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Editor's Choice

Determinants of Fluoroscopy Time for Invasive Coronary Angiography and Percutaneous Coronary Intervention: Insights from the NCDR®

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ABSTRACT: Objectives: Identifying the distributions and determinants of fluoroscopy time for invasive coronary angiography (ICA) and percutaneous coronary intervention (PCI). Background: ICA and PCI are significant contributors to radiation exposure from medical imaging in the US. Fluoroscopy time is a potentially modifiable determinant of radiation exposure for these procedures, but has not been well characterized in contemporary practice. Methods: We evaluated the distribution of fluoroscopy time in patients undergoing ICA and/or PCI in the CathPCI Registry®, stratifying patients by numerous clinical scenarios. Hierarchical models were used to determine patient, procedure, operator and hospital-level factors associated with fluoroscopy time for these procedures. Results: Our study included a total of 3,295,348 ICA and PCI procedures performed by 9,600 operators from January 2005 through June 2009. There was wide variation in fluoroscopy times for these procedures with median [IQR] fluoroscopy times of 2.6 [1.7–4.5] minutes for ICA, 6.7 [4.2–10.8] minutes for ICA in patients with

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prior coronary artery bypass grafting (CABG), 10.1 [6.0–17.4] minutes for PCI, 10.7 [7.0–16.9] minutes for PCI with ICA, and 16.0 [10.6–24.0] minutes for PCI and ICA in patients with prior CABG. Prolonged fluoroscopy times (>30 minutes) were rare for ICA, but occurred in 6.7% of PCIs and 14.7% of PCIs in patients with prior CABG. After accounting for patient characteristics and procedure complexity, operator and hospital-level factors explained nearly 20% of the variation in fluoroscopy time. Conclusions: Fluoroscopy times vary widely during ICA and PCI with operator and hospital-level factors contributing substantially to these differences. A better understanding of potentially modifiable sources of this variation will elucidate opportunities for enhancing the radiation safety of these procedures.

Key words: RDA—radiation physics; CATH—diagnostic cardiac catheterization; PCI—percutaneous coronary intervention

INTRODUCTION

Over one million invasive coronary angiography (ICA) and 490,000 percutaneous coronary intervention (PCI) procedures are performed annually in the United States [1]. These two procedures alone account for nearly 8% of all radiation exposure from medical imaging in the general population [2–4]. In contrast to protocol-based imaging procedures such as computed tomography or nuclear medicine scans, the performance of ICA and PCI also has inherent variability in its duration, leading to wide ranges of radiation exposure for patients undergoing the same type of procedure [5–7].

In contrast to noncardiac fluoroscopic procedures, fluoroscopy times for ICA and PCI correlate well with air kerma-area product ($R^2 = 0.53$ to 0.61) [6,8], the preferred measure for estimating total radiation exposure during such procedures [9,10]. Lack of routine use of collimation by cardiologists during ICA and PCI is probably a key reason for this distinction between cardiac and noncardiac fluoroscopic procedures. As fluoroscopy time accounts for the majority of variation in air kerma-area product [6,8], it serves as a practical surrogate measure of total radiation exposure during ICA and PCI. For these reasons and based on the ALARA principle—which states that every reasonable effort should be made to reduce radiation exposure [11,12]—minimizing fluoroscopy time has long been considered a cornerstone of improving radiation safety in cardiac catheterization labs [13,14]. Yet, despite its importance, no national benchmarks for ICA and PCI fluoroscopy time, with or without adjusting for procedure complexity, have been previously developed.

Accordingly, we used data from the CathPCI Registry to describe the distribution of fluoroscopy time for ICA and PCI in the United States. In addition to describing overall patterns of fluoroscopy time in contemporary practice, we also evaluated the specific contribution of operator and hospital-level factors—including operator volume—on variation in fluoroscopy time after accounting for patient characteristics and procedure complexity. This last analysis was performed to elucidate potential opportunities for further enhancing the radiation safety of these procedures.

MATERIALS AND METHODS

Data Sources

We included ICA and PCI procedures that were performed between January 1, 2005 and June 30, 2009 at facilities participating in the CathPCI Registry. Details of the registry's participants, cohorts, and data collection methods have been described previously [15,16]. Briefly, the CathPCI Registry is an initiative of the American College of Cardiology Foundation and the Society for Cardiovascular Angiography and Interventions, and is composed of clinical data related to diagnostic ICAs and/or PCIs performed at over 1,000 hospitals in the United States. Participating hospitals submit data pertaining to characteristics of patients, procedure findings and complications, interventions performed, and in-hospital outcomes for all ICA and PCI procedures performed at their facilities.

Study Population

All ICA and PCI procedures with known fluoroscopy time and operator were eligible for this study. Fluoroscopy time was defined as total fluoroscopy time recorded, during the procedure, to the nearest 0.1-minute [17]. Based on specific procedure components and the presence of prior coronary artery bypass grafting (CABG), procedures were categorized into five mutually exclusive groups: (1) ICA, (2) ICA in patients with prior CABG, (3) PCI, (4) PCI and ICA, and (5) PCI and ICA in patients with prior CABG. Procedures with missing values for ICA indication ($n = 101$), PCI lesion location ($n = 341$), clinical presentation ($n = 427$), or hospital census region ($n = 6{,}495$) were excluded. As only the overall fluoroscopy time for any given procedure was available, fluoroscopy times for combined ICA and PCI procedures with two different

operators ($n = 17,869$) were assigned to the operator performing the PCI. Importantly, the distribution of fluoroscopy times for procedures with unknown operator ($n = 1,142,130$) was nearly identical to that for procedures with operator identifier recorded (Appendix) suggesting that exclusion of procedures with unknown operator from our study did not lead to a significant bias in fluoroscopy time.

Patient, Procedure, Operator, and Hospital Data

Patient records included data elements on demographic characteristics (age, gender, race, and insurance status), cardiovascular risk factors (hypertension, dyslipidemia, family history of premature coronary artery disease, diabetes mellitus, end-stage renal disease), cardiovascular disease history (prior myocardial infarction, congestive heart failure, prior PCI, cerebrovascular disease, peripheral vascular disease), clinical presentation (asymptomatic, atypical chest pain, stable angina, unstable angina, non-ST-segment elevation myocardial infarction (non-STEMI), or STEMI). Procedure-related information for ICA without PCI included indication (rule out of coronary artery disease, valvular heart disease, evaluation of cardiomyopathy, preoperative evaluation for non-cardiac surgery, congenital heart disease, or cardiogenic shock within 24 hours prior to procedure), concomitant procedures (right heart catheterization or intra-aortic balloon pump insertion), arterial access site (femoral, radial or brachial), and presence and location (native coronary arteries versus bypass grafts) of coronary stenosis of $\geq 50\%$. For PCI, lesion location and characteristics (complexity, previously treated lesion, bifurcation lesion), complications (coronary dissection, perforation, no reflow phenomenon), and use of specific intracoronary devices (atherectomy, thrombectomy, or extraction catheter, laser, or embolic protection device) were also included. Significant coronary dissection was defined as the appearance of contrast materials outside the expected luminal dimensions of the target vessel and extending longitudinally >5 mm beyond the length of the lesion [18]. Operators were identified based on their Unique Physician Identification Number (UPIN) and/or National Provider Identifier (NPI). Annual operator volume was calculated by dividing the total number of procedures performed by an operator in the study cohort by the number of quarters in which they performed at least one procedure and multiplying this value by four. Operators who performed at least one PCI in the CathPCI Registry during the study period were categorized as interventional cardiologists. Hospital information included data elements on teaching status, number of beds, ownership (government, university, or community/private), and US Census region.

