

Patient Radiation Doses in Interventional Cardiology Procedures

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Abstract: Interventional cardiology procedures result in substantial patient radiation doses due to prolonged fluoroscopy time and radiographic exposure. The procedures that are most frequently performed are coronary angiography, percutaneous coronary interventions, diagnostic electrophysiology studies and radiofrequency catheter ablation. Patient radiation dose in these procedures can be assessed either by measurements on a series of patients in real clinical practice or measurements using patient-equivalent phantoms. In this article we review the derived doses at non-pediatric patients from 72 relevant studies published during the last 22 years in international scientific literature. Published results indicate that patient radiation doses vary widely among the different interventional cardiology procedures but also among equivalent studies. Discrepancies of the derived results are patient-, procedure-, physician-, and fluoroscopic equipment-related. Nevertheless, interventional cardiology procedures can subject patients to considerable radiation doses. Efforts to minimize patient exposure should always be undertaken.

Keywords: Patient dosimetry, interventional cardiology.

INTRODUCTION

The medical use of ionizing radiation, while offering great benefit to patients, also contributes significantly to radiation exposure of individuals and populations [1-3]. Interventional radiology and interventional cardiology (IC) contributes a significant proportion of the collective dose of the population from medical exposures. According to the results published by the United Nations Scientific Committee on the Effects of Atomic Radiation, interventional procedures contribute only 1% to the frequency of radiation use on the medical field whereas their contribution to collective dose is 10% [4]. When complex procedures are performed or procedures are repeated for the same patient, high radiation dose levels can occur because procedures often require long fluoroscopy time and a large number of images.

Over the last 10 years the number of IC procedures has increased rapidly [5, 6]. The main reasons is that IC permits specialists to avoid complicated invasive surgery which some patients might not tolerate due to factors of age or pathology [7] and results in limited hospitalization [5]. Additionally, knowledge of the benefits of IC becomes more widely spread and more complicated procedures are technically possible. Nevertheless, population dose and associated health risks are also increasing. The potential of occurrence of deterministic effects (injury of radiation, the severity of which varies with the dose and for which a dose threshold exists), especially to the skin, has been a subject of great concern. Additionally, estimation of the health risk owing to stochastic effects of radiation (malignant disease and heritable effects without a threshold level of dose, whose probability is proportional to the dose and whose severity is independent of the dose) especially for the younger patients is also under thorough investigation.

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Reviewing the various studies on patient dosimetry in IC, it is evident that there is great variability in both methods of measurement and levels of radiation dose received by the patient. Some of the factors responsible for dose variability are the complexity of the procedure, operator experience, level of training in radiation protection, and type and performance of x-ray equipment available in the catheterization laboratory.

The purpose of this study is to review published literature on patient dosimetry in IC, discuss discrepancies of results, and comment on risks to patients and strategies to minimize patient radiation doses.

Patient Dosimetry Review in IC

Data were collected from 72 studies published in international scientific literature between 1986 and 2008 concerning non-pediatric patient dose measurements and

Table 1. Type of Procedures and Corresponding Number of Studies

Type of procedure	Number of studies	References
CA	47	[5, 8-53]
PCI	43	[5, 8-10, 12, 13, 15, 16, 19-22, 24, 25, 27, 28, 30, 32, 34, 35, 38, 40, 43-47, 49-51, 53-65]
RFA	17	[5, 20, 33, 45, 49, 53, 65-75]
CA+PCI	9	[14, 19, 22, 23, 25, 28, 41, 42, 49]
CA+LV	8	[24, 26, 33, 45, 54, 56, 58, 76]
EF	7	[33, 45, 49, 53, 71, 73, 74]
PCI with stenting	7	[22, 25, 27, 28, 33, 56, 58]
CA+PCI with stenting	2	[22, 28]
CA+LV+PCI with stenting	1	[76]

CA: coronary angiography; PCI: percutaneous coronary intervention; LV: left ventriculography; EF: electrophysiological study; RFA: radiofrequency ablation

calculations in IC. Cardiac procedures reported in these studies fall into nine categories which are shown in Table 1 together with the corresponding number of studies.

The most frequently reported procedures were coronary angiography (CA) and percutaneous coronary intervention (PCI), followed by radiofrequency ablation (RFA) and combined CA and PCI. Other procedures for which patient dosimetric data were reported were CA with left ventriculography, electrophysiology studies, PCI with stent implantation, CA with PCI and stent implantation, and CA with left ventriculography and stent implantation. Many studies reported data for more than one procedure whereas some studies compared the dosimetric data for the same procedure under varying conditions (e.g. procedural technique, equipment, cardiologist's experience etc).

The quantities used to assess patient dosimetry in these studies are tabulated in Table 2.

