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CLINICAL RESEARCH
Interventional cardiology

Intravascular imaging during percutaneous coronary intervention: temporal trends and clinical outcomes in the USA

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Abstract

Aims Prior trials have demonstrated that intravascular imaging (IVI)-guided percutaneous coronary intervention (PCI) results in less frequent target lesion revascularization and major adverse cardiovascular events (MACEs) compared with standard angiographic guidance. The uptake and associated outcomes of IVI-guided PCI in contemporary clinical practice in the USA remain unclear. Accordingly, temporal trends and comparative outcomes of IVI-guided PCI relative to PCI with angiographic guidance alone were examined in a broad, unselected population of Medicare beneficiaries.

Methods and results Retrospective cohort study of Medicare beneficiary data from 1 January 2013, through 31 December 2019 to evaluate temporal trends and comparative outcomes of IVI-guided PCI as compared with PCI with angiography guidance alone in both the inpatient and outpatient settings. The primary outcomes were 1 year mortality and MACE, defined as the composite of death, myocardial infarction (MI), repeat PCI, or coronary artery bypass graft surgery. Secondary outcomes were MI or repeat PCI at 1 year. Multivariable Cox regression was used to estimate the adjusted association between IVI guidance and outcomes. Falsification endpoints (hospitalized pneumonia and hip fracture) were used to assess for potential unmeasured confounding. The study population included 1 189 470 patients undergoing PCI (38.0% female, 89.8% White, 65.1% with MI). Overall, IVI was used in 10.5% of the PCIs, increasing from 9.5% in 2013% to 15.4% in 2019. Operator IVI use was variable, with the median operator use of IVI 3.92% (interquartile range 0.36%–12.82%). IVI use during PCI was associated with lower adjusted rates of 1 year mortality [adjusted hazard ratio (aHR) 0.96, 95% confidence interval (CI) 0.94–0.98], MI (aHR 0.97, 95% CI 0.95–0.99), repeat PCI (aHR 0.74, 95% CI 0.73–0.75), and MACE (aHR 0.85, 95% CI 0.84–0.86). There was no association with the falsification endpoint of hospitalized pneumonia (aHR 1.02, 95% CI 0.99–1.04) or hip fracture (aHR 1.02, 95% CI 0.94–1.10).

Conclusion Among Medicare beneficiaries undergoing PCI, use of IVI has increased over the previous decade but remains relatively infrequent. IVI-guided PCI was associated with lower risk-adjusted mortality, acute MI, repeat PCI, and MACE.

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Structured Graphical Abstract

Key Question

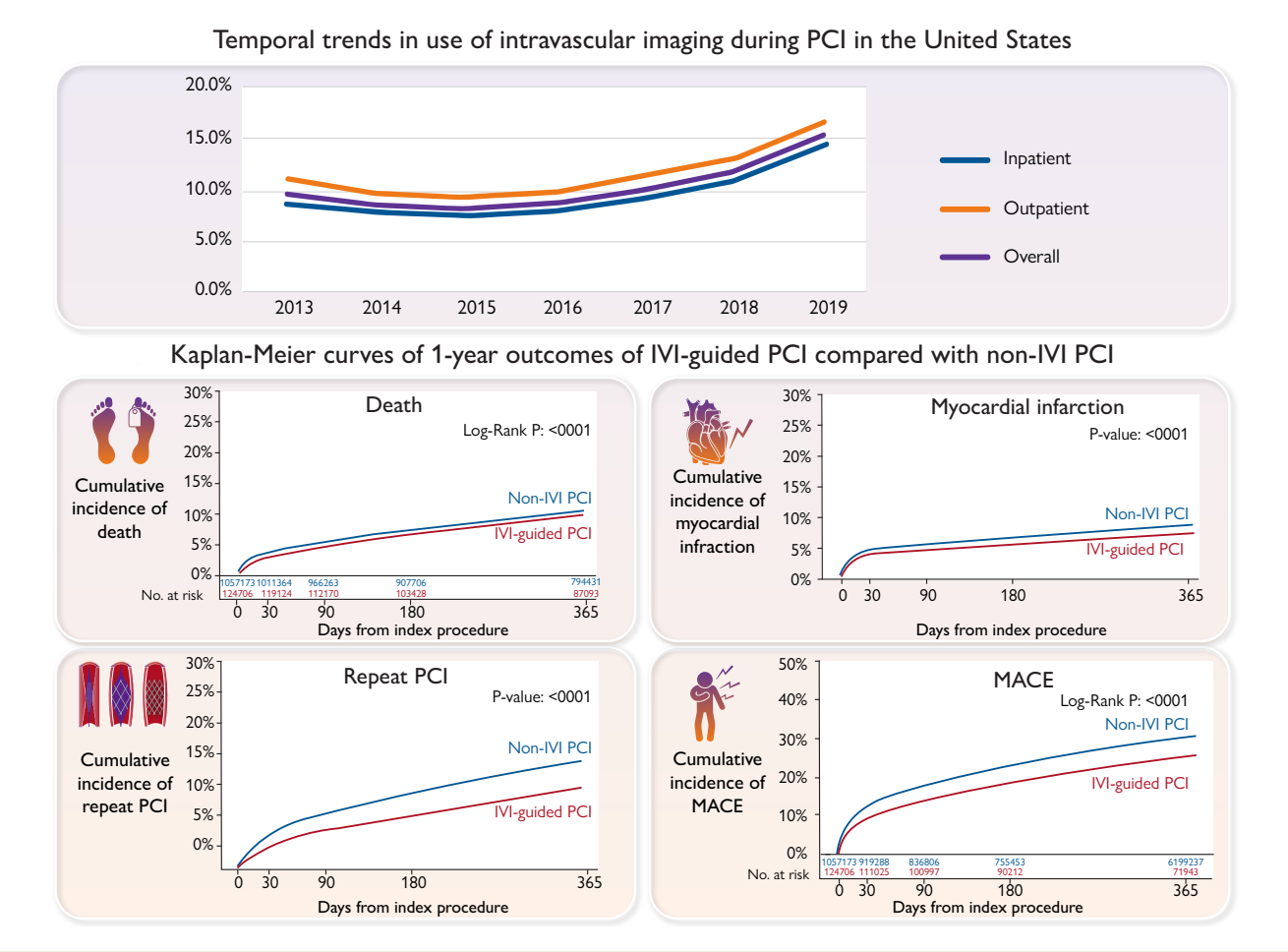
How frequently is intravascular imaging (IVI) used during PCI in the United States (US), and how does its use impact clinical outcomes?