Statistical Analysis

Our primary outcome was fluoroscopy time. Fluoroscopy times are presented as medians with interquartile ranges (IQRs) given their skewed distribution. Other continuous variables are summarized as mean with standard deviation, and categorical variables are displayed as frequencies and percentages. Hierarchical multivariable regression was used to examine the association between fluoroscopy time and the above-mentioned patient, procedure, operator, and hospital factors after accounting for the potential effects of clustering of patients within operators and hospitals [19]. A two-level hierarchical model was used, with patient and procedure factors included in level 1, and operator and hospital factors in level 2. Variables included in the hierarchical models consisted of the data elements listed above as well as the year of admission to adjust for potential secular temporal trends in fluoroscopy time. Given concern about the accuracy of very high and low operator volumes, we performed a sensitivity analysis by repeating the hierarchical models after excluding procedures performed by operators with annual volume of <50 or $>2,000$ procedures per year ($n = 218,101$). To assess the potential influence of complicated procedures on our estimates, we also performed a separate analysis by repeating the multivariable analyses after excluding procedures in which major complications occurred within the catheterization laboratory, including coronary dissection, coronary perforation, acute coronary vessel closure, or no reflow phenomenon.

Finally, in order to determine the proportion of the overall variation in fluoroscopy time that was related to operator- and hospital-level factors (i.e., level-2 factors in the hierarchical models) we used the intraclass correlation coefficients. In addition to the above analyses, we used fractional polynomial regression to further assess the relationship between fluoroscopy time and operator volume. This approach has the benefit of introducing the possibility of non-linear associations between these two variables without imposing constraints using artificially constructed categories. This relationship was evaluated separately for diagnostic ICA (without PCI) and PCI (with or without ICA). Because of concern about the accuracy of very high or low annual volume estimates, operators with annual volume of the <50 or $>2,000$ procedures were excluded from this analysis to minimize the impact of these outliers. The above listed patient, procedure,

TABLE I. Characteristics of Patients Undergoing Invasive Coronary Angiography (ICA)

	ICA (n = 1,517,930)		ICA (prior CABG) (n = 255,431)	
	n	%	n	%
Female	703,640	46.4	74,705	29.2
Age				
Under 35	23,478	1.5	334	0.1
35 to <55	426,473	28.1	28,838	11.3
55 to <75	779,988	51.4	146,315	57.3
75 or over	287,991	19.0	79,944	31.3
Body mass index (kg/m2), mean (sd)	30.5	7.3	29.7	6.1
Race				
White	1,220,849	80.4	221,897	86.9
Black	141,896	9.3	11,920	4.7
Other	155,185	10.2	21,614	8.5
Comorbidities				
Hypertension	1,053,205	69.4	205,347	80.4
Dyslipidemia	922,456	60.8	206,783	81.0
Prior myocardial infarction	219,660	14.5	105,701	41.4
Congestive heart failure	156,579	10.3	53,142	20.8
Family history of premature CAD	395,474	26.1	69,009	27.0
Prior PCI	303,068	20.0	106,051	41.5
End-stage renal disease	282,74	1.9	6,244	2.4
Cerebrovascular disease	138,174	9.1	43,064	16.9
Peripheral vascular disease	133,329	8.8	50,160	19.6
Chronic lung disease	263,013	17.3	49,792	19.5
Diabetes mellitus	426,841	28.1	104,044	40.7
Commercial insurance	470,851	31.0	50,706	19.9
Clinical presentation				
No symptoms	381,455	25.1	57,215	22.4
Atypical chest pain	353,262	23.3	35,455	13.9
Stable angina	237,111	15.6	46,368	18.2
Unstable angina	401,359	26.4	90,295	35.4
Non-ST-segment elevation MI	115,621	7.6	23,021	9.0
ST-segment elevation MI	29,122	1.9	3,077	1.2
Indication				
Rule out CAD	1,430,005	94.2	238,772	93.5
Valvular heart disease	138,253	9.1	25,750	10.1
Evaluation of cardiomyopathy	407,452	26.8	110,681	43.3
Pre-operative evaluation for non-cardiac surgery	53,128	3.5	8,168	3.2
Congenital heart disease	4,805	0.3	320	0.1
Cardiogenic shock within 24 hours	13,660	0.9	2,325	0.9
Arterial access site				
Femoral	1,488,066	98.0	252,328	98.8
Brachial	7,538	0.5	1,824	0.7
Radial	22,326	1.5	1,279	0.5
Intraaortic balloon pump inserted	21,864	1.4	1,992	0.8
Concomitant right heart catheterization	205,457	13.5	29,713	11.6
Coronary artery stenosis present				
Native coronary vessels	519,639	34.2	244,526	95.7
Bypass grafts	n/a	n/a	99,733	39.0
Operator volume, mean (sd)	325	385	338	360
Operator subspecialty (interventional)	1,320,128	87.0	226,400	88.6
Teaching hospital	767,367	50.6	130,581	51.1
Hospital size >250 beds	1,208,384	79.6	205,710	80.5
Census region				
Northeast	252,195	16.6	40,464	15.8
South	638,205	42.0	109,765	43.0
Midwest	430,514	28.4	74,380	29.1
West	197,016	13.0	30,822	12.1
Ownership				
Government	19,689	1.3	3,615	1.4
Private/community	1,340,446	88.3	225,614	88.3
University	157,795	10.4	26,202	10.3
Year of procedure				
2005	203,492	13.4	35,297	13.8
2006	281,245	18.5	47,853	18.7
2007	360,301	23.7	60,843	23.8
2008	432,796	28.5	72,228	28.3
2009	240,096	15.8	39,210	15.4

CABG, coronary artery bypass graft; CAD, coronary artery disease; MI, myocardial infarction.

TABLE II. Characteristics of Patients Undergoing Percutaneous Coronary Intervention (PCI)