Table 2. Assessed Quantities, Dosimetry Objective and Corresponding Number of Studies

Quantity	Dosimetry objective	No. of studies assessed this quantity
Fluoroscopy time*	Quality assurance	60
Dose Area Product (DAP)†	Quality assurance	53
Cine frames*	Quality assurance	27
Effective dose‡	Stochastic risk	23
Cine time*	Quality assurance	12
Skin dose‡	Deterministic risk	12
Coronary dose‡‡	Deterministic risk	2

* non-dosimetric; † dosimetric; ‡ dose to a coronary artery (in Gy) measured with a catheter based dosimeter during irradiation

The most commonly used quantities were fluoroscopy time and DAP followed by the number of cine frames and effective dose. Other quantities assessed were cine time, skin dose and coronary dose, the dose to a coronary artery measured by a catheter based dosimeter during irradiation [28]. Fluoroscopy time (usually measured in minutes) is a non-dosimetric quantity; however it is widely used to evaluate patient dosimetry since it is readily available and still the only dose metric routinely employed in many interventional laboratories. Nevertheless it does not incorporate information about dose rate and skin entrance ports [77, 78]. DAP (measured in $\text{Gy}\cdot\text{cm}^2$) is the product of the dose in air in a given plane by the area of the irradiating beam and is independent of the distance from the x-ray source because the decrease in dose with distance parallels the increase in area [79]. DAP is the initial quantity not only for estimating patient skin dose but for first establishing the stochastic risk to patients, characterized by effective dose (E) [42]. DAP is measured by an ionization chamber incorporated into the x-ray equipment and includes field non-uniformity effects such as anode-heel effect and use of beam-equalizing shutters (lung shutter). However it does not provide any information regarding the spatial distribution of the entrance beam on patient's skin [77]. Cine time and cine

frames (measured in seconds and number respectively) are also non-dosimetric quantities which are readily available but have the same limitations as fluoroscopy time. Effective dose (measured in mSv) introduced by the International Commission on Radiological Protection [80] is widely used as a stochastic risk related factor to assess radiation detriment and is also used to set dose limits and constraints, to limit the risk of cancer and hereditary effects. Effective dose can be assessed by three methods: (1) measurements in physical anthropomorphic phantoms using thermoluminescent dosimeters (TLDs), (2) by multiplying DAP by a conversion factor. Multiple sources of conversion factors exist but the most widely used are those proposed by the National Radiological Protection Board (NRPB) [81] and (3) by Monte Carlo based computer simulation codes such as WinODS [82], PCXMC [83] and XDOSE [84] which are fed with data of DAP for each projection, tube potential, field sizes and patient data. Skin dose is usually assessed by peak skin dose (measured in Gy) which is the highest absorbed dose received by any location on the patient's skin and is thought to be best predictor of skin injury. Skin dose can be assessed with different methodologies [77]: (1) by direct calculation with off-line or on-line techniques, (2) by direct measurements on the patient with point detectors, (3) by direct measurement on the patient with large area detectors (e.g. Films). Coronary dose (measured in Gy) is measured by a TLD dosimeter placed at the tip of a catheter which is then advanced at the vicinity of the coronary artery subjected to angiography or intervention [28].

Patient dosimetry methodologies and quantities can be divided into three categories according to dosimetry objective (Table 2) [85]: (i) dosimetry for stochastic risk evaluation, (ii) dosimetry for quality assurance and (iii) dosimetry to prevent deterministic effects of radiation. Effective dose (E) is the most suitable indicator in the assessment of diagnostic practice and population exposure and estimates the health risk owing to stochastic effects of radiation. DAP, fluoroscopy time, cine time and number of cine images are useful indicators to evaluate optimization level of radiological practise, to compare performance of equipment and operator skill or to compare the practice among different centres. Peak skin dose is important to assess the potential of deterministic effects due to skin irradiation and to prevent them. The literature of case reports, describing radiation induced skin injuries due to IC procedures is growing [86]. Therefore the potential of deterministic effects in some procedures may be of more concern than stochastic risk [85]. Coronary dose received during IC procedures although not frequently reported has been proposed as an iatrogenic component to coronary artery restenosis [87] and therefore might be of importance.