Key Finding

IVI use during PCI remains infrequent in the US, however its use has been increasing over the past decade. IVI-guided PCI was associated with lower mortality, myocardial infarction, repeat PCI, and MACE in a broad, unselected population of Medicare beneficiaries.

Take Home Message

Use of IVI guidance for PCI is associated with improved outcomes, however its use in the US remains relatively infrequent.



Temporal trends and clinical outcomes associated with intravascular imaging during PCI in the United States. MACE, major adverse cardiovascular event; PCI, percutaneous coronary intervention.

Keywords Intravascular imaging • Percutaneous coronary intervention • Intravascular ultrasound • Optical coherence tomography

Introduction

Coronary angiography is the traditional standard for guiding percutaneous coronary intervention (PCI). However, angiography has inherent limitations as it relies on 2D projections of complex 3D vessel lumens and does not visualize the vascular structures, themselves. Intravascular imaging (IVI) can help overcome these limitations by providing more complete visualization of the vessel lumen and lesion characteristics. More specifically, IVI allows pre-PCI assessment of plaque burden, extent of calcification, vessel diameter, and lesion length as well as post-PCI assessment of stent malapposition, underexpansion, residual disease, and stent edge dissection.

Several meta-analyses of randomized trials have demonstrated reductions in mortality, myocardial infarction (MI), and target lesion revascularization associated with IVI-guided PCI as compared with angiography-guided PCI.[1–3] However, clinical trials are rarely

representative of the broader population of patients being treated with cardiovascular devices.[4] Moreover, virtually all recent randomized trials of IVI-guided PCI have been performed in practice settings outside of the USA. As such, there is a need to examine the trends in use and outcomes of IVI in contemporary clinical practice in the USA. Although prior observational studies have attempted to do so,[5,6] they are limited by failing to capture procedures performed among patients not requiring hospitalization, a trend which has grown substantially over recent years. Furthermore, evaluation of the influence of unmeasured confounding, in particular treatment selection bias, may be highly impactful in comparative analyses using observational data and should be evaluated when assessing treatment strategies.

Accordingly, we leveraged comprehensive Medicare claims data, including inpatient and outpatient PCI procedures, to accomplish two aims. First, we sought to examine temporal trends and practice patterns in nationwide operator use of IVI during PCI from 2013 through 2019. Second, we sought to compare outcomes of IVI-guided PCI relative to angiography-guided PCI in a broad, unselected population of Medicare beneficiaries using multiple approaches to mitigate confounding including multivariable regression and falsification endpoint assessment.[7]

Methods

Data source and study population

The study population was derived from Centers for Medicare and Medicaid Services (CMS) data, including 100% samples of the MedPAR inpatient files, institutional outpatient files, and carrier files. The study was conducted in compliance with the data use agreement in place between CMS and Beth Israel Deaconess Medical Center. The study was approved by the institutional review board of Beth Israel Deaconess Medical Center, with a waiver of informed consent for retrospective data analysis.

The study cohort for the temporal trend analysis included all inpatient and outpatient PCIs performed from 1 January 2013, through 31 December 2019, among Medicare fee-for-service beneficiaries aged 66 years and older. All PCIs performed between 2013 and 2019 were ascertained using International Classification of Diseases, Ninth Revision (ICD-9) procedure codes, International Classification of Diseases, Tenth Revision (ICD-10)-Procedure Coding System codes and Current Procedural Terminology codes (see Supplementary data online, *Table S1A*). Use of IVI was identified using specific claims codes for intravascular ultrasound or optical coherence tomography submitted on the same calendar day as the PCI claim (see Supplementary data online, *Table S1A*).

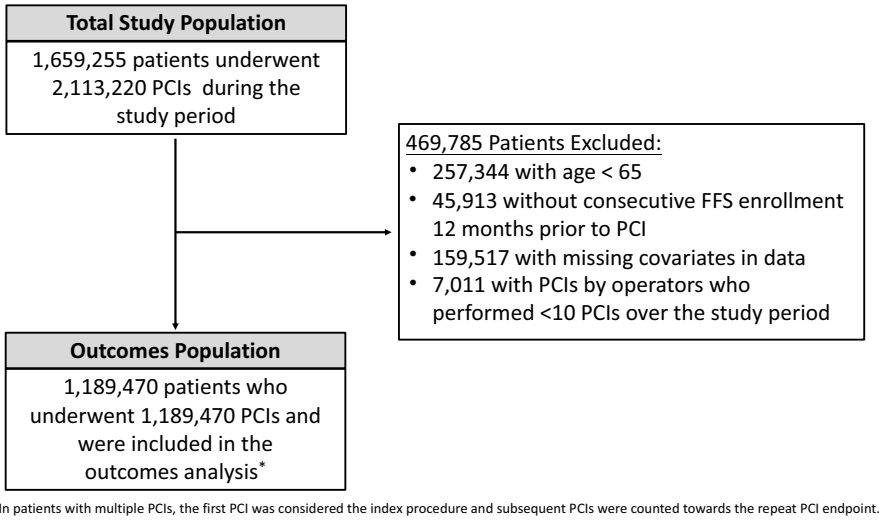
For the comparative analysis of IVI-guided vs. angiographic-guided PCI, we restricted our study to patients with at least 1 year of enrolment in Medicare prior to their index procedure and to procedures performed by operators who contributed at least 10 PCIs during the entire study period (*Figure 1*). For patients with more than one PCI during the study period, the first PCI was considered their index procedure, and subsequent PCIs were counted as repeat revascularizations. As determining whether these repeat revascularizations were related to target lesion failure is not possible with claims data, we performed a sensitivity analysis in which any PCI during the 30 day period following the index PCI was considered a staged PCI and not counted towards the repeat PCI outcome.