	PCI (n = 318,779)		PCI and ICA (n = 988,719)		PCI and ICA (prior CABG) (n = 214,489)	
	n	%	n	%	n	%
Female	108,630	34.1	342,001	34.6	56,716	26.4
Age						
Under 35	1,124	0.4	6,255	0.6	206	0.1
35 to <55	58,568	18.4	251,721	25.5	24,767	11.5
55 to <75	176,941	55.5	526,823	53.3	125,641	58.6
75 or over	82,146	25.8	203,920	20.6	63,875	29.8
Body mass index (kg/m^2), mean (sd)	29.9	6.3	29.8	6.4	29.6	5.9
Race						
White	272,215	85.4	825,790	83.5	187,029	87.2
Black	20,777	6.5	65,476	6.6	9,783	4.6
Other	25,787	8.1	97,453	9.9	17,677	8.2
Comorbidities						
Hypertension	261,642	82.1	739,809	74.8	187,145	87.3
Dyslipidemia	253,627	79.6	715,885	72.4	189,167	88.2
Prior myocardial infarction	95,437	29.9	217,493	22.0	101,298	47.2
Congestive heart failure	41,504	13.0	78,320	7.9	41,220	19.2
Family history of premature CAD	77,133	24.2	252,542	25.5	57,256	26.7
Prior PCI	125,073	39.2	322,018	32.6	114,869	53.6
End-stage renal disease	6,607	2.1	15,583	1.6	5,187	2.4
Cerebrovascular disease	42,372	13.3	92,517	9.4	38,558	18.0
Peripheral vascular disease	45,411	14.2	91,053	9.2	44,732	20.9
Chronic lung disease	57,719	18.1	151,799	15.4	39,107	18.2
Diabetes mellitus	116,346	36.5	299,150	30.3	94,142	43.9
Commercial insurance	86,197	27.0	314,768	31.8	47,376	22.1
Clinical presentation						
No symptoms	59,849	18.8	111,398	11.3	24,933	11.6
Atypical chest pain	21,905	6.9	74,379	7.5	14,512	6.8
Stable angina	65,188	20.4	134,238	13.6	35,637	16.6
Unstable angina	112,758	35.4	305,277	30.9	93,901	43.8
Non-ST-segment elevation MI	39,775	12.5	170,434	17.2	33,949	15.8
ST-segment elevation MI	19,304	6.1	192,993	19.5	11,557	5.4
Cardiogenic shock within 24 hours	4,022	1.3	26,625	2.7	3,333	1.6
Arterial access site						
Femoral	311,907	97.8	968,916	98.0	212,138	98.9
Brachial	1,486	0.5	3,273	0.3	1,040	0.5
Radial	5,386	1.7	16,530	1.7	1,311	0.6
Intraaortic balloon pump inserted	5,486	1.7	30,758	3.1	3,683	1.7
Number of lesions intervened upon: mean (SD)	1.5	0.8	1.4	0.7	1.4	0.7
Concomitant right heart catheterization	1,958	0.6	44,379	4.5	11,107	5.2
PCI lesion characteristics						
Previously treated lesion	29,267	9.2	95,433	9.7	35,050	16.3
Complex lesion (class C)	135,593	42.5	409,495	41.4	100,115	46.7
Bifurcation lesion	47,381	14.9	123,243	12.5	21,434	10.0
PCI lesion location						
Native coronary vessel	293,707	92.1	988,719	100.0	132,587	61.8
Bypass graft- artery	18,699	5.9	0	0.0	65,292	30.4
Bypass graft-vein	1,532	0.5	0	0.0	4,433	2.1
Multiple locations (any combination of above locations)	4,841	1.5	0	0.0	12,177	5.7
Use of intracoronary devices						
Atherectomy, thrombectomy catheter, or laser	14,097	4.4	61,042	6.2	11,218	5.2
Embolic protection device	6,796	2.1	1,275	0.1	15,855	7.4
Procedural complications						
Significant dissection	10,510	3.3	29,278	3.0	5,127	2.4

TABLE II. *Continued*

	PCI (n = 318,779)		PCI and ICA (n = 988,719)		PCI and ICA (prior CABG) (n = 214,489)	
	n	%	n	%	n	%
Coronary perforation	1,276	0.4	3,820	0.4	995	0.5
No reflow phenomenon	3,229	1.0	13,575	1.4	3,881	1.8
Operator volume	325	363	311	391	333	402
Teaching hospital	160,423	50.3	515,930	52.2	112,766	52.6
Hospital size >250 beds	266,768	83.7	816,600	82.6	178,677	83.3
Census region						
Northeast	41,626	13.1	155,807	15.8	30,218	14.1
South	154,464	48.5	382,764	38.7	89,494	41.7
Midwest	84,664	26.6	291,127	29.4	63,543	29.6
West	38,025	11.9	159,021	16.1	31,234	14.6
Ownership						
Government	6,097	1.9	12,035	1.2	2,522	1.2
Private/community	278,905	87.5	871,974	88.2	187,831	87.6
University	33,777	10.6	104,710	10.6	24,136	11.3
Year of procedure						
2005	49,392	15.5	129,498	13.1	27,915	13.0
2006	67,185	21.1	183,340	18.5	39,809	18.6
2007	74,771	23.5	234,064	23.7	50,486	23.5
2008	83,833	26.3	287,065	29.0	62,312	29.1
2009	43,598	13.7	154,752	15.7	33,967	15.8

operator, and hospital characteristics were included in these models.

Two-tailed $P < 0.05$ was considered statistically significant for all tests. All analyses were performed using SAS version 9.2 (SAS Institute, Cary, NC) and Stata version 11 (StataCorp LP, College Station, TX).

RESULTS

We examined 1,773,361 diagnostic ICAs (without PCI) and 1,521,987 PCIs (with or without ICA) performed in 2,768,434 patients by 9,600 operators at 942 hospitals during the study period. The mean age of patients was 63.5 (±12.5) years, 1,285,692 (39.0%) were female, and 535,912 (16.3%) had had prior CABG. Tables I and II display baseline characteristics of the study population stratified by procedure category.

Distribution of Fluoroscopy Times

Median fluoroscopy times for each procedure category are listed in Table III. There was wide variation in fluoroscopy times for all procedure categories (Fig. 1). The presence of coronary artery bypass grafts was associated with increases of 4.1 and 5.3 minutes in median fluoroscopy times for ICA and ICA with PCI, respectively. ICAs performed for evaluation of patients with valvular heart disease and congenital heart disease were associated with longer fluoroscopy times as compared to other indications such as ruling out coronary artery disease (Fig. 2—top panel). These differences in fluoroscopy times by ICA indication were less prominent in patients with prior CABG (Fig. 2—bottom panel).

Fluoroscopy times of greater than 30 minutes were uncommon for ICA but occurred in a sizeable minority of patients undergoing PCI, ranging in this latter group from 6.7% in patients without prior CABG to nearly 15% of those with prior CABG (Table III). Approximately 1.3% of PCI patients had fluoroscopy times of more than 60 minutes, a threshold beyond which the risk of radiation-related skin injury increases significantly.

Multivariable Analyses

Incremental fluoroscopy times associated with patient, operator, and hospital factors after multivariable adjustment are listed in Tables IV and V, separately for ICA and PCI. For ICA, factors associated with the largest increments in fluoroscopy time were brachial arterial access (up to 6.0 minutes of added fluoroscopy time), radial arterial access (up to 3.6 minutes), congenital heart disease (3.2 minutes), concomitant right heart catheterization (2.7 minutes), a university hospital setting (up to 2.6 minutes), and presence of coronary stenosis of ≥50% in patients with prior CABG (up to 1.7 minutes) (Table IV). Other factors associated with longer fluoroscopy times during

