Journal of the Society for Cardiovascular Angiography & Interventions 2 (2023) 100973

JSCAI

The official journal of the Society for
Cardiovascular Angiography & Interventions

Original Research

Hospital-Level Variability in Use of Intracoronary Imaging for Percutaneous Coronary Intervention in the United States

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ABSTRACT

Background: Intracoronary (IC) imaging for percutaneous coronary intervention (PCI) is associated with better patient outcomes and carries a class IIA guideline recommendation, but it remains rarely used. We sought to characterize hospital-level variability in IC imaging for PCI in the United States and to identify factors that may explain this variability.

Methods: Patients who underwent PCI, with or without IC imaging, in the Nationwide Readmissions Database (2016-2020) were included. A regression model with a random effect for site was used to generate the median odds ratio (MOR) of IC imaging use for a patient at one site vs another, sequentially adjusting for procedural, patient, and hospital factors to examine the extent to which different factors account for this variability.

Results: The analytic cohort included 1,328,517 PCI procedures (patient mean age 65.8 years, 32.4% female, IC imaging used in 9.2%) at 1068 hospitals. The median hospital use of IC imaging increased from 2.7% (IQR, 0.6-7.7) in 2016 to 6.3% (IQR, 1.7-17.8) in 2020. In 2020, the MOR for IC imaging during PCI was 4.6 (IQR, 4.3-5.0), indicating a >4-fold difference in the odds of a patient undergoing IC imaging with PCI at one random hospital vs another. Adjusting for procedure, patient, and hospital factors did not meaningfully alter the MOR.

Conclusion: The average US hospital uses IC imaging for <1 in 15 PCI procedures, with marked variability across hospitals. Strategies to increase and standardize the use of IC imaging are needed to improve the quality of PCI in the United States.

Introduction

Coronary angiography has important limitations in the evaluation of coronary artery dimensions, plaque characteristics, and the result of coronary stent implantation.[1,2] Intracoronary (IC) imaging, with either intravascular ultrasound (IVUS) or optical coherence tomography (OCT), to guide percutaneous coronary intervention (PCI) offers more accurate measurement of vessel dimensions, lesion characterization to support optimal vessel preparation, better stent sizing, and guidance of the stenting strategy.[3] IC imaging also improves evaluation of the stent expansion after implantation.[3] There is robust evidence from observational studies,[4,5] randomized controlled trials,[6–9] and meta-analyses[10,11] showing that IC imaging improves long-term clinical outcomes, including cardiovascular death, myocardial infarction, target lesion revascularization, and stent-thrombosis. Accordingly, IC imaging to optimize PCI was assigned a class IIA guideline recommendation in the most recent American College of Cardiology/American Heart Association coronary revascularization guidelines.[12] Despite this, IC imaging to optimize PCI was used in only 3% to 5% of PCI procedures in the United States in 2014-2015.[13,14] Although IC imaging rates have increased in recent years,[15] hospital variability in the use of IC imaging for PCI and its association with procedural, patient, and hospital characteristics is not known.

Methods

Data source and study population

To obtain a national perspective of current PCI practice, we used data from 2016 to 2020 from the Nationwide Readmissions Database

Abbreviations: CTO, chronic total occlusion; IC, intracoronary; ICD-10, International Classification of Disease, Tenth Revision, Clinical Modification/Procedure Coding System; IVUS, intravascular ultrasound; MOR, median odds ratio; NRD, Nationwide Readmissions Database; OCT, optical coherence tomography; PCI, percutaneous coronary intervention.

Keywords: intracoronary imaging; percutaneous coronary intervention; quality improvement.

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https://doi.org/10.1016/j.jscai.2023.100973
Received 16 March 2023; Received in revised form 27 March 2023; Accepted 28 March 2023
Available online 19 May 2023

(NRD) of the Healthcare Cost and Utilization Project, adhering to methodological standards set by the Healthcare Cost and Utilization Project.[16] The NRD includes discharges for patients in a year and those who have died in the hospital. The NRD includes data from 31 states for the year 2020. These data account for 62.2% of the US resident population and 60.8% of all hospitalizations. However, the NRD does not comprise a random sample of US hospitals, and the findings within this cohort may not be fully representative of the entire US population. The NRD includes all discharge records of patients treated in US community hospitals, excluding rehabilitation and long-term acute care facilities. All patients who underwent PCI were included in the analysis. Patients from hospitals with a PCI volume <10 procedures/year were excluded. Patients who had a PCI during the hospital stay were identified using the International Classification of Disease, Tenth Revision, Clinical Modification/Procedure Coding System (ICD-10).