Patient, procedural, operator, and hospital characteristics

Baseline demographic characteristics were measured as of the index procedure date. Race/ethnicity was classified based on self-report using categories specified at the time of Medicare enrolment. Comorbidities were ascertained using the CMS Chronic Conditions Warehouse common chronic conditions.[8] In addition, ICD-9, Clinical Modification and ICD-10, Clinical Modification claims codes ascertained via a 1 year lookback period were used to identify current or prior tobacco use. Specific claims codes were additionally used to classify presence of acute coronary syndrome, cardiogenic shock, cardiac arrest, and bifurcation lesions, as well as procedural factors such as use of mechanical circulatory support [percutaneous ventricular assist device (pVAD), intra-aortic balloon pump, extracorporeal membrane oxygenation], adjunctive atherectomy, and fractional flow reserve (FFR) during the index procedure (see Supplementary data online, *Table S1B*). Operator PCI volumes were determined based on Medicare claims data during the study period. Institutional characteristics were ascertained through linkage with the 2016 American Hospital Association Annual Survey File and included hospital size, community, region, and teaching status.

Study outcomes for comparative analysis

The primary outcomes for the comparative analysis were 1 year mortality and major adverse cardiovascular events (MACEs), defined as death, MI, repeat PCI, or coronary artery bypass grafting (CABG). The secondary outcomes were MI or repeat PCI at 1 year. Finally, hospitalization for pneumonia and hip fracture were used as pre-specified falsification endpoints to assess for the presence of unmeasured confounding.[9]



*In patients with multiple PCIs, the first PCI was considered the index procedure and subsequent PCIs were counted towards the repeat PCI endpoint.

Figure 1 Flow diagram of the study population. PCI, percutaneous coronary intervention.

Statistical analysis

Categorical variables are reported as counts and percentages and continuous variables as means and standard deviations. Given the large sample size, standardized differences with a threshold of greater than or equal to 10% were used to define imbalance between groups.[10]

Annual trends of the proportion of PCIs that used IVI were evaluated and plotted from 2013 through 2019. To evaluate for heterogeneity in practice between operators, each operator's proportional use of IVI during PCI for the total study period was assessed and depicted in a histogram. In addition, the median odds ratio (OR) was used to analyse the heterogeneity in operator-level IVI use.[11] A median OR of >1.2 is considered to reflect a high degree of heterogeneity in practice.[12] Regression models were used to determine factors associated with the use of IVI, with candidate variables listed in *Table 1*.

Multivariable Cox regression analysis was pre-specified as the primary statistical method to compare outcomes associated with IVI-guided PCI. All variables included in *Table 1* were included for adjustment. As the decision to use IVI may rely on a number of factors that cannot typically be determined based on claims data alone, we used two falsification endpoints (hospitalization for pneumonia and hip fracture) to assess for residual confounding between treatment groups.

This analysis was repeated in the subgroup of patients with or without acute coronary syndromes at the time of index PCI. Acute coronary syndrome included patients presenting with any MI, unstable angina, cardiac arrest, or cardiogenic shock. The analysis was also repeated in the following subgroups: patients undergoing PCI in the inpatient and outpatient settings and patients with and without complex coronary lesions, defined as chronic total occlusions, bifurcation lesions, and those requiring atherectomy.

As Medicare claims are required for reimbursement, missing data are infrequent. However, in order to assess the potential impact of excluding patients with missing data, analyses were repeated with these subjects included and with adjustment for all covariates except those with missing data.

As a pre-specified sensitivity analysis to address potential residual confounding, an instrumental variable analysis was planned,[13–15] using operator preference for IVI use (defined as the proportion of an operator's PCIs over the study period that were IVI-guided) as the instrument.[16–18] However, this instrument did not meet the basic assumptions required for an instrumental variable analysis. In particular, after examining patient characteristic by quintiles of operator IVI use (see Supplementary data online, *Table S2*), there were significant residual imbalances in both patient- and operator-level characteristics (including atherectomy use, mechanical support use, and operator volumes) which violated the random assignment assumption.[19] This suggested that the instrument failed to create similar patient populations as would be observed following randomization in a clinical trial. Other instruments were also explored, including hospital/facility, but the same issue was encountered. As such, this sensitivity analysis was not performed.

Statistical analyses were performed using SAS software, version 9.4 (SAS Institute Inc) and R (version 4.1.3) software. A two-sided *P*-value of <.05 was considered significant for all analyses without adjustment for multiplicity.

Results

Study population and temporal trends

A total of 2 113 220 PCIs performed in 1 659 255 patients were identified during the study period and included in the temporal trend analysis. As depicted in the flow diagram (*Figure 1*), after exclusions, 1 189 470 patients were included in the comparative outcomes analysis of IVI-guided vs. angiography-guided PCI.

The mean age of the overall study population was 75.2 (SD 6.9) years, 38.0% ($n = 452\,253$) were female, and 89.8% ($n = 1\,068\,427$) were White (*Table 1*). PCI was performed in the setting of acute MI in 65.1% ($n = 774\,104$), of which 26.8% ($n = 207\,256$) were for ST-elevation myocardial infarction (STEMI). Furthermore, PCIs were performed for cardiogenic shock in 3.8% ($n = 45{,}101$) and cardiac arrest in 2.3% ($n = 26\,970$).