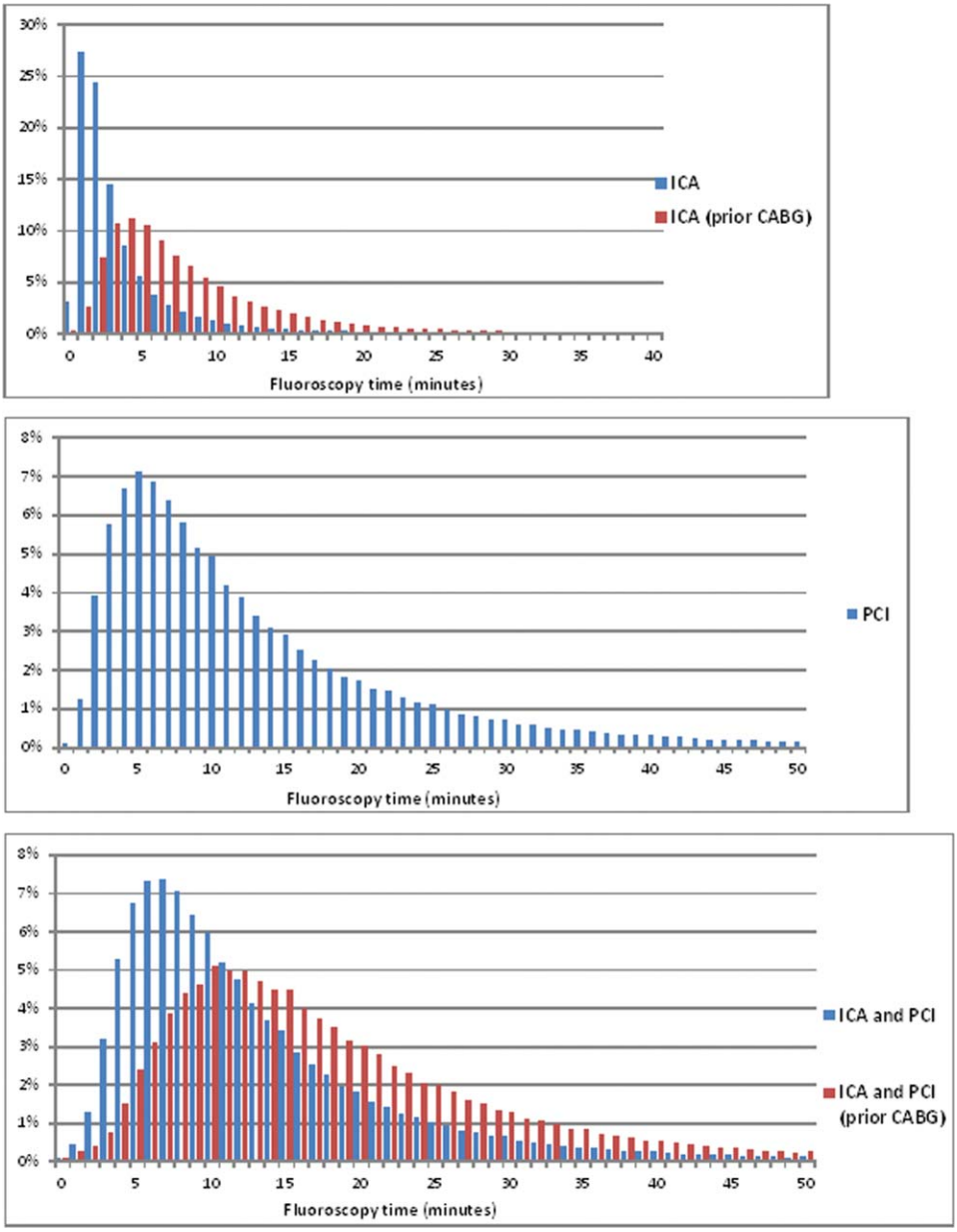

Fig. 1. Distribution of fluoroscopy times for invasive coronary angiography (ICA) and percutaneous coronary intervention (PCI) procedures. CABG indicates coronary artery bypass graft.

ICA included age ≥75 years, peripheral vascular disease, valvular heart disease, and lower operator volume (Table IV).

For PCI, the largest increments in fluoroscopy time were associated with significant coronary dissection or perforation (up to a 7.7 minute increase in fluoroscopy time), use of atherectomy, thrombectomy or extraction catheter or laser (up to 7.1 minutes), brachial artery access (up to 7.2 minutes), number of lesions intervened upon, university hospital setting (up to 4.9 minutes), intra-aortic balloon pump insertion (up to 3.7 minutes), and radial artery access (up to 3.3 minutes) (Table V). In addition, age ≥ 75 years, endstage renal disease, peripheral vascular disease, concomitant right heart catheterization, complex (class C) or bifurcation lesions, no reflow phenomenon, lower operator volume, and Northeast and West census regions were associated with substantial increases in fluoroscopy time (Table V). Intervention on every additional coronary lesion was associated with an average increase of nearly 4 minutes in fluoroscopy time. Right heart catheterization concomitant with any PCI procedure was, on average,

associated with 2.1 minutes of additional fluoroscopy time.

Female gender was associated with modestly shorter fluoroscopy times for both ICA and PCI, ranging from 0.3 to 1.3 fewer minutes of fluoroscopy time. Presentation with STEMI was also associated with shorter fluoroscopy times (up to 1.9 minutes) as compared with other clinical presentations. After accounting for patient, procedure, operator, and hospital factors, there was a modest but statistically significant temporal trend for decreasing fluoroscopy times for PCI during the study period (decline of 1.0–1.5 minutes over the study period). There were no significant changes in our results after excluding procedures performed by operators with annual procedure volume of <50 or >2,000. Similarly, exclusion of procedures in which coronary dissection, coronary perforation, acute coronary vessel closure, or no reflow phenomenon occurred did not significantly alter our findings.

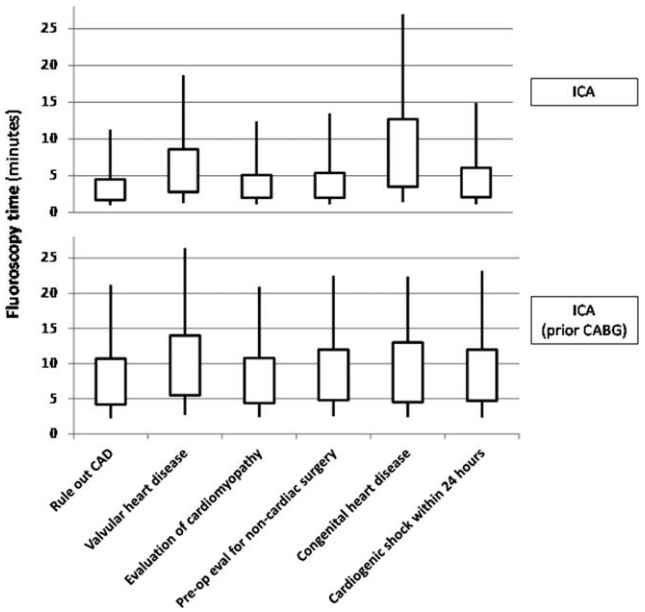

Fig. 2. Distribution of fluoroscopy times for invasive coronary angiography (ICA) stratified by clinical indication in patients without prior CABG (top panel) and with prior CABG (bottom panel). The boxplots denote the interquartile range and the lower and upper whiskers display the 5th and 95th percentiles, respectively. CABG indicates coronary artery bypass graft; CAD, coronary artery disease.

Overall, after accounting for differences in patient characteristics and procedure complexity, operator and hospital-level factors explained 17.0% and 19.0% of the variation in fluoroscopy time for ICA and PCI, respectively. Mean operator volume was 118 (±148) procedures per year with 87.2% of ICAs performed by an interventional cardiologist. After multivariable adjustment, interventional cardiologists had lower ICA fluoroscopy times as compared to noninterventionalists, particularly in patients with prior CABG. Operators' average fluoroscopy time for each of the five procedure categories varied widely, indicating substantial operator-level variation in fluoroscopy times (Fig. 3).