Published Results

Published results on dosimetry in IC are presented in Table 3. In order to calculate the mean of the reported average and median values for each IC procedures, the average and median value of each study was considered against the total number of patients included in the particular study. The total sample for each IC procedure and the sample used to calculate the mean values are also shown in Table 3. The range of values shown in the table is the entire

Table 3. Dosimetric Measurements Per Type of Intervention

Examination	Total Sample	Fluoroscopy Time (min)			Cine Time (s)			Cine Frames (count)			DAP (Gy·cm ²)			Peak Skin Dose (mGy)			Effective Dose (mSv)			Coronary Dose (mGy)		
		Average (sample)	Median (sample)	range	Average (sample)	Median (sample)	range	Average (sample)	Median (sample)	range	Average (sample)	Median (sample)	range	Average (sample)	Median (sample)	range	Average (sample)	Median (sample)	range	Average (sample)	Median (sample)	range
CA	9100	4.7 (6398)	4.1 (1504)	0.3-57	52 (445)	49 (741)	-	644 (4122)	1041 (646)	10-4490	39.9 (7592)	41.7 (3365)	1.1-2400	351 (108)	-	49-711	9.1 (3418)	-	0.3-15.8	24 (16)	-	-
PCI	5294	15 (4273)	11.1 (645)	1.4-172	93 (1034)	77 (106)	-	972 (1749)	1361 (539)	206-7969	78.3 (4042)	57.0 (661)	3.0-403.6	1304 (253)	-	170-1660	17.0 (500)	-	-	60.6 (291)	-	-
RFA	1682	45.8 (1528)	70.4 (119)	0.8-164	-	-	-	109 (123)	-	0-1270	54.6 (407)	46 (285)	0.03-430	513 (132)	-	3-3200	20.3 (1043)	-	-	-	-	-
CA+PCI	661	18 (269)	-	2.5-86	74 (125)	-	-	2199 (78)	-	360-6833	109.3 (225)	-	15.5-557.4	-	-	-	13.6 (147)	-	0.9-44.7	55 (7)	-	-
CA+LV	1297	4.6 (1182)	-	0.3-39	49 (10)	-	-	1038 (106)	-	470-1331	28.0 (1176)	20.0 (1139)	1.0-202.8	343.5 (50)	-	-	7 ¹ (100)	-	-	-	-	-
EF	237	9.0 (136)	-	0.1-258	-	-	-	38 (24)	-	0-670	14.5 (112)	-	0.5-210	-	-	-	-	3.2 (19)	1.3-23.9	-	-	-
PCI with stenting	343	18.3 (73)	-	3-46	108 (58)	-	-	-	-	-	78.2 (83)	-	2.4-357	1606 (35)	-	-	9.6 (29)	-	-	43.6 (15)	-	-
CA+PCI with stenting ²	16	30.4 (16)	-	-	152 (16)	-	-	-	-	-	81.8 (16)	-	-	-	-	-	15.1 (16)	-	-	64.7 (9)	-	-
CA+LV+PCI with stenting ¹	100	80 (100)	70 (100)	15-361	-	-	-	-	-	-	-	-	-	-	-	-	16 (100)	-	-	-	-	-

CA: coronary angiography, PCI: percutaneous transluminal coronary angioplasty, LV: left ventriculography, EF: electrophysiological study, RFA: radiofrequency ablation