IVI was used in 10.5% of all PCIs, increasing from 9.5% of PCIs in 2013 to 15.4% of PCIs in 2019 (*Figure 2*). After a small decline in IVI use between 2013 and 2015, the annual relative growth in IVI use in successive years from 2016 through 2019 was 5.4%, 15.1%, 17.4%, and 29.6% (see Supplementary data online, *Table S3*). A similar trend was seen in both the inpatient and outpatient settings. Among patients with acute MI ($n = 774\,104$), IVI was used in 9.6% ($n = 75\,060$) at the time of PCI.

Patient, procedural, and hospital characteristics of PCIs by IVI use

Unadjusted rates of IVI-guided PCI were higher in patients undergoing atherectomy or concomitant FFR and those with a pVAD and lower in patients with acute MI (*Table 1*). More frequent IVI use was also observed in patients treated by higher volume operators and hospitals, in the outpatient setting, at larger hospitals (>500 beds) and those located in the Mountain and Pacific regions.

After multivariable adjustment, the likelihood of IVI use remained highest in the Mountain [adjusted OR 3.65; 95% confidence interval (CI) 2.42–5.49] and Pacific (adjusted OR 2.95; 95% CI 2.00–4.35) regions and lowest in the Northeast (reference for comparisons) (*Figure 3*; Supplementary data online, *Table S4*). Procedural factors associated with more frequent IVI use included use of pVAD (adjusted OR 3.09; 95% CI 2.94–3.23) or intra-aortic balloon pump (adjusted OR 1.33; 95% CI 1.25–1.40), use of adjunctive atherectomy (adjusted OR 1.83; 95% CI 1.79–1.87), and bifurcation lesions (adjusted OR 1.64; 95% CI 1.57–1.71). IVI use was more frequent in the outpatient setting (adjusted OR 1.07; 95% CI 1.05–1.09) and at teaching hospitals (adjusted OR 1.23; 95% CI 1.06–1.42).

Factors associated with less frequent use of IVI included STEMI (adjusted OR 0.54, 95% CI 0.52–0.55), non-ST-elevation myocardial infarction (adjusted OR 0.77, 95% CI 0.75–0.79), prior CABG (adjusted OR 0.79, 95% CI 0.78–0.81), cardiogenic shock (adjusted OR 0.84, 95% CI 0.81–0.88), diabetes mellitus (adjusted OR 0.90, 95% CI 0.89–0.91), hypertension (adjusted OR 0.92; 95% CI 0.89–0.94), cardiac arrest (adjusted OR 0.93, 95% CI 0.88–0.98), and Black race (adjusted OR 0.91, 95% CI 0.89–0.94) or other non-White race (adjusted OR 0.96, 95% CI 0.93–0.99) (*Figure 3*; Supplementary data online, *Table S4*).

Operator preference for intravascular imaging use

The distribution of IVI use among operators ($n = 9346$) is displayed in *Figure 4*. Individual operators' proportional IVI use ranged from 0% to 100%, with median IVI use of 3.9%, first quartile of 0.4%, and third quartile of 12.8%. The median OR, which is a measure of operator-level variation in IVI use that is not explained by the modelled factors, was 3.40 (95% CI 3.26–3.56), suggesting a high level of heterogeneity in operator IVI use. Nearly a quarter of operators [$n = 2282$ (24%)] did not use IVI during the study period. Among operators with at least one IVI-guided PCI during the study period ($n = 7064$), operator IVI use ranged from 0.12% to 100% of PCIs, with mean (±SD) IVI use of 13.8% (±17.2%) and median of 7.06% and first and third quartiles of 2.68% and 17.78%, respectively (see Supplementary data online, *Figure S1*). In this subgroup, the operator-level median OR was 2.90 (95% CI 2.79–3.01), indicating a high level of variation in operator IVI use.

Table 1 Patient, procedure, operator, and hospital characteristics of the study population

Baseline characteristics	IVI-guided PCI		Angiography-guided PCI		Standardized difference (%)
n	125 227		1 064 243		
Age, mean (SD), years	75.0 ± 6.8		75.2 ± 7.0		−3.2
Male	78 496	62.7%	658 721	61.9%	1.6
Race					
Caucasian	112 422	89.8%	956 005	89.8%	−0.2
African American	6661	5.3%	59 601	5.6%	−1.2
Other	6144	4.9%	48 637	4.6%	1.6
Clinical characteristics					
Hypertension	113 286	90.5%	963 168	90.5%	−0.1
Hyperlipidaemia	112 052	89.5%	940 499	88.4%	3.5
Diabetes mellitus	61 970	49.5%	534 205	50.2%	−1.4
Prior CABG	22 508	18.0%	209 506	19.7%	−4.4
Prior PCI	38 519	30.8%	312 034	29.3%	3.1
Congestive heart failure	56 570	45.2%	459 576	43.2%	4
Cardiomyopathy	17 880	14.3%	133 174	12.5%	5.2
Prior stroke or TIA	22 312	17.8%	195 492	18.4%	−1.4
Peripheral arterial disease	41 967	33.5%	348 462	32.7%	1.6
Chronic kidney disease	52 690	42.1%	435 751	40.9%	2.3
Obesity	37 428	29.9%	305 285	28.7%	2.6
ESRD	3642	2.9%	29 298	2.8%	0.9
Tobacco use	21 191	16.9%	180 781	17.0%	−0.2
Depression	39 219	31.3%	329 419	31.0%	0.8
Atrial fibrillation	27 371	21.9%	217 737	20.5%	3.4
Anaemia	71 925	57.4%	599 494	56.3%	2.2
COPD	42 154	33.7%	357 991	33.6%	0.1
Breast cancer	4942	3.9%	41 136	3.9%	−0.4
Colorectal cancer	3592	2.9%	30 895	2.9%	0.2
Prostate cancer	10 713	8.6%	87 954	8.3%	−1
Lung cancer	2409	1.9%	19 502	1.8%	−0.7
Endometrial cancer	915	0.7%	7375	0.7%	−0.4
Clinical presentation					
Acute coronary syndrome					
STEMI	14 638	11.7%	192 618	18.1%	−18.1
NSTEMI	27 346	21.8%	255 812	24.0%	−5.2
Unspecified MI	373	0.3%	3101	0.3%	0.1
Unstable angina	32 027	25.6%	243 746	22.9%	6.2
Cardiac arrest	2344	1.9%	24 626	2.3%	−3.1
Cardiogenic shock	4333	3.5%	40 768	3.8%	−2.0
Stable CAD	50 167	40.1%	365 199	34.3%	11.9