Operator volume was inversely associated with fluoroscopy time. The magnitude of this association varied by procedure category, ranging from a reduction of 0.50 minutes in fluoroscopy time per 250 cases performed per year for ICA in patients without prior CABG to 1.49 minutes per 250 cases performed per year for ICA with PCI in patients with prior CABG. Fractional polynomials regression analysis confirmed a significant operator volume–fluoroscopy time relationship and also indicated that this relationship was stronger for PCI as compared to ICA (Fig. 4).

DISCUSSION

In this large, contemporary national registry of patients undergoing ICA and PCI in the United States, we found wide variation in fluoroscopy times for these procedures, including substantial operator and hospital-level variation. However, we found a large proportion (approximately 80%) of this variation was "fixed" in

TABLE III. Distribution of Fluoroscopy Time for Invasive Coronary Angiography (ICA) and Percurtaneous Coronary Intervention (PCI)

Table 1. Distribution of fluoroscopy time for ICA and PCI procedures

	ICA	ICA (prior CABG)	PCI	PCI and ICA	PCI and ICA (prior CABG)
Fluoroscopy time (min.), median (IQR)	2.6 (1.7–4.5)	6.7 (4.2–10.8)	10.1 (6.0–17.4)	10.7 (7.0–16.9)	16.0 (10.6–24.0)
10th percentile, 90th percentile	1.2–8.1	2.9–16.5	3.7–28.1	4.9–25.9	7.3–34.6
5th percentile, 95th percentile	1.0–11.5	2.2–21.2	2.9–37.0	3.9–33.3	5.8–43.0
1st percentile, 99th percentile	0.6–23.2	1.3–34.1	1.7–60.3	2.4–53.6	3.3–63.7
Mean physician-level fluoroscopy time (min.), median (IQR)	4.1 (3.1–5.4)	9.0 (6.9–11.9)	13.6 (10.3–18.1)	13.3 (10.6–16.7)	18.8 (15.0–23.6)
Fluoroscopy time >30 min., no. (%)	8,044 (0.5%)	4,031 (1.6%)	27,146 (8.5%)	66,006 (6.7%)	31,462 (14.7%)
Fluoroscopy time >60 min., no. (%)	1,556 (0.1%)	351 (0.1%)	3,226 (1.0%)	6,205 (0.6%)	2,810 (1.3%)

CABG, coronary artery bypass graft; IQR, interquartile range.

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TABLE IV. Incremental ICA Fluoroscopy Time (in Minutes, with 95% CI) Associated with Listed Variables After Multivariable Adjustment

Variable	ICA		ICA (prior CABG)	
Female gender	−0.31	(−0.33 to −0.29)	−0.83	(−0.89 to −0.77)
Age				
Under 35	−0.51	(−0.59 to −0.44)	−2.06	(−2.80 to −1.32)
35 to <55	−0.83	(−0.86 to −0.80)	−1.82	(−1.92 to −1.71)
55 to <75	−0.60	(−0.62 to 0.57)	−0.98	(−1.04 to −0.91)
75 or over	Ref	Ref	Ref	Ref
Body mass index (per kg/m2)	0.015	(0.014 to 0.016)	0.03	(0.03 to 0.04)
Race				
White	Ref	Ref	Ref	Ref
Black	−0.035	(−0.069 to −0.001)	0.20	(0.06 to 0.33)
Other	−0.06	(−0.09 to −0.02)	0.07	(−0.05 to 0.18)
Comorbidities				
Hypertension	0.13	(0.10 to 0.15)	0.19	(0.11 to 0.27)
Dyslipidemia	−0.03	(−0.05 to −0.01)	−0.10	(−0.18 to −0.02)
Prior myocardial infarction	−0.06	(−0.09 to −0.03)	−0.13	(−0.19 to −0.07)
Congestive heart failure	0.12	(0.09 to 0.16)	−0.11	(−0.18 to −0.04)
Family history of premature CAD	−0.07	(−0.10 to −0.05)	−0.02	(−0.08 to 0.05)
Prior PCI	−0.02	(−0.04 to 0.01)	−0.87	(−0.93 to −0.81)
End-stage renal disease	−0.01	(−0.08 to 0.06)	0.51	(0.34 to 0.69)
Cerebrovascular disease	0.22	(0.18 to 0.25)	0.20	(0.12 to 0.27)
Peripheral vascular disease	0.99	(0.95 to 1.02)	0.92	(0.84 to 0.99)
Chronic lung disease	0.027	(0.002 to 0.051)	0.04	(−0.03 to 0.11)
Diabetes mellitus	−0.14	(−0.16 to −0.12)	−0.24	(−0.29 to −0.18)
Commercial insurance	−0.08	(−0.10 to −0.06)	−0.17	(−0.24 to −0.10)
Clinical presentation				
No symptoms	Ref	Ref	Ref	Ref
Atypical chest pain	−0.28	(−0.32 to −0.27)	−0.43	(−0.52 to −0.33)
Stable angina	−0.22	(−0.25 to −0.19)	−0.19	(−0.28 to −0.10)
Unstable angina	−0.27	(−0.30 to −0.24)	−0.37	(−0.45 to −0.29)
Non-ST-segment elevation MI	−0.28	(−0.32 to −0.24)	−0.19	(−0.30 to −0.08)
ST-segment elevation MI	0.02	(−0.05 to 0.09)	0.09	(−0.17 to 0.35)
Indication				
Rule out CAD	−0.33	(−0.37 to −0.28)	0.10	(−0.03 to 0.23)
Valvular heart disease	1.35	(1.32 to 1.39)	0.93	(0.83 to 1.03)
Evaluation of cardiomyopathy	−0.18	(−0.20 to −0.16)	−0.27	(−0.33 to −0.21)
Pre-op evaluation for noncardiac surgery	0.04	(−0.01 to 0.09)	0.12	(−0.04 to 0.27)
Congenital heart disease	3.22	(3.06 to 3.39)	0.19	(−0.57 to 0.95)
Cardiogenic shock within 24 hours	0.21	(0.12 to 0.31)	−0.23	(−0.53 to 0.06)
Arterial access site				
Femoral	Ref	Ref	Ref	Ref
Brachial	4.69	(4.56 to 4.82)	5.98	(5.66 to 6.30)
Radial	2.74	(2.65 to 2.84)	3.59	(3.18 to 4.00)
Intraaortic balloon pump inserted	0.52	(0.44 to 0.60)	0.15	(−0.17 to 0.47)
Concomitant right heart catheterization	2.75	(2.72 to 2.78)	2.69	(2.59 to 2.79)
Coronary artery stenosis present				
Native coronary vessels	0.80	(0.78 to 0.83)	1.72	(1.58 to 1.85)
Bypass grafts	n/a	n/a	0.80	(0.74 to 0.85)
Operator volume (/250 procedures per year)	−0.50	(−0.54 to −0.41)	−1.35	(−1.49 to −1.22)
Operator subspecialty (interventional)	−0.18	(−0.27 to −0.09)	−1.23	(−1.46 to −1.01)
Teaching hospital	0.23	(0.17 to 0.29)	0.32	(0.17 to 0.48)
Hospital size >250 beds	−0.06	(−0.11 to 0.00)	−0.09	(−0.24 to 0.07)
Census region				
Northeast	Ref	Ref	Ref	Ref
South	−0.06	(−0.16 to 0.04)	−0.98	(−1.23 to −0.73)
Midwest	−0.12	(−0.23 to −0.01)	−0.81	(−1.07 to −0.55)
West	−0.01	(−0.13 to 0.11)	−0.47	(−0.77 to −0.18)