¹One study reported results; ²Two studies reported results

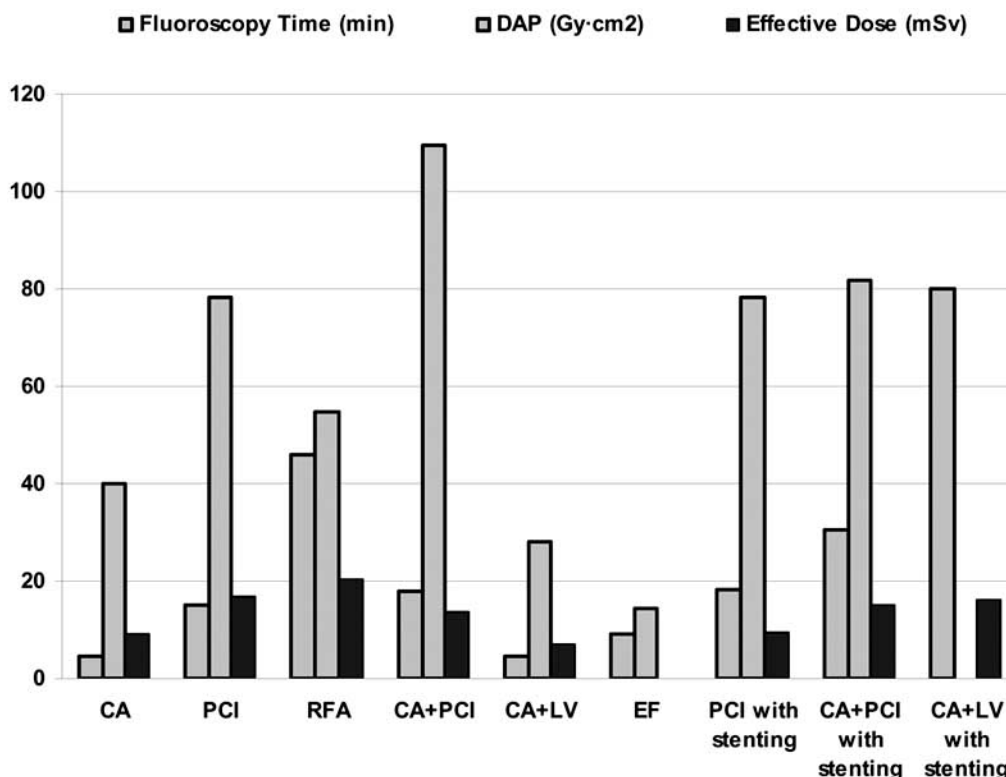


Fig. (1). Mean fluoroscopy time, DAP and effective dose per type of intervention.

range considering the range of values reported in each study. The mean fluoroscopy time, mean DAP and mean effective dose are graphically presented in Fig. (1). Mean cine frames and mean cine time per procedure are presented in Fig. (2) while mean peak skin dose and mean coronary dose are presented in Fig. (3).

DISCUSSION

It is evident from the tabulated data that the range of the reported values for each IC procedure is considerably wide. For example the range of DAP values for CA (1.1-2400 Gy·cm²) comprises the DAP values reported for almost any IC procedure. This is however due to the fact the CA is the most extensively studied procedure and dosimetric data include results reported in the 80s and 90s when radiation protection and catheterization laboratory equipment were less advanced. A recent study collected DAP values for 2265 coronary angiographies performed between 2003-2005 in seven centers and has also reported large variability of results although DAP values spanned in a narrower range of 5-130 Gy·cm² [88]. The wide range of reported values are evident in all IC procedures and can be attributed to operator experience [40], workload [61], use of radiation-reducing techniques [38], procedural complexity [60, 89], examination technique [11] and catheterization laboratory equipment [42, 90]. In order to compare results between older and newer studies, mean DAP, mean fluoroscopy time and mean effective dose were calculated for results published before and after the year 2000 concerning the most extensively studied procedures (CA and PCI) (Table 4). It is evident that due to on-going development in radiation protection and catheterization laboratory equipment there is considerable reduction in radiation received by patients.

Table 4. Comparison of Results Between Studies Published Before and After the Year 2000

	Fluoroscopy Time (min)		DAP (Gy·cm ²)		Effectime Dose (mSv)	
	CA	PCI	CA	PCI	CA	PCI
before year 2000	6.2	21.3	52.5	81.7	11.7	20
after year 2000	3.7	12.2	31.1	59.2	8.4	13.6

The calculated mean values of the dosimetric and non-dosimetric quantities indicate that PCI procedures either with or without stent implantation result in increased radiation received by patients compared to angiography. When coronary angiography is combined with left ventriculography DAP and E are similar, or even slightly reduced in the combined procedures. However this is probably due to the fact that considerably lesser studies included ventriculography (8 studies, 1297 total patients) than CA without ventriculography (51 studies, 9100 total patients) and thus the calculated mean values are less representative, particularly for E which is calculated only in one study. The same applies for the particularly high fluoroscopy time and effective dose reported for procedures that combine CA with left ventriculography and stenting since these values result from a single study. Contradictory results on mean effective dose at PCI (sample 500, mean E=17 mSv) and CA with PCI