Outcomes assessment

The primary outcome of interest was the use of IC imaging for PCI. This was identified using ICD-10 codes for IVUS and OCT, respectively. Supplementary Table 1 details all the ICD-10 codes used for data abstraction.

Covariates

Patient demographic characteristics, socioeconomic status, comorbidities, and hospital characteristics are provided by the NRD. Hospital bed size was categorized as small, medium, and large, depending on number of beds, teaching status, and location as specified by the NRD criteria[16] (Supplementary Table 2). Procedural characteristics (PCI for myocardial infarction, ST-segment elevation myocardial infarction, and non–ST-segment elevation myocardial infarction), presence of a chronic total occlusion, and use of atherectomy were abstracted using ICD-10 codes. Most of the covariates, as well as our study outcome (IVUS or OCT use), have multiple ICD-10 codes. We determined the covariate or our study outcome to be present for a PCI procedure if any of these codes (for a particular covariate or outcome) were listed.

Statistical analysis

Baseline patient and hospital characteristics in the analytical cohort were described using mean and SD for continuous variables and frequency (%) for categorical variables. Due to the large sample size (for procedures), baseline characteristics were compared using standardized mean difference. By convention, standardized mean differences of greater than 10% are considered significant.[17]

For each hospital, we examined the proportion of PCI procedures with use of IC imaging for each year of analysis. To explore trends in the use of IC imaging for PCI, we plotted the use of any IC imaging (IVUS or OCT), as well as the individual modalities of IVUS or OCT, over time (2016-2020).

The NRD assigns a unique identifier for each hospital each year, so it is not possible to evaluate the performance of one hospital over sequential years. Hence, hospital-level variability in the use of IC imaging was analyzed separately for each year. In this manuscript, we present the analysis for the year 2020, with analyses for years 2016-2019 in the Supplementary Material. An unadjusted hierarchical logistic regression model with random effects for hospitals was first constructed, using the outcome of IC imaging during PCI as the dependent variable. To describe variability in IC use across hospitals, we calculated median odds ratio (MOR), which quantifies the average difference in the likelihood that 2 statistically identical patients would receive IC imaging at one random hospital as compared with another. For example, a MOR of 1.4 would mean that a similar patient would have a 40% higher odds of having IC imaging when treated at one hospital vs another.[18] Moreover, to understand better how the addition of procedural, patient, and hospital factors affected the ability of the model to predict outcome (use of IC imaging), we also calculated a c-statistic for each of our models. The c-statistic is a unitless index that measures the goodness of fit of a regression model, and values >0.7 indicate a good model.[19]

To identify how procedural, patient, and hospital characteristics might influence the variability in the use of IC imaging, we sequentially adjusted the logistic regression model for these factors and created subsequent models after each level of adjustment. We obtained an estimate of the variance explained by the addition of these factors using the c-statistic. Model 1 was the unadjusted evaluation of variability in IC imaging between hospitals without risk adjustment. Next, we incorporated procedural factors, which may be associated with higher complexity and greater propensity to use IC imaging. Use of atherectomy devices was selected as a readily identifiable procedural variable and a reliable surrogate for heavy vessel calcification. Acute myocardial infarction and presence of a chronic total occlusion were also selected given the established benefits of IC imaging in these populations.[5,20,21] To assess whether these procedural characteristics accounted for the observed variability in IC imaging use, we added these procedural factors to model 1 to create model 2 and obtained a new c-statistic. To explore whether patient factors (demographic characteristics [age, sex], socioeconomic status [mean household income, insurance status], comorbidities [diabetes, hypertension, chronic kidney disease, previous myocardial infarction, PCI, or coronary artery bypass grafting]) accounted for some of the observed variability, we then added these factors to model 2 to create model 3. Finally, we adjusted for hospital factors (bed size, teaching status, academic vs private, rural vs urban location, annual PCI volume) to create a fourth model and calculated

Table 1. Baseline characteristics for the analytical cohort (N = 1,328,517 procedures) stratified by patients who received intracoronary imaging versus those who did not.