Continued

Table 1 *Continued*

Baseline characteristics	IVI-guided PCI		Angiography-guided PCI		Standardized difference (%)
Procedure					
PCI (with stent)	121 518	97.0%	1 014 483	95.3%	9
Angioplasty alone	3709	3.0%	49 760	4.7%	−9
Concomitant FFR	14 653	11.7%	90 621	8.5%	10.6
Chronic total occlusion	6042	4.8%	46 932	4.4%	2.0
Adjunctive atherectomy	14 670	11.7%	63 551	6.0%	20.3
Percutaneous VAD	3635	2.9%	9729	0.9%	14.6
ECMO	196	0.2%	1313	0.1%	0.9
Intra-aortic balloon pump	2200	1.8%	19 503	1.8%	−0.6
Bifurcation lesion	3497	2.8%	18 164	1.7%	7.3
Procedure setting					
Inpatient	64 905	51.8%	609 495	57.3%	−10.9
Outpatient	60 322	48.2%	454 748	42.7%	10.9
Operator characteristics					
Annual Medicare PCI volume, mean ± SD	67.3 ± 60.5		61.0 ± 49.7		11.5
Hospital characteristics					
Rural	281	0.2%	4037	0.4%	−2.8
Teaching	92 776	74.1%	773 825	72.7%	3.1
Bed size					
6–24	132	0.1%	1707	0.2%	−1.5
25–49	763	0.6%	9363	0.9%	−3.1
50–99	4338	3.5%	45 879	4.3%	−4.4
100–199	18 384	14.7%	156 921	14.7%	−0.2
200–299	24 815	19.8%	217 440	20.4%	−1.5
300–399	19 936	15.9%	204 558	19.2%	−8.7
400–499	13 815	11.0%	120 355	11.3%	−0.9
≥500	43 044	34.4%	308 020	28.9%	11.7
US region					
Northeast	3477	2.8%	44 267	4.2%	−7.6
Mid-Atlantic	15 089	12.0%	121 003	11.4%	2.1
South Atlantic	30 740	24.5%	228 949	21.5%	7.2
East North Central	16 633	13.3%	175 546	16.5%	−9
West North Central	9189	7.3%	91 270	8.6%	−4.6
East South Central	6495	5.2%	94 206	8.9%	−14.4
West South Central	15 475	12.4%	145 594	13.7%	−3.9
Mountain	10 747	8.6%	62 008	5.8%	10.7
Pacific	17 283	13.8%	100 147	9.4%	13.7
Other	99	0.1%	1253	0.1%	−1.2

PCI, percutaneous coronary intervention; IVI, intravascular imaging; SD, standard deviation; CABG, coronary artery bypass graft; TIA, transient ischaemic attack; ESRD, end-stage renal disease; COPD, chronic obstructive pulmonary disease; STEMI, ST-elevation myocardial infarction; NSTEMI, non-ST-elevation myocardial infraction; CAD, coronary artery disease; FFR, fractional flow reserve; VAD, ventricular assist device; ECMO, extracorporeal membrane oxygenation.

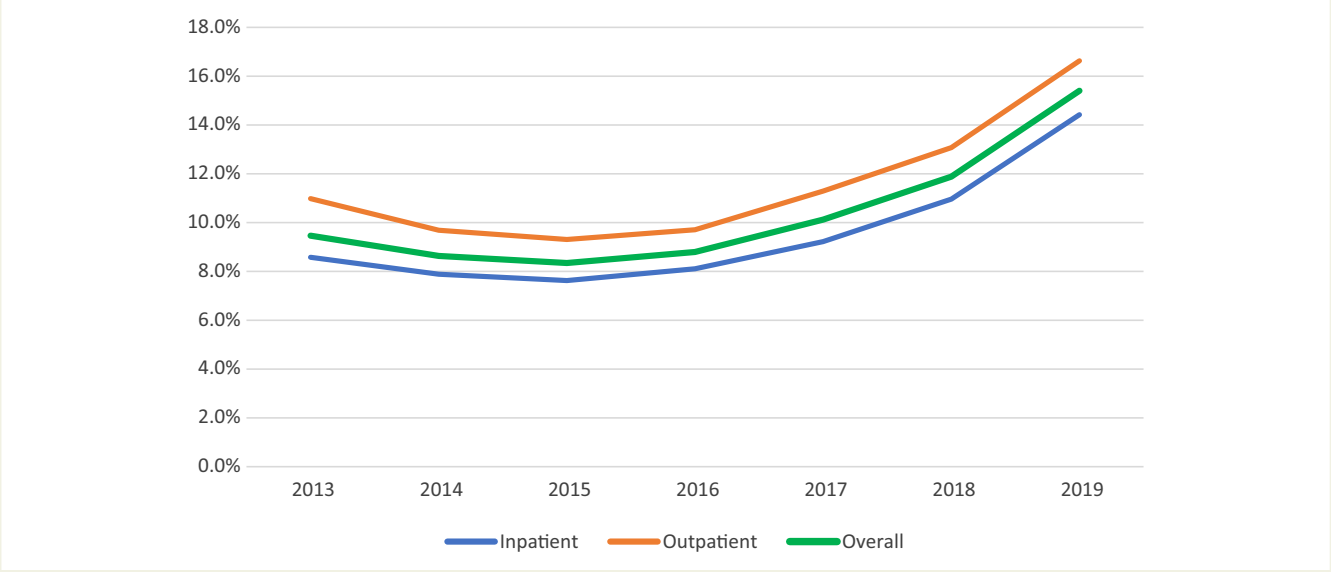


Figure 2 Temporal trends in use of intravascular imaging for percutaneous coronary intervention.