TABLE IV. *Continued*

Variable	ICA		ICA (prior CABG)	
Ownership				
Private/community	Ref	Ref	Ref	Ref
Government	0.29	(0.07 to 0.51)	0.05	(−0.48 to 0.58)
University	1.55	(1.46 to 1.65)	2.57	(2.31 to 2.83)
Year of procedure				
2005	Ref	Ref	Ref	Ref
2006	−0.02	(−0.05 to 0.02)	−0.04	(−0.14 to 0.06)
2007	−0.07	(−0.10 to −0.04)	−0.23	(−0.32 to −0.13)
2008	−0.12	(−0.16 to −0.09)	−0.33	(−0.42 to −0.23)
2009	−0.16	(−0.20 to −0.13)	−0.63	(−0.74 to −0.52)

CABG, coronary artery bypass graft; CAD, coronary artery disease.

that it was tied directly to patient characteristics and procedural complexity, which are largely nonmodifiable factors. This finding alone highlights the need to consider "adjustment" of fluoroscopy time and other quality measures of radiation safety when benchmarking these procedures. Yet we also noted that operator and hospital-level factors, including operator volume, had a moderate impact on fluoroscopy time, contributing to nearly 20% of its variation even after accounting for differences in patient characteristics and procedure complexity.

These findings have important implications for quality improvement. First, outlining the distribution of fluoroscopy times for contemporary ICA and PCI provides a basis for defining national benchmarks for this measure. As cardiac catheterization labs increasingly adopt strategies for operators and their institutions to enhance the radiation safety of these procedures, these results provide a reference basis for gauging improvement. Second, we identified key patient and procedure factors associated with fluoroscopy time, which could be used to adjust such benchmarks to account for procedure complexity. This is important because of the strong correlation between procedure complexity and radiation exposure for both ICA and PCI. Finally, these findings highlight the potential for quality improvement by noting the important role that operator and hospital-level factors play in determining fluoroscopy times beyond patient characteristics and procedure complexity.

Our findings also have significant population health implications given the high prevalence of these procedures. For example, a modest reduction in fluoroscopy time for ICA from the 75th percentile to the 50th percentile translates into a 42% reduction in actual fluoroscopy time. Assuming a linear relationship between fluoroscopy time and KAP, this would lead to a proportionate decrease in effective dose, e.g., from 7 mSv to 4.1 mSv for the average ICA [20]. While such a dose reduction is small for an individual patient (roughly equivalent to annual US background radiation exposure from natural sources), it would translate to much more substantial, meaningful reductions in radiation exposure at the population level [21]. Importantly, simple technical measures such as increased use of collimation and reducing the dose-rate for fluoroscopy and cine could help achieve even greater reductions in radiation exposure from ICA and PCI. This highlights the importance and potential impact of efforts such as the Image Wisely campaign [22], which focuses on enhancing radiation safety of medical imaging, including fluoroscopic procedures, by educating health care professionals and patients. By partnering with such programs, the American Heart Association, American College of Cardiology and Society for Cardiac Angiography and Intervention could provide a much wider platform for these educational efforts among cardiologists and other health care providers. In order to narrow the current knowledge gap [23,24], it is also imperative that principles of radiation safety, including appropriate use of cardiac imaging and dose reduction techniques, be incorporated in cardiology fellowship training curricula in a meaningful manner. This knowledge should also be required for recertification of practicing operators.

Several key factors deserve to be highlighted given their potential for modification. For example, we found that operator volume was inversely associated with fluoroscopy time for ICA and PCI, a relationship that has been noted for other types of fluoroscopic procedures in prior studies [25]. This finding likely reflects the greater efficiency of more experienced operators and is consistent with the volume–outcomes relationship demonstrated for these procedures in previous studies [26,27]. Longer fluoroscopy times at university hospitals may be related to the involvement of trainees in procedures performed at these hospitals, which have been shown to increase fluoroscopy time for other fluoroscopic procedures [25,28]. From this standpoint, greater awareness and focus on radiation safety during

TABLE V. Incremental PCI (with or without ICA) Fluoroscopy Time (in Minutes, with 95% CI) Associated with Listed Variables After Multivariable Adjustment