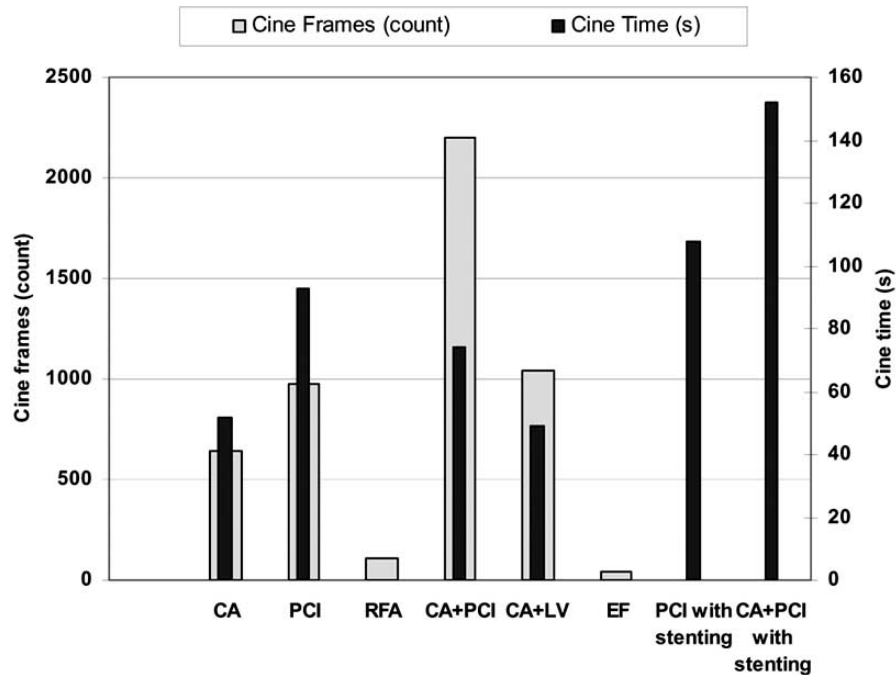


Fig. (2). Mean cine frames and cine time per type of intervention.

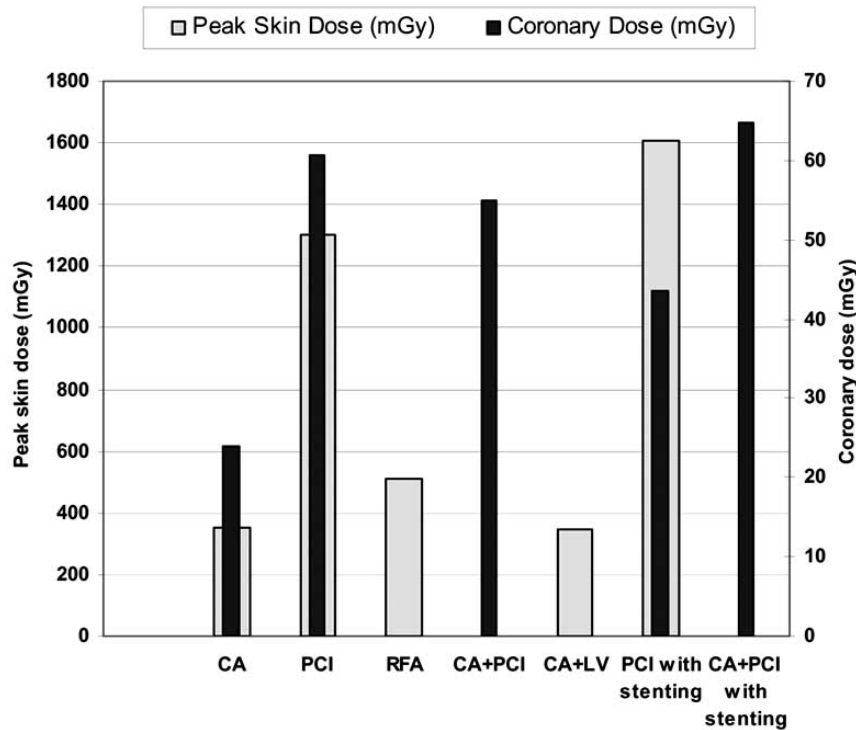


Fig. (3). Mean peak skin dose and coronary dose per type of intervention.

(sample 147, E=13,6 mSv) are observed since it is expected that the combined procedure would result in higher effective dose. A likely explanation is that two studies on PCI with a large patient cohort (total 220 patients) are reporting effective dose values of 23.2 mSv [34] and 15,3 mSv [50] which are particularly high compared to other studies [34] and thus their contribution to mean effective dose results in an overall high mean value. Other studies on PCI with smaller patient cohort (total 22 patients) are reporting

substantially lower effective dose values of 6.6 mSv [28] and 6.9 mSv [22]. EF studies generally result in low patient exposure since fluoroscopy is exclusively used (without image acquisition) while RFA ablation is the procedure where the maximum values of DAP and effective dose are reported owing to the extended fluoroscopic times (average fluoroscopic time 45.8 min).

A few studies have included measurements of coronary dose, the dose received by the coronary vessels during

Table 5. DAP Values (cGy·cm²) Reported by Various Investigators. Evaluation of the Effect of Various Parameters on Patient Dose

		CA	PCI			CA	PCI
Broadhead <i>et al.</i> [20]	biplane system	47.7	72.2	Philippe <i>et al.</i> [64]	femoral approach		18.8
	single plane system	23.4	51.6		radial approach		28.6
Bernardi <i>et al.</i> [57]	simple procedure		65.8	Sandborg <i>et al.</i> [41]	femoral approach	38	47
	medium procedure		93		radial approach	51	75
	complex procedure		116.7				
Padovani <i>et al.</i> [60]	simple procedure		66.7	Tsapaki <i>et al.</i> [43]	image intensifier	39.3	44.3
	medium procedure		96.4		flat panel	27.7	51.1
	complex procedure		132.7	Tsapaki <i>et al.</i> [44]	image intensifier	30	45
			flat panel		31	48	
Arthur <i>et al.</i> [31]	cardiologist controlled radiation exposure	15.6		Traini <i>et al.</i> [47]			
	radiographer controlled radiation exposure	17.3			image intensifier	31.1	52
	cardiologist grade: first operator	13.6			flat panel	33.4	66.9
	cardiologist grade: assistant	20.8					
Kuon <i>et al.</i> [94]	dose level A (lowest)	5.97		Davies <i>et al.</i> [73]		EF	RFA
	dose level B	6.73			standard dose	27.17	74.77
	dose level C	8.11			low dose	3.55	11.62
	dose level D (highest)	8.9					