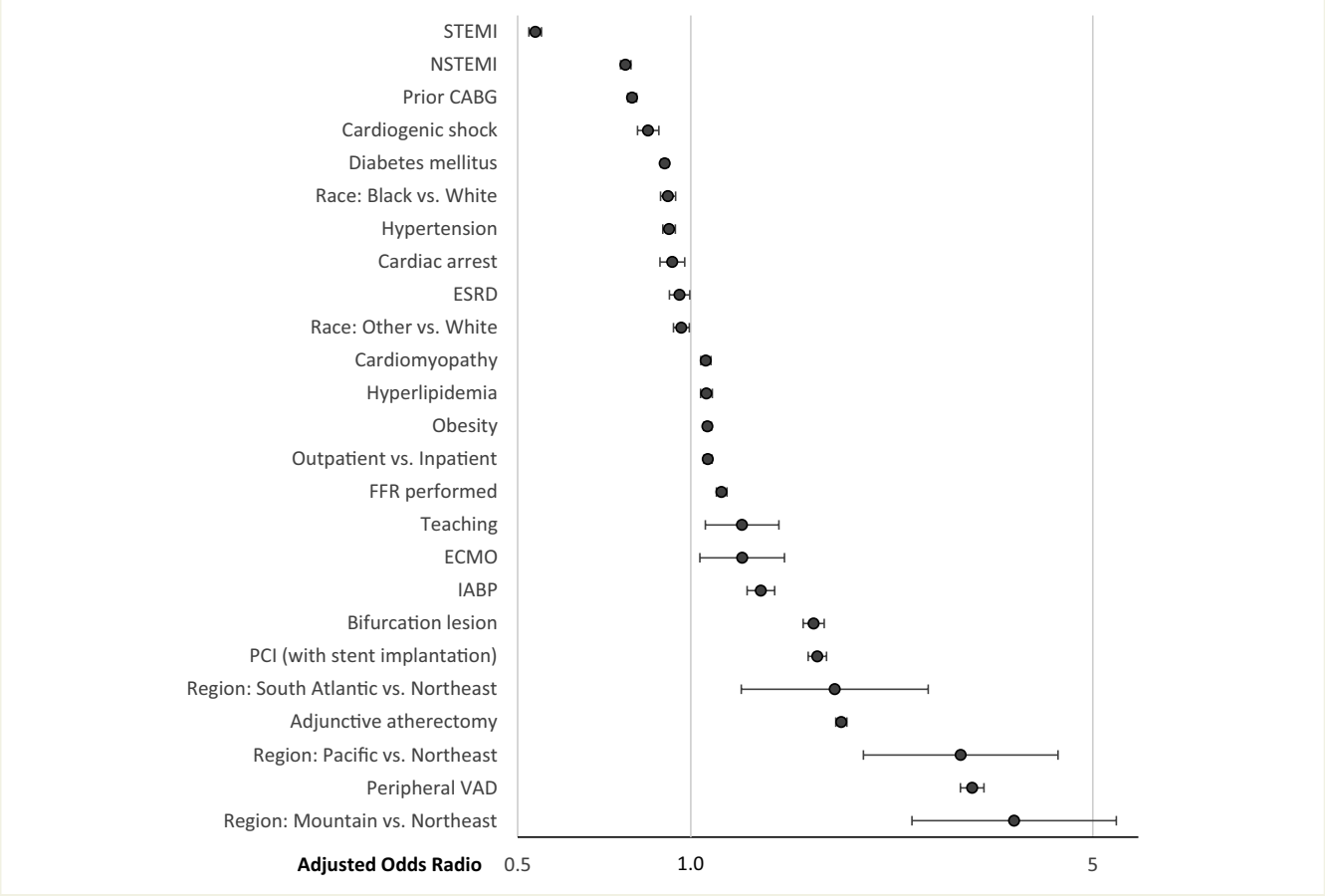


Figure 3 Association of select patient, procedural and hospital characteristics with intravascular imaging use during PCI after multivariable adjustment. PCI, percutaneous coronary intervention; STEMI, ST-elevation myocardial infarction; NSTEMI, non-ST-elevation myocardial infarction; CABG, coronary artery bypass graft; ESRD, end-stage renal disease; FFR, fractional flow reserve; ECMO, extracorporeal membrane oxygenation; IABP, intra-aortic balloon pump; VAD, ventricular assist device.

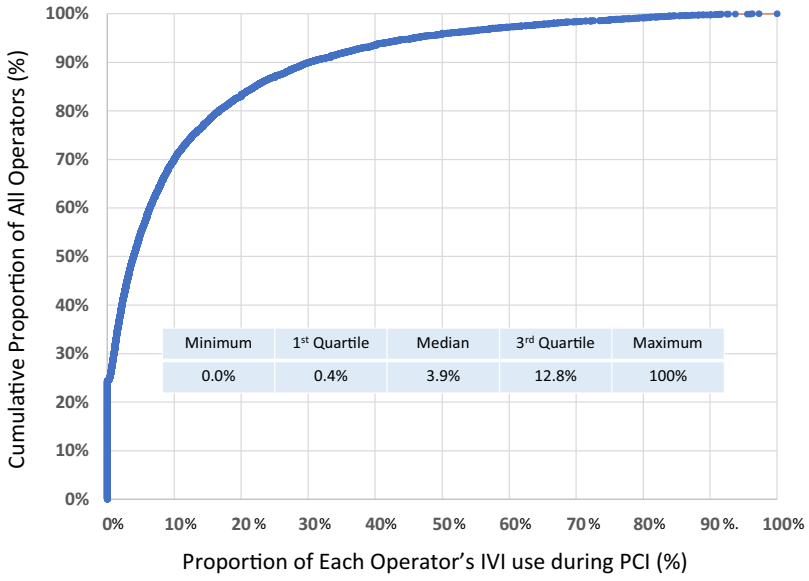


Figure 4 Cumulative distribution of operator use of intravascular imaging during percutaneous coronary intervention.