	IC imaging used n = 122,081	IC imaging not used n = 1,206,436	Standardized difference (%)
Demographic characteristics			
Age, y	65.7±12.4	65.8±12.3	0.7%
Female sex	31.4%	32.5%	2.4%
Comorbidities			
Diabetes	39.9%	40.8%	1.7%
Obesity	21.1%	21.1%	0.1%
Hypertension	54.9%	58.6%	7.5%
Systolic heart failure	22.1%	18.7%	8.4%
Smoking	49.0%	49.9%	1.8%
Prior MI	19.9%	17.8%	5.4%
Chronic kidney disease	22.4%	21.0%	3.4%
Prior PCI	21.4%	20.5%	2.2%
Prior CABG	8.0%	10.1%	7.1%
Pulmonary disease	19.1%	19.2%	0.4%
Socioeconomic status			
Median household income (based on zip code)			
≤1st quartile	23.8%	28.5%	17.3%
≥4th quartile	25.1%	19.0%	–
No medical insurance	3.7%	4.0%	4.6%
Procedural characteristics			
CTO	7.7%	6.8%	3.3%
MI (STEMI)	2.6%	3.2%	3.6%
MI (NSTEMI)	39.5%	40.8%	2.6%
Atherectomy used	15.1%	8.7%	19.8%

Values are mean ± SD or %.

CABG, coronary artery bypass graft surgery; CTO, chronic total occlusion; IC, intracoronary; MI, myocardial infarction; NSTEMI, non–ST-elevation myocardial infarction; PCI, percutaneous coronary intervention; STEMI, ST-elevation myocardial infarction.

Table 2. Hospital characteristics for the analytical cohort for 2020 (N = 1068 hospitals) stratified by quartiles for use of IC imaging.

	Quartile 1 0-1.68% n = 267	Quartile 2 1.69-6.32% n = 267	Quartile 3 6.33-17.98% n = 267	Quartile 4 >17.98% n = 267	*P*-trend
Bed size					
Small	27.7%	18.7%	22.8%	19.1%	.001
Medium	36.3%	31.1%	34.5%	26.6%	
Large	36.0%	50.2%	42.7%	54.3%	
Ownership					
Government	13.1%	10.5%	6.0%	10.1%	.23
Private not-profit	62.2%	70.0%	75.3%	75.3%	
Private for profit	24.7%	19.5%	18.7%	14.6%	
Teaching	53.6%	62.9%	71.9%	65.2%	< .001
PCI volume	187.2±148.9	242.1±208.5	246.7±195.9	257.0±204.1	< .001

Values are mean ± SD or %.
PCI, percutaneous coronary intervention.

the c-statistic to estimate the proportion of variability explained by procedural, patient, and hospital related factors.

To understand the contribution of procedural, patient, and hospital factors on the hospital-to-hospital variability in use of IC imaging for PCI, we obtained an estimate of variance explained by the independent variables using the coefficient of determination (R^2 statistic). The R^2 statistic is a measure of the proportion of variance that a dependent variable in the regression model is explained by the independent variables.[22]

It is possible that some hospitals that did not perform any IC imaging for a particular year might not have had the capability (for example equipment/staff not trained in IC imaging, etc.) to perform OCT and IVUS. To see if there remained significant hospital-to-hospital variability when excluding these hospitals, we did an additional sensitivity analysis. We excluded hospitals that did not perform any IC imaging and examined the hospital-level variability in use of IC imaging and factors associated with the variability, using the above models.

All analyses were performed with SAS 9.4 (SAS Institute) and evaluated with a 2-sided significance of <0.05.

Results

Between 2016 and 2020, there were 1,330,106 PCI procedures in the NRD. Of these, 1589 procedures were at hospitals with a PCI volume of <10 procedures/year and were excluded. The final analytical cohort included 1,328,517 procedures (Supplementary Figure 1).

The mean age of the patients was 65.8 ± 12.3 years, and 32.4% (n = 430,745) were female. Comorbidities were common; 40.7% of patients had diabetes and 21.1% had chronic kidney disease. PCI was performed to treat acute myocardial infarction in 43.8% of cases. Chronic total occlusion was present in 6.9%, and atherectomy was performed in 9.3% of procedures. Overall, IC imaging was used in 9.1% (n = 122,081) of the PCI procedures. Differences between patients who underwent PCI with vs without IC imaging are provided in Table 1. Procedures performed with IC imaging had more atherectomy use but were otherwise generally well balanced in terms of age, sex, and proportion of patients with major comorbidities.

Of 1068 hospitals analyzed in 2020, 22.1% were categorized as small, 32.1% as medium, and 45.8% as large. In terms of ownership, 9.9% of the hospitals were government owned, 70.7% were private not-for-profit, and 19.4% were private for profit. Sixty-three percent of the hospitals were categorized as teaching. Table 2 compares hospital characteristics among hospitals stratified by quartiles of percentage use of IC imaging. There was a trend of higher use of IC imaging in teaching hospitals and hospitals with higher PCI volumes.