Variable	PCI		ICA and PCI		ICA and PCI (prior CABG)	
Female gender	−0.89	(−0.97 to −0.81)	−0.71	(−0.75 to −0.67)	−1.24	(−1.36 to −1.13)
Age						
Under 35	−1.26	(−1.89 to −0.62)	−1.34	(−1.58 to −1.10)	−2.04	(−3.59 to −0.49)
35 to <55	−1.92	(−2.05 to −1.79)	−2.10	(−2.16 to −2.04)	−2.16	(−2.34 to −1.98)
55 to <75	−0.97	(−1.06 to −0.87)	−1.21	(−1.27 to −1.16)	−0.93	(−1.05 to −0.82)
75 or over	Ref	Ref	Ref	Ref	Ref	Ref
Body mass index	0.012	(0.005 to 0.018)	0.024	(0.021 to 0.028)	0.03	(0.02 to 0.04)
Race						
White	Ref	Ref	Ref	Ref	Ref	Ref
Black	0.08	(−0.08 to 0.24)	0.17	(0.09 to 0.25)	0.14	(−0.11 to 0.38)
Other	−0.32	(−0.47 to −0.16)	−0.13	(−0.21 to −0.06)	0.04	(−0.17 to 0.24)
Comorbidities						
Hypertension	0.42	(0.31 to 0.52)	0.41	(0.36 to 0.46)	0.31	(0.17 to 0.46)
Dyslipidemia	0.21	(0.11 to 0.30)	0.10	(0.05 to 0.14)	−0.02	(−0.18 to 0.13)
Prior myocardial infarction	0.21	(0.12 to 0.30)	0.33	(0.28 to 0.39)	−0.01	(−0.11 to 0.10)
Congestive heart failure	0.05	(−0.07 to 0.17)	0.15	(0.07 to .22)	−0.13	(−0.26 to 0.00)
Family history of premature CAD	−0.07	(−0.16 to 0.03)	−0.09	(−0.14 to −0.05)	−0.01	(−0.12 to 0.11)
Prior PCI	−0.23	(−0.32 to −0.14)	−0.29	(−0.34 to −0.24)	−0.83	(−0.94 to −0.73)
End-stage renal disease	1.30	(1.03 to 1.57)	1.19	(1.04 to 1.35)	1.18	(0.86 to 1.50)
Cerebrovascular disease	0.20	(0.09 to 0.31)	0.29	(0.22 to 0.35)	0.05	(−0.08 to −0.18)
Peripheral vascular disease	0.89	(0.78 to 1.00)	1.14	(1.07 to 1.21)	0.75	(0.62 to 0.87)
Chronic lung disease	0.08	(−0.02 to 0.18)	0.09	(0.03 to 0.14)	−0.15	(−0.28 to −0.03)
Diabetes mellitus	−0.09	(−0.17 to −0.01)	−0.10	(−0.15 to −0.06)	−0.16	(−0.27 to −0.06)
Commercial insurance	−0.12	(−0.21 to −0.02)	−0.13	(−0.09 to 0.17)	−0.27	(−0.39 to −0.14)
Clinical presentation						
No symptoms	Ref	Ref	Ref	Ref	Ref	Ref
Atypical chest pain	−0.12	(−0.29 to 0.06)	−0.27	(−0.36 to −0.18)	−0.22	(−0.46 to 0.02)
Stable angina	0.11	(−0.01 to 0.24)	−0.03	(−0.11 to 0.05)	0.15	(−0.04 to 0.34)
Unstable angina	−0.05	(−0.17 to 0.06)	−0.48	(−0.55 to −0.41)	−0.14	(−0.31 to 0.03)
Non-ST-segment elevation MI	−0.31	(−0.45 to −0.16)	−0.56	(−0.63 to −0.48)	−0.11	(−0.30 to 0.09)
ST-segment elevation MI	−1.54	(−1.73 to −1.35)	−1.87	(−1.95 to −1.79)	−1.47	(−1.73 to −1.20)
Cardiogenic shock within 24 hours	−0.24	(−0.59 to 0.11)	0.22	(0.09 to 0.35)	−0.44	(−0.86 to −0.03)
Arterial access site						
Femoral	Ref	Ref	Ref	Ref	Ref	Ref
Brachial	4.58	(4.03 to 5.12)	5.69	(5.36 to 6.02)	7.24	(6.55 to 7.93)
Radial	1.27	(0.90 to 1.64)	3.23	(3.03 to 3.43)	3.27	(2.57 to 3.96)
Intra-aortic balloon pump inserted	3.74	(3.43 to 4.04)	2.80	(2.67 to 2.92)	3.06	(2.66 to 3.46)
Concomitant right heart catheterization	na	na	2.13	(2.03 to 2.22)	2.15	(1.91 to 2.38)
Number of lesions intervened upon	3.95	(3.90 to 4.00)	4.01	(3.98 to 4.04)	3.88	(3.80 to 3.96)
PCI lesion characteristics						
Previously treated lesion	0.33	(0.11 to 0.55)	0.68	(0.57 to 0.79)	−0.23	(−0.44 to −0.02)
Complex lesion (class C)	3.81	(3.73 to 3.83)	2.91	(2.87 to 2.95)	2.81	(2.71 to 2.92)
Bifurcation lesion	1.43	(1.31 to 1.54)	1.53	(1.47 to 1.59)	1.23	(1.06 to 1.40)
PCI lesion location						
Native coronary vessel	Ref	Ref	N/A	N/A	Ref	Ref
Bypass graft-artery	−1.32	(−1.52 to −1.11)			−0.27	(−0.39 to −0.15)
Bypass graft-vein	0.53	(−0.02 to 1.08)			1.48	(1.14 to 1.82)
Multiple locations (any combination of above locations)	0.80	(0.48 to 1.13)			0.88	(0.65 to 1.11)
Use of intracoronary devices						
Atherectomy, thrombectomy catheter, or laser	7.13	(6.94 to 7.32)	2.75	(2.66 to 2.83)	5.06	(4.83 to 5.29)
Embolic protection device	−0.78	(−1.08 to −0.49)	2.14	(1.61 to 2.67)	−0.07	(−0.28 to 0.13)
Procedural complications						
Significant dissection	7.05	(6.84 to 7.27)	6.33	(6.22 to 6.44)	7.67	(7.35 to 7.99)
Coronary perforation	6.47	(5.88 to 7.07)	4.43	(4.12 to 4.73)	4.35	(3.64 to 5.06)
No reflow phenomenon	1.45	(1.07 to 1.83)	1.72	(1.56 to 1.89)	1.83	(1.45 to 2.20)
Operator volume (/250 procedures per year)	−1.04	(−1.26 to −0.81)	−1.17	(−1.35 to −0.99)	−1.49	(−1.76 to −1.22)
Teaching hospital	0.22	(−0.02 to 0.46)	0.42	(0.30 to 0.54)	0.62	(0.35 to 0.89)

TABLE V. *Continued*

Variable	PCI		ICA and PCI		ICA and PCI (prior CABG)	
Hospital size >250 beds	−0.18	(−0.45 to 0.09)	−0.11	(−0.23 to 0.01)	0.23	(−0.06 to 0.52)
Census region						
Northeast	Ref	Ref	Ref	Ref	Ref	Ref
South	−1.21	(−1.63 to −0.80)	−0.75	(−1.01 to −0.50)	−1.52	(−1.98 to −1.06)
Midwest	−1.06	(−1.50 to −0.61)	−0.86	(−1.14 to −0.58)	−1.08	(−1.57 to −0.59)
West	0.50	(0.01 to 0.99)	0.01	(−0.29 to 0.30)	0.01	(−0.52 to 0.54)
Ownership						
Private/community	Ref	Ref	Ref	Ref	Ref	Ref
Government	−0.97	(−1.85 to −0.09)	−0.46	(−1.07 to 0.15)	−0.51	(−1.63 to 0.61)
University	3.64	(3.26 to 4.01)	2.95	(2.75 to 3.14)	4.88	(4.47 to 5.29)
Year of procedure						
2005	Ref	Ref	Ref	Ref	Ref	Ref
2006	−0.23	(−0.36 to −0.10)	−0.33	(−0.40 to −0.26)	−0.14	(−0.32 to 0.03)
2007	−0.59	(−0.72 to −0.46)	−0.66	(−0.73 to −0.59)	−0.64	(−0.82 to −0.46)
2008	−0.77	(−0.90 to −0.63)	−0.93	(−1.00 to −0.86)	−0.94	(−1.11 to −0.76)
2009	−1.06	(−1.22 to −0.91)	−1.25	(−1.33 to −1.17)	−1.46	(−1.66 to −1.26)

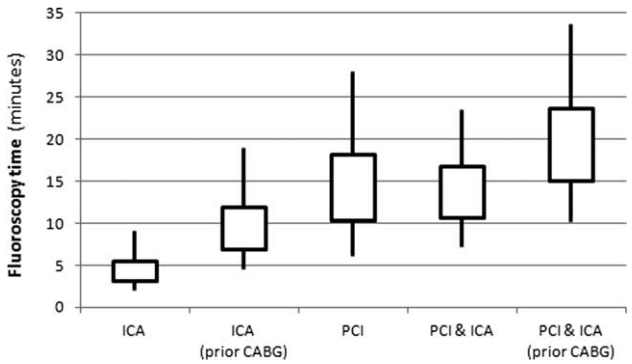

Fig. 3. Distribution of average physician-level fluoroscopy times for invasive coronary angiography (ICA) and percutaneous coronary intervention (PCI). The boxplots denote the interquartile ranges and the lower and upper whiskers display the 5th and 95th percentiles, respectively. CABG indicates coronary artery bypass graft.

training may improve the use of these procedures [29]. Finally, modest regional variation in PCI fluoroscopy times noted in our study may be related to differences in rates of adoption of newer fluoroscopy cameras (with options such as last image hold or cine loop that allow reduction in fluoroscopy times), operator volume and experience, awareness of radiation safety principles, and local efforts to reduce fluoroscopy time. It is important to develop further understanding of operator and hospital determinants of fluoroscopy time, as they will provide insights into specific approaches that may improve radiation safety.