Longitudinal outcomes

The unadjusted rates of death, MI, repeat PCI, and MACE at 1 year were all lower for IVI-guided PCI relative to PCI with angiography alone (*Table 2*). In adjusted analyses, IVI use during PCI continued to be associated with lower mortality [adjusted hazard ratio (HR) 0.96, 95% CI 0.94–0.98], MI (adjusted HR 0.97, 95% CI 0.95–0.99), repeat PCI (adjusted HR 0.74, 95% CI 0.73–0.75), and MACE (adjusted HR 0.85, 95% CI 0.84–0.86) at 1 year (*Table 2*; *Figure 5*). There was no significant difference in the falsification endpoints of hospitalization for pneumonia (5.6% vs. 5.6%; adjusted HR 1.02, 95% CI 0.99–1.04) or hip fracture (0.7% vs. 0.7%; adjusted HR 1.02, 95% CI 0.94–1.10) for IVI-guided vs. angiography-guided PCI.

In the sensitivity analysis that considered PCIs within 30 days after the index procedure as staged PCIs and did not count them towards the repeat PCI outcomes, there was no change in the analysis results (see Supplementary data online, *Table S5*).

Missing data were minimal in this study ($n = 159\,517$) and primarily related to lack of hospital characteristics for some centres. The baseline characteristics of patients excluded due to missing data were similar overall to the final study population (see Supplementary data online, *Table S6*). Furthermore, when these patients were included in the analyses evaluating the endpoints, there was no significant change in the risk estimates (see Supplementary data online, *Table S7*).

Subgroup analyses

In the subset of patients who underwent PCI in the setting of an acute coronary syndrome, IVI was also associated with a reduction in MACE and each of its components, similar to the overall population (see Supplementary data online, *Table S8A*). Among patients without acute coronary syndrome, IVI was associated with reduction in MI, repeat PCI, and MACE, but no significant difference in mortality (see Supplementary data online, *Table S8B*).

Among patients undergoing PCI for complex lesions, defined as chronic total occlusions, bifurcations, or lesions requiring atherectomy, use of IVI was associated with a reduction in mortality, repeat PCI, MACE but not MI (see Supplementary data online, *Table S9A*). In patients with non-complex lesions, IVI use was associated with a reduction in MACE and each of its components (see Supplementary data online, *Table S9B*).

In the inpatient setting, IVI use during PCI was associated with a reduction in death, repeat PCI, and MACE but not MI (see Supplementary data online, *Table S10A*). Among outpatients, IVI use was associated with lower rates of MI, repeat PCI, and MACE but no difference in mortality (see Supplementary data online, *Table S10B*).

Discussion

In this nationwide study of IVI use during PCI among Medicare beneficiaries from 2013 through 2019, overall IVI use was low during the study period, but demonstrated a trend towards increased utilization from 2015 through 2019. There was significant operator and regional variation in IVI use, with the highest utilization rates in the Mountain and Pacific regions and the lowest in the Northeast. Key patient and procedural factors associated with IVI use included use of pVADs, intravascular physiology testing (FFR), and treatment of a bifurcation lesion. Overall, IVI use during PCI was associated with lower rates of MACE and its components (including all-cause mortality) at 1 year in the overall study population as well as in the subset of patients with acute coronary syndromes (*Structured Graphical Abstract*). Unmeasured confounding appeared to be minimal as demonstrated by the non-significant relationship with the falsification endpoints of hospitalized pneumonia and hip fracture.

Prior randomized trials of IVI-guided PCI, including trials in all-comers,[20] patients with long lesions,[21] and chronic total occlusions[22] have consistently shown a reduction in target lesion revascularization and MACE with IVI. In addition, several meta-analyses of IVI-guided PCI have found IVI use to be associated with reduced mortality, MI, target vessel revascularization, and MACE.[1–3] Based on these trials, the American College of Cardiology/American Heart Association PCI guidelines have given a Class IIa recommendation for IVI use during PCI for complex lesions.[23] Similarly, the European Society of Cardiology PCI guidelines have given a Class IIa recommendation for

Table 2 One-year outcomes associated with intravascular imaging use estimated from the multivariable cox regression model

Clinical outcome	Crude event rates		Unadjusted cumulative incidence rate, %		Multivariable Cox regression	
	IVI-guided PCI	Angiography	IVI-guided PCI	Angiography	Adjusted hazard ratio (95% CI)	*P*-value
Death	11 431	106 728	9.9	10.6	0.96 (0.94–0.98)	.0002
Myocardial infarction	8817	89 737	7.4	8.7	0.97 (0.95–0.99)	.0034
Repeat PCI	14 307	168 027	12.5	16.7	0.74 (0.73–0.75)	<.0001
MACE (death/MI/repeat PCI/CABG)	30 088	312 954	25.8	30.7	0.85 (0.84–0.86)	<.0001
Falsification endpoints						
Hospitalized pneumonia	6315	55 628	5.6	5.6	1.02 (0.99–1.04)	.24
Hip fracture	758	6754	0.7	0.7	1.02 (0.94–1.10)	.64

IVI, intravascular imaging; PCI, percutaneous coronary intervention; CI, confidence interval; MACE, major adverse cardiovascular events; MI, myocardial infarction; CABG, coronary artery bypass graft.