From 2016 to 2020, there was trend toward increased IC imaging use during PCI. Overall IC imaging use increased from 6.6% in quarter 1 of 2016 to 15.4% in quarter 4 of 2020. This was mostly driven by higher use of IVUS. Use of OCT rates remained similar (Figure 1). Figure 2 describes the variability in IC imaging use for PCI among hospitals in 2020. Median use was 6.3% with an interquartile range of 16.2% (1.7-17.9).

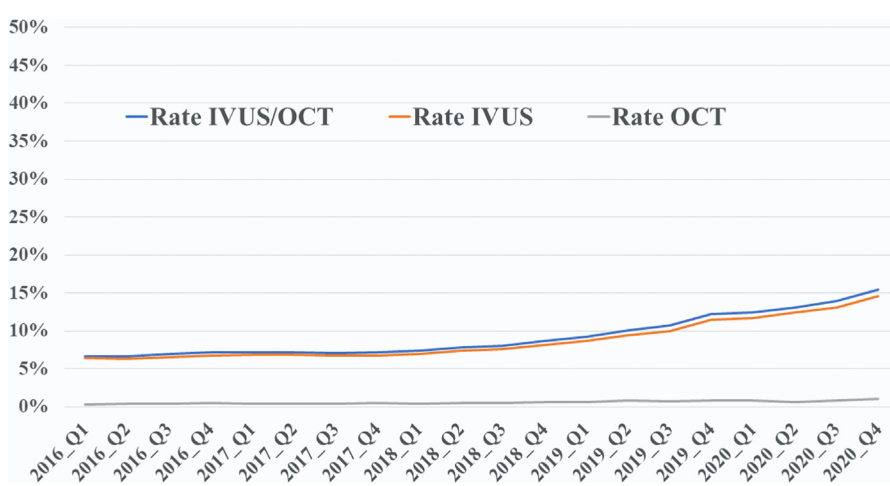


Figure 1.
Trend in uptake of intracoronary imaging for guiding percutaneous coronary intervention, across the United States, from 2016 to 2020. IVUS, intravascular ultrasound; OCT, optical coherence tomography.

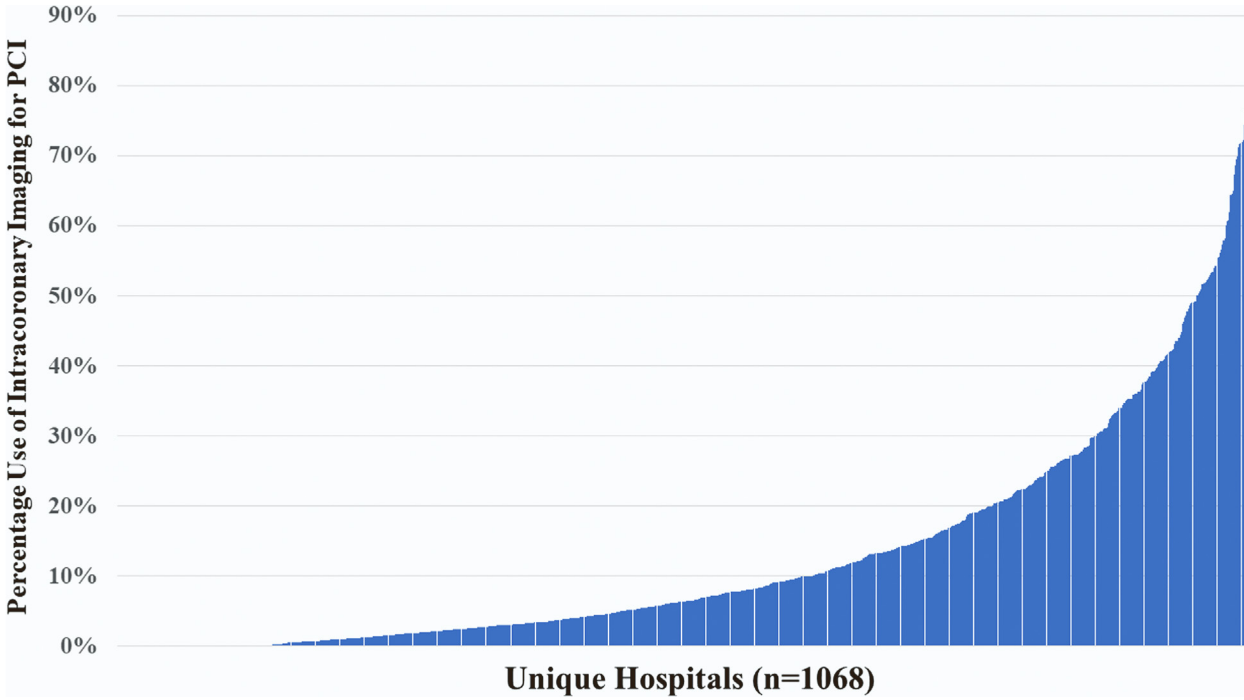


Figure 2.
Hospital variability in use of intracoronary imaging to guide percutaneous coronary intervention (PCI), for year 2020.