irradiation. The method of measurement involves the insertion of a catheter with a TLD dosimeter at its tip which is then advanced to the sinus of Valsalva corresponding to the coronary artery subjected to angiography or intervention [28]. The obvious advantage of the method is that it allows direct measurement of coronary dose, although this is not absolutely correct since due to technical and ethical reasons the dosimeter is not advanced inside the artery. Such a measurement might be important since experimental studies have shown that external beam radiation after stent implantation increases the restenosis rate [91, 92]. However the measured coronary doses were found approximately 2 orders of magnitude lower than the doses that have resulted in neointimal hyperplasia after external beam irradiation [93]. The main disadvantage is the invasive nature of the technique which makes it difficult to adopt in everyday clinical practice.

A number of studies have evaluated the effect of various parameters on patient dose at IC procedures. The parameters that have been investigated include catheterization laboratory equipment, procedural complexity, operator experience, and irradiation parameters. Broadhead *et al.* [20] compared patient dosimetry in two cardiology rooms, one equipped

with biplane image intensifier system and one with single intensifier system, and found that the biplane system provides greater imaging capability but also increases patient dose. Bernardi *et al.* [57] and Padovani *et al.* [60] investigated the effect of the complexity of PCI procedures on patient exposure by dividing the procedures in 'simple', 'medium' and 'complex' based on a set of indexes and they found correlation between patient dose and procedural complexity. Arthur *et al.* [31] explored whether radiation dose was lower during cardiologist- or radiographer-controlled radiation exposure and determined whether the grade of the cardiologist influences radiation dose. They found that cardiologist-operated exposure and senior cardiologists result in lower radiation doses during CA. Kuon *et al.* [94] varied the image intensifier entrance dose level in CA and found that with the exception of cases with special requirements, lower dose levels guarantee adequate image quality with reduced patient dose. Philippe *et al.* [64] and Sandborg *et al.* [41] compared the radial arterial approach to the femoral approach and found that radial approach yielded significantly higher patient dose. Tsapaki *et al.* [44, 95] and Trianni *et al.* [47] evaluated the dose performance of flat-panel systems compared to conventional image intensifier systems. They concluded that flat panel

