, coupled with knowledge that both sets of views provide ideal visualisation of each of the five vessel segments evaluated, that sways recommendation of the scatter biased projection set (comprising LAO/Cr, RAO and AP-RAO/Cr projections).

Similar analysis of the left coronary system projection combination selection depicted in Figures 1a and 2a also compels a choice between minimising scatter dose to the operator and minimising E to the patient. If E is used as the radiation measure, optimum information efficiency yield is achieved through the use of five views: LAO/Cr, LL, AP-RAO/Ca, RAO/Ca and AP-RAO/Cr. When scatter dose to the cardiologist is considered, the projection combination identified comprises only three views, omitting the LL and LAO/Cr from the views identified for E. Review of the data for the E projection combination analysis reveals that the scatter-biased combination is ranked fourth, having only marginally lower efficiency (5.98 *vs* 6.31 units), but with markedly lower E (~40% less owing to the omission of the two views). By comparison, the five-view combination identified when E is considered ranks seventh in the table of scatter-biased combinations (an efficiency score of 4.32 *vs* 5.38), delivering some 2.4 times more scatter (23.48 *vs* 9.64 units). An issue for the three-view set, however, is that it achieves ideal ratings in only seven of eight vessel segments (the LAD diagonal being rated only as very useful). In reviewing the results of the scatter and E analysis simultaneously, the set of views appearing to offer the best compromise between patient dose, scatter dose to the operator and information yield is one that combines LAO/Cr, shallow RAO/Cr, RAO/Ca and shallow RAO/Ca. This achieves ideal ratings in all eight vessel segments, ranking third on the list for E (5% less efficient and 8% less dose when compared with the set ranked first) and second on the list for scatter dose (5%

less efficient but at 40% more dose when compared with the set ranked first owing to inclusion of the LAO/Cr).

In both cases the overall bias against sets of projections that include a LL view, as well as other views where the detector is on the left side of the patient, should not be a surprise. Although the LL projection provides clear visualisation of coronary segments such as the distal LAD and mid RCA, the substantial scatter dose "penalty" of this view and other views with the detector on the patient's left weighs heavily against any projection set in which they are included. This finding is supported in the literature where warnings concerning the operator scatter dose from steep LAO and LL projections are common [13, 17]. Although not considered in the data sets employed in this study, consideration could be given to inclusion of a right lateral (RL) projection in place of the LL. Reference to the radiation data of Kuon et al [13] suggests that the scatter radiation "cost" to the operator of the RL projection is approximately 30% of the LL (190 *vs* 630 $\mu\text{Sv h}^{-1}$), although the DAP is marginally higher (~10%).

Comparison of the views identified in this analysis with those suggested by Partridge and Slaughter [12] (left: LAO/Cr, LAO/Ca, LAO, LL, RAO and RAO/Ca; right: LAO/Cr, LAO, LL and RAO/Ca) shows considerable difference. Acknowledging that the exact views recommended by Partridge and Slaughter vary in their angulations when compared with the views we have used, their projection sets appear quite well down on the evaluation lists based on the Q set scores for patient E and scatter dose (ranked >100 in each evaluation). This can be attributed to a combination of the number of views they have suggested for the left (six *vs* four) and right (four *vs* three) systems and the side of the patient on which the imaging system is positioned for these views. As previously identified, the set of views we propose are composed largely of projections where the detector is on the patient's right side. This effectively minimises scatter dose to the clinician. This contrasts with the Partridge and Slaughter sets, where four of six views used for the left system and three of four views for the right system are on the patient's left.

Although not explicitly evaluated in this study, if it is assumed that a similar volume of contrast medium is used in the acquisition of data for each projection, strategies that lead to a reduction in the number of views taken can also be expected to have a proportional impact on the total volume of contrast medium used in a study. Use of an optimised projection set for cardiac angiography could therefore be expected to have a flow on beneficial effect in terms of minimising the risk of contrast-medium-induced nephropathy (CIN), particularly in high-risk patient groups. It must be emphasised, however, that total contrast medium volume is only one of a number of factors (including hydration, diabetic status and renal dysfunction) that has been linked to the risk and severity of CIN [18].

While the intent of this paper is to identify a core set of imaging projections for use by clinicians seeking to minimise radiation risk in diagnostic angiography, it must be emphasised that controlling the number and orientation of views employed goes only part of the way to addressing the overall issue of risk minimisation. Radiation risk reduction in operator-directed procedures such as cardiac angiography is achieved through a

multifaceted approach that involves optimisation of equipment use and conduct of the case by the clinical team. For example, substantial dose reduction (both E and scatter) can be achieved by making active use of collimation, and ensuring that the fluoroscopy and fluorography frame rates (as well as the detector entrance dose rates in these modes) are as low as necessary for the clinical task [19, 20]. Furthermore, scatter dose to the cardiologist can be significantly reduced through the use of appropriate personal protective equipment, as well as table-, floor- and ceiling-mounted operator shielding.

After considering the combined constraints of optimum information yield at minimum risk to the patient and cardiologist, it is recommended that the following views be included in the core imaging set:

- Right coronary system: LAO/Cr, RAO and AP-RAO/Cr.
- Left coronary system: LAO/Cr, AP-RAO/Ca, RAO/Ca and AP-RAO/Cr.

In sequencing the views for the left coronary system, it is further recommended that the study commence with the LAO/Cr view followed by the AP-RAO/Ca, as this will ensure that efficient imaging of the LM ostium and bifurcation is completed before moving to the other segments.

Our method has been directed primarily at developing an algorithm to identify sets of views to efficiently detect disease in the major vessel segments of an average patient undergoing diagnostic coronary angiography. The view sets suggested will need to be supplemented by additional projections once the presence of disease is identified, to facilitate planning an intervention. For example, the RAO/Cr view might provide more diagnostic information than an AP/Ca in a patient with LAD and LAD diagonal disease. A left or right lateral might be useful in assessment of mid or distal LAD disease. An LAO/Ca might provide important information in the assessment of ostial LAD or left circumflex disease. The additional views to be used, while guided by the anatomy, should be selected while keeping in mind the radiation consequence of the various options (see Kuon et al [13] for detailed exposure tables).

Conclusion

A core set of angiographic views has been identified that optimises the conflicting requirements of maximising diagnostic information yield and minimising both patient and operator radiation risk. The core view sets would be supplemented by additional clinically determined views selected by the angiographer for each case. The selection of additional views might be assisted by a relative radiation dose table (such as Table 2). This analysis highlights the operator radiation "penalty" associated with the LL projection, ultimately recommending alternative angiographic view sets that achieve similar clinical performance without inclusion of this view.

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