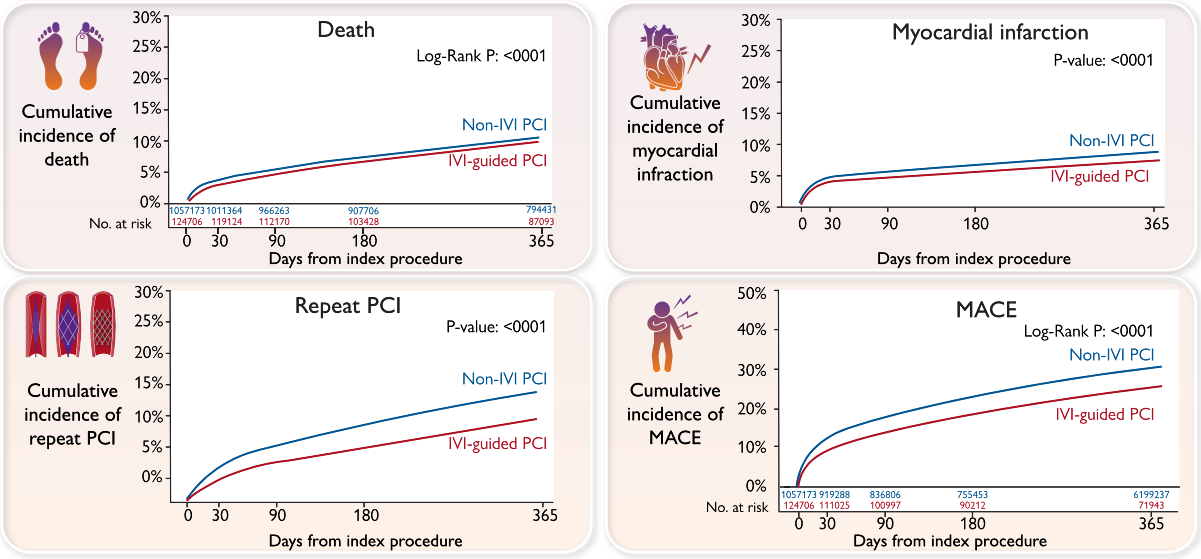


Figure 5 Kaplan–Meier curves of 1 year outcomes of IVI-guided PCI compared with non-IVI PCI. IVI, intravascular imaging; PCI, percutaneous coronary intervention; MACE, major adverse cardiovascular event.

IVI use for treatment of unprotected left main lesions and in selected patients, such as those with stent failure.[24,25] Despite these recommendations, IVI use in the USA remains low, as reflected in the present analysis as well as prior studies of inpatient PCI between 2007 and 2017 in the USA where IVI was used in <10% of cases.[5,26] Several large trials evaluating the impact of IVI use for PCI, including the ILUMIEN-IV, IVUS-CHIP, and IMPROVE trials, are currently ongoing and expected to provide the data necessary to further refine practice guidelines.[27,28]

Our study adds to the growing body of evidence indicating that IVI use improves outcomes for patients undergoing PCI. Our findings are consistent with a prior study of Medicare beneficiaries and an analysis of the National Inpatient Sample, both of which were limited to inpatient procedures.[5,6] Our study provides a more comprehensive view of the PCI landscape by including both inpatient and outpatient procedures. The fact that close to half of PCIs in Medicare beneficiaries were performed in the outpatient setting highlights the importance of including this practice location in studies of contemporary PCI outcomes.

Understanding the reasons for underutilization of IVI in the USA, despite existing guidelines and evidence, is essential to increasing its use in appropriate cases. Potential barriers to IVI include added time and cost to procedures, lack of adequate operator training for imaging interpretation, and lack of familiarity with data supporting its effectiveness.[29] A recent cost-effectiveness analysis of IVI-guided PCI from Australia found that it

is cost-effective, and another from Italy concluded that it is a dominant strategy, i.e. both more effective and less costly.[30,31] Education and support by professional societies and fellowship training programmes as well as the creation of appropriate incentives may be necessary to promote further growth in utilization of IVI for PCI in the USA.[32]

It is worth noting that IVI use in our study population was less frequent in Black and other non-White patients. This finding is consistent with racial disparities described in prior studies of treatment of coronary artery disease, valvular heart disease, and heart failure.[33–35] Further investigation into the causes of racial disparities in IVI use can help to elucidate strategies to eliminate these inequities.

Our analysis should be interpreted in the context of the following limitations. First, operator and hospital PCI volumes were determined based on Medicare claims only and will therefore underestimate total PCI volumes among both groups. Second, it was not possible to determine if repeat PCI was related to target lesion failure or to an unrelated lesion or vessel based on claims data alone. However, assuming all PCIs within a 30 day period after the index procedure were staged PCIs did not change the analysis results. Third, how IVI was used as an adjunct to the PCI procedure, such as prior to stent placement, after stent placement, or both, cannot be determined from claims data alone. Fourth, as this study relied on claims data, it lacked granular information on lesion and procedural characteristics, including number of lesions intervened upon. Furthermore, outpatient claims codes could not differentiate between IVI modality (IVUS vs. optical coherence tomography), although the predominant IVI modality used in the USA is IVUS.[26] Fifth, as information on pharmacological treatment of patients was not available, it was not incorporated in the analysis. Sixth, as with any observational study, the potential for confounding could not be fully addressed; however, the falsification endpoints suggest lack of significant confounding between treatment groups in our outcomes analyses. Finally, our analysis includes Medicare beneficiaries only and may not be fully representative of the US population undergoing PCI.

In conclusion, while IVI use during PCI was relatively infrequent over the study period, it has grown significantly in recent years. In risk-adjusted analyses, IVI use was associated with reductions in subsequent mortality, MI, repeat PCI, and MACE among Medicare beneficiaries, adding to the body of evidence showing improved outcomes with IVI use for PCI. Further studies to understand the mechanisms of regional variation as well as racial disparities in IVI use are warranted.

Supplementary data

Supplementary data are available at *European Heart Journal* online.

Declarations

Disclosure of Interest

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Data Availability

The data underlying this article are available in the article and in its supplementary material online.

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Ethical Approval

Ethical approval was not required.

Pre-registered Clinical Trial Number

Not applicable.

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