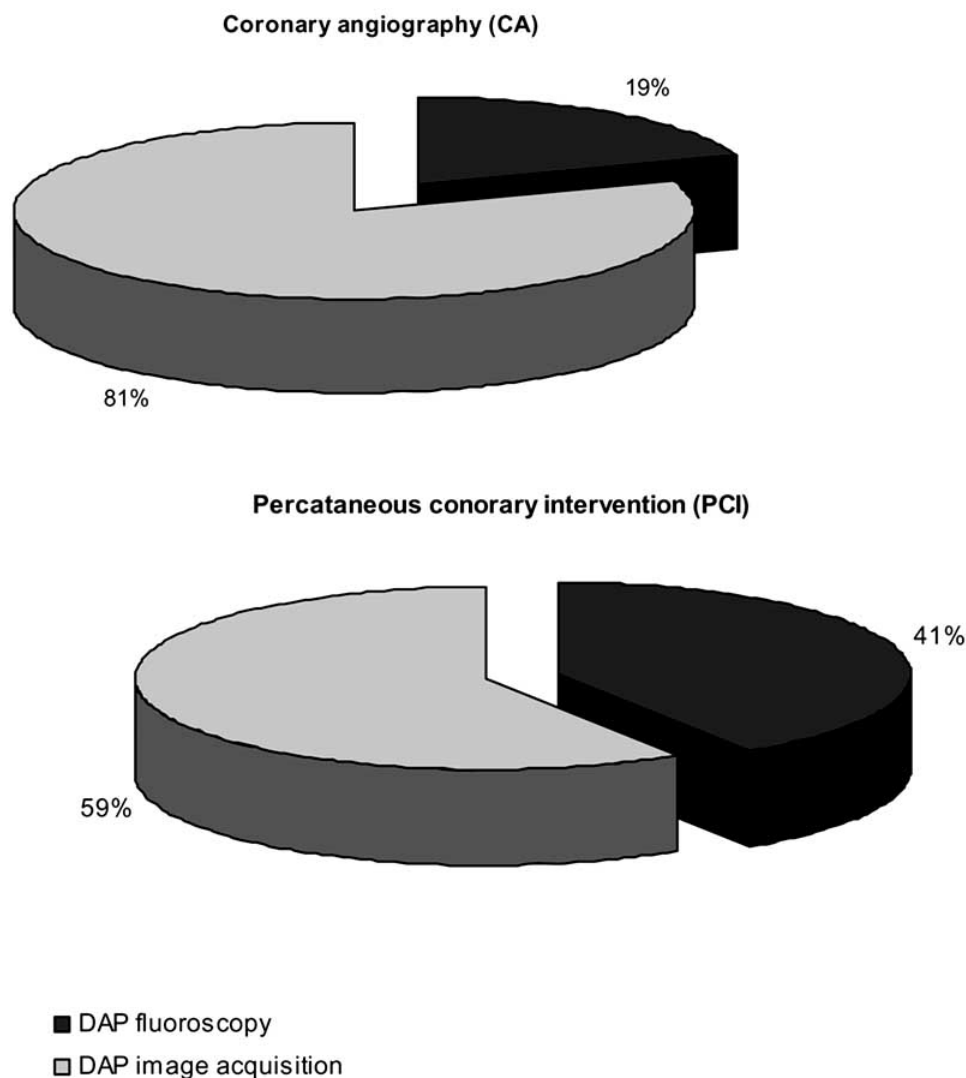


Fig. (4). Contribution to total DAP of fluoroscopy and image acquisition during coronary angiography (CA) and percutaneous coronary intervention (PCI).

systems produce images of higher quality with lower entrance dose rates than image intensifier systems and thus dose reduction with flat panel systems is possible. However in clinical practise the final performance of flat panel systems in terms of patient dose could give opposite results. Davies *et al.* [73] studied patient dose levels before and after the introduction of a dose reduction regime in EF and RFA procedures and found a considerable overall reduction in DAP. The results of these studies are tabulated in Table 5.

An interesting issue regarding patient dosimetry is the contribution of fluoroscopy and image acquisition in total patient exposure. A number of studies report separate DAP values for fluoroscopy and fluorography during CA and PCI procedures [35, 62, 63, 96]. Mean DAP for fluoroscopy and image acquisition calculated from the values reported in these studies is shown in Fig. (4). In both procedures image acquisition contributes more in patient exposure although this is more profound in CA. Therefore minimization of fluorography would potentially lead to considerable patient dose reduction.

Another interesting issue is the comparison of patient radiation doses during non-invasive examinations with

patient radiation doses during conventional coronary angiography. Multi-slice computed tomography (MSCT) coronary angiography is currently considered as a promising non-invasive alternative to conventional angiography due to recent advantages in spatial and especially temporal resolution of the technique [97, 98]. However, radiation dose is a major concern for MSCT coronary angiography, especially in cases of repeated examinations or in particular subgroups of patients (for example young female patients) [99]. Some investigators have compared radiation dose exposure during MSCT and conventional coronary angiography. The results are tabulated in Table 6.

All investigators conclude that mean effective dose for MSCT coronary angiography is significantly higher than that of conventional angiography. The organs receiving the highest equivalent doses in MSCT coronary angiography are the female breasts, lungs, liver and oesophagus [78]. Thus as MSCT cardiac scanners are becoming increasingly available, operators must be aware of the radiation doses, the factors that affect it and the importance of dose reduction techniques.

Table 6. Comparison of Effective Dose Reported by Investigator Comparing Multislice Computed tomography Coronary Angiography (MSCT CA) with Conventional Coronary Angiography (CCA)

Study	Scanner	Effective dose (mSv)			
		MSCT CA	CCA	MSCT CA	CCA
		<i>patients without bypass grafts</i>		<i>patients with bypass grafts</i>	
Dill <i>et al.</i> [100]	16-slice	9.76±1.84	2.60±1.27	12.95±1.75	6.27±4.04
Coles <i>et al.</i> [48]	16-slice	14.7±2.2	5.6±2.7		
Jabara <i>et al.</i> [98]	64-slice			14.1±3.8	9.0±2.7