We identified other factors associated with increased fluoroscopy time, but the extent to which these factors are modifiable is less clear. Nonfemoral arterial access, particularly brachial arterial access, was associated with significantly longer fluoroscopy times for both ICA and PCI. As brachial arterial access is often obtained after failed attempts to gain radial and/or femoral arterial access, the added fluoroscopy time associated with this approach may be a reflection of difficult arterial access in patients with peripheral vascular disease. The presence of coronary stenosis was associated with longer fluoroscopy times, which may be related to the additional images and views needed to accurately characterize lesions. Factors contributing to longer fluoroscopy times in the elderly probably include a combination of the above factors, i.e., more difficult access because of increased peripheral vascular disease as well as more coronary disease requiring additional images to define coronary anatomy. In patients with congenital heart disease, navigation of and defining the complex anatomy likely adds to the fluoroscopy time. The shorter fluoroscopy times in patients presenting with STEMI may be related to the more time-sensitive nature of these interventions where the operator's primary goal is re-establishing coronary flow as quickly as possible. Finally, possible causes of the modest decrease in average fluoroscopy times over time during the study period include improved image quality with newer cameras, the increased availability of options such as last image hold and loop replay, and increasing awareness of radiation safety principles among operators.

Finally, several patient and procedure-related factors that we identified as being associated with increased fluoroscopy time are less predictable and should probably be used to place excessive radiation exposures, when they occur, into appropriate clinical context. For example, operators typically only utilize atherectomy, thrombectomy, or extraction catheters or laser when lesion complexity necessitates their use. Similarly, there are much more pressing reasons to avoid complications such as coronary dissection or perforation than risks related to radiation exposure. However, understanding

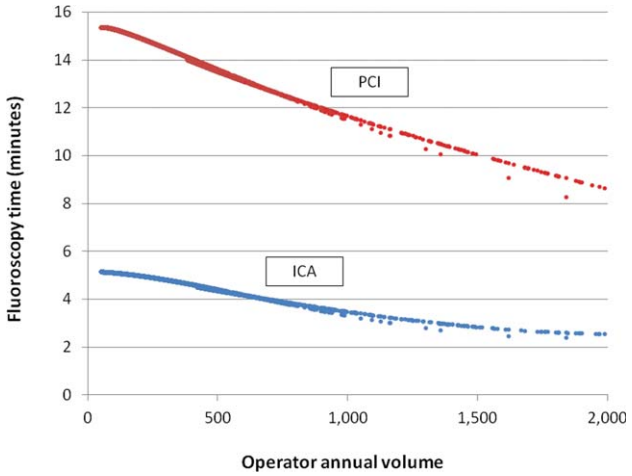

Fig. 4. Operator volume–fluoroscopy time relationship for invasive coronary angiography (ICA) and percutaneous coronary intervention (PCI).

TABLE VI. Fluoroscopic Dose-Rate Management Techniques

- Keep the patient as close as reasonably possible to the image receptor and as far as possible from the x-ray tube.
- Use collimation to reduce the irradiated area.
- Use the lowest acceptable magnification.
- Use the lowest clinically acceptable dose-rate at all times.
- Use fluoroscopy only for real-time imaging guidance.
- Use image acquisition (Cine or DSA) only when higher-quality image review is essential.
- Use last-image-hold or loop replay in place of live imaging whenever practicable. In some cases, retrospectively stored fluoroscopy may replace image acquisition.
- Minimize the number of cine series.
- Never use cine as a substitute for fluoroscopy.
- Use wedge filters when they are appropriate.
- Try to avoid steeply angulated projections (especially LAO cranial).
- Try to vary the C-arm angulation slightly, to avoid concentrating the radiation dose at a single site on the patient's skin.
- Remember that for large patients, and also for steeply angulated projections, the dose to the patient increases substantially.
- Pay attention to the patient radiation dose display in the procedure room.
- If the patient has had previous similar procedures, try to obtain information about the previous radiation doses to optimize subsequent procedures.

Adapted from NCRP-168 and ICRP Draft Report for Consultation on Patient and Staff Radiological Protection in Cardiology.

the relationship between these factors and increased fluoroscopy time may still be useful in these settings. Fluoroscopy time cannot be used as an indicator of peak skin dose because it does not account for key determinants of peak dose such as dose-rate, projection angles, cine use, and patient size. However, in cases with prolonged fluoroscopy times, operators should pay even closer attention to monitoring total air kerma at the reference point (also known as cumulative air kerma), which indicates peak skin dose. Attention to the principles of radiation safety with fluoroscopy (Table VI) is particularly important in such cases. In our study, fluoroscopy times exceeded 30 minutes in 8.1% of PCIs and 60 minutes in 0.8% of PCIs. In cases in which the total air kerma at the reference point exceeds 5 Gy, early follow-up and more extensive patient education to monitor for skin injury is appropriate [9]. Both total air kerma at the reference point and air kerma-area product are reported by all fluoroscopy machines manufactured since 2006 as mandated by the Food and Drug Administration [30]. Registries such as the CathPCI Registry should incorporate these measures in order to provide more accurate and meaningful feedback regarding radiation safety to participating hospitals.

Our study should be interpreted in the context of the following limitations. First, because of the limitations of our data source, we used fluoroscopy time rather than air kerma-area product which is admittedly a more appropriate and accurate estimate of radiation exposure [9]. However, prior studies have shown that for ICA and PCI, in contrast to noncardiac fluoroscopic procedures, there is a good correlation between fluoroscopy time and air kerma-area product (published estimates of correlation coefficient [R]= 73% to 78%), and fluoroscopy time is a modifiable and easily understandable factor that is responsible for the majority of its variation across these procedures [6,8,9]. Second, we defined operator volume based on procedures recorded in the CathPCI Registry and did not capture procedures performed in other (non-CathPCI Registry-participating) hospitals. As this approach is likely to lead to underestimations of operator volume, it would minimize the degree of associations between operator volume and fluoroscopy time that we identified. Finally, we excluded procedures for which key data were missing, but these constituted a very small proportion (<2%) of the overall procedures and their exclusion was unlikely to create a significant bias in the study results.

CONCLUSIONS

There is wide variation in fluoroscopy times for ICA and PCI procedures. Operator and hospital factors contribute significantly to this variation and provide potential targets for improving the radiation safety of these procedures.

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The views expressed in this manuscript represent those of the author(s), and do not necessarily represent the official views of the NCDR or its associated professional societies identified at www.ncdr.com."

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APPENDIX

Fluoroscopy times (in minutes) of procedures in the CathPCI Registry during the study period in which the operator ID was known (included in analysis) and unknown (excluded from the analysis)

Distribution	Operator known (n = 3,321,988)	Operator unknown (n = 1,142,130)
Mean	9.26	9.21
Std Deviation	10.57	10.67
100% (maximum)	300.0	300.0
99%	48.1	48.4
95%	28.0	28.1
90%	20.7	20.7
75% (3rd quartile)	12.0	12.0
50% (median)	6.0	5.9
25% (1 quartile)	2.7	2.6
10%	1.5	1.5
5%	1.2	1.2
1%	0.8	0.8
0% (minimum)	0.0	0.0