Risk to Patients

Invasive cardiology procedures provide great diagnostic and therapeutic benefit to patients but also subject them to considerable radiation exposure. On average, a coronary angiography corresponds to a radiation exposure to the patient of about 300 chest x-rays, while coronary stent implantation corresponds to 1000 chest x-rays and a radiofrequency ablation procedure up to 1500 chest x-rays [6, 101]. It is estimated that radiation induced cases of cancer per year in the UK is 280 cases per million of coronary angiographies whereas for CT scans, screening mammography and chest X-rays the cases of radiation induced cancer is 60, 8 and 1 cases per million examinations respectively [102]. In general, the justification of IC procedures is evident since they permit patients to avoid complicated invasive surgery which some might not tolerate due to factors of age or pathology [7]. Radiation is one of the many hazards to which a patient undergoing an IC procedure is exposed and it is generally accepted that the radiological risk, although high, will always be lower than other risks involved in the procedure [103, 104]. Nevertheless, radiation risk to patient must always be a matter of concern since in some complex procedures, patient skin doses can cross the threshold of deterministic effects whereas the increment of stochastic effects probability should also be taken into account, especially in young patients.

During a IC procedure the patient skin dose may occasionally exceed the threshold of 2Gy above which transient erythema and skin burns are observed [105]. In procedures where prolonged fluoroscopy time is used or when fluoroscopy is performed in a single projection the danger of large peak skin doses is increased. To avoid radiation skin injuries it is necessary to keep the exposure doses as low as can be reasonably achieved [106, 107], and it is recommended to monitor entrance surface doses. Unfortunately, real time maximum dose monitoring of the skin is difficult to assess in clinical practice since it is impossible to predict the site of maximum exposure before the intervention commences. In the absence of a direct measurement, conversion factors published in the literature may be used to establish peak skin dose from DAP values for CA and PCI [30, 46, 65]. Regarding CA, published conversion factors are 3.8 mGy/Gy·cm² [65], 3.9 mGy/Gy·cm² [46] and 4.3 mGy/Gy·cm² [108] whereas regarding PCI published conversion factors are 8.1 mGy/Gy·cm² [65], 8.7 mGy/Gy·cm² [108] and 9.7 mGy/Gy·cm² [46].

To assess the potential risk of stochastic effects such as cancer and leukaemia, the effective dose to the patient must be calculated [109]. Unfortunately, determining the effective dose in clinical practise is not straightforward, mainly because of the complexity of the x-ray beam geometry and field size, variations during the catheterization procedure, and the individual patient anatomy. However an excellent correlation between effective dose and DAP has been found based on phantom measurements and Monte Carlo simulations, indicating that using a simple conversion factor to estimate effective dose from DAP values is acceptable [49]. Published conversion factors are 0.183 mSv/ Gy·cm² [22], 0.185 mSv/ Gy·cm² [50], and 0.221 mSv/ Gy·cm² [18].

Patient Dose Reduction

According to the 'as low as reasonably achievable' (ALARA) and optimization principles [2] it is necessary to minimize patient dose in order to outweigh the radiation risk by the benefit of the interventional procedure. Therefore efforts should be made to properly manage radiation exposure to the patient. The most evident approach in order to reduce patient dose is by minimizing the beam-on time both for fluoroscopy and acquisition [79]. This can be achieved through the practice of intermittent fluoroscopy (short bursts of beam-on time) rather than continuous fluoroscopy [110]. Radiation field should be minimized to include only the anatomic region of interest since proper collimation of the x-ray beam substantially decreases patient dose. The image intensifier should be positioned as close to the patient's body as possible while the height of the table should be adjusted to keep the body of the patient as further away from the x-ray tube as possible [69]. Fluoroscopic systems providing pulsed-fluoroscopy mode are preferable since, compared to a non pulsed system, a system that pulses the beam at 12.5 frames/s can result to 80% less exposure [110]. The use of high-level control to improve image quality under specific circumstances by increasing the dose rate should be avoided as much as possible. The same applies for the use of magnification which also increases the dose received by the patient. On the contrary, last image hold, a feature which presents the last acquired fluoroscopic frame on the video monitor [79, 111], obviating the need for continuous fluoroscopy, reduces fluoroscopic time and should be used as much as possible. At cine mode, the lower setting of frames per second should be used whenever possible (e.g. 15 frames/s instead of 30 frames/s). During procedures that require long fluoroscopy time, if clinically feasible, changing the radiographic projection minimizes patient skin dose [79]. Inspection and quality control of both

the dose levels and the image quality of fluoroscopic equipment should be routinely contacted in order to assure optimum performance [69, 79]. Finally motivation and training of all laboratory personnel including radiographers and nursing staff and the overall efficiency of the catheterization laboratory contribute to patient dose reduction.

CONCLUSION

Patient radiation doses vary widely among the different interventional cardiology procedures but also among published studies. Discrepancies of the derived results are patient-, procedure-, physician-, and fluoroscopic equipment-related. Nevertheless, IC procedures can subject patients to considerable radiation doses and efforts to minimize patient exposure should always be undertaken.

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