Among all hospitals included in 2020, no IC imaging was performed at 13.7% of the hospitals (Figure 3). Most hospitals (86.3%) did perform some IC imaging (IVUS or OCT) in some of the PCI procedures. IVUS only (and no OCT) was performed at 73.7% of hospitals, whereas 12.6% of hospitals performed both IVUS and OCT for PCI procedures, and 0.4% of hospitals performed OCT only (and not IVUS).

The unadjusted MOR for use of IC imaging during PCI was 4.6. The MOR did not change significantly after sequentially adjusting for procedural factors in model 2, patient factors in model 3, or hospital factors in model 4 (Table 3). Moreover, the c-statistic of the completely adjusted model was 0.61, indicating poor ability of the factors in the model to predict use of IC imaging. Procedural, patient, and hospital related factors accounted for 26% of the variability in the use of IC imaging use among hospitals. These results were similar for the years 2016-2019 (Supplementary Table 3). These results are graphically summarized in the Central Illustration. When excluding hospitals that did not perform any IC imaging for a particular year, there remained substantial variability in hospital use of IC imaging for PCI. Neither procedural, patient, nor hospital factors accounted for this variability. Supplementary Table 4 presents these results. For the year 2020, the unadjusted MOR was 3.7, whereas the completely adjusted MOR was 3.6.

Discussion

Among over 1.3 million PCI procedures performed in the United States from 2016 to 2020, the following principal findings were observed. First, there was a trend of increased uptake of IC imaging, with a doubling of its use overall from 2016 to 2020. However, the absolute rate of IC imaging remains low, with an average hospital in the United States using IC imaging for <1 in 15 PCI procedures in

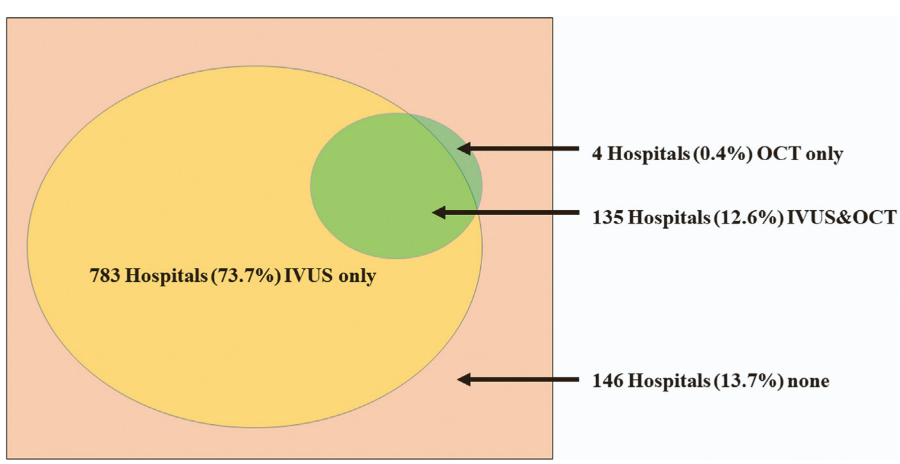


Figure 3.
Any use of intracoronary imaging (IVUS and OCT) for percutaneous coronary interventions among hospitals, for year 2020. IVUS, intravascular ultrasound; OCT, optical coherence tomography.

Table 3. Hospital-level variability in use of intracoronary imaging during percutaneous coronary intervention, for year 2020.

	Median odds ratio (95% CI)	c-statistic
Model 1: Unadjusted	4.6 (4.3, 5.0)	NA
Model 2: Adjusted for Procedural Factors (Use of atherectomy devices, PCI for MI, CTO)	4.6 (4.2, 4.9)	0.54
Model 3: Additionally Adjusted for Patient Factors (Demographic characteristics, socioeconomic status, comorbidities)	4.5 (4.2, 4.9)	0.59
Model 4: Additionally Adjusted for Hospital Factors (Bed size, teaching status, ownership)	4.5 (4.1, 4.8)	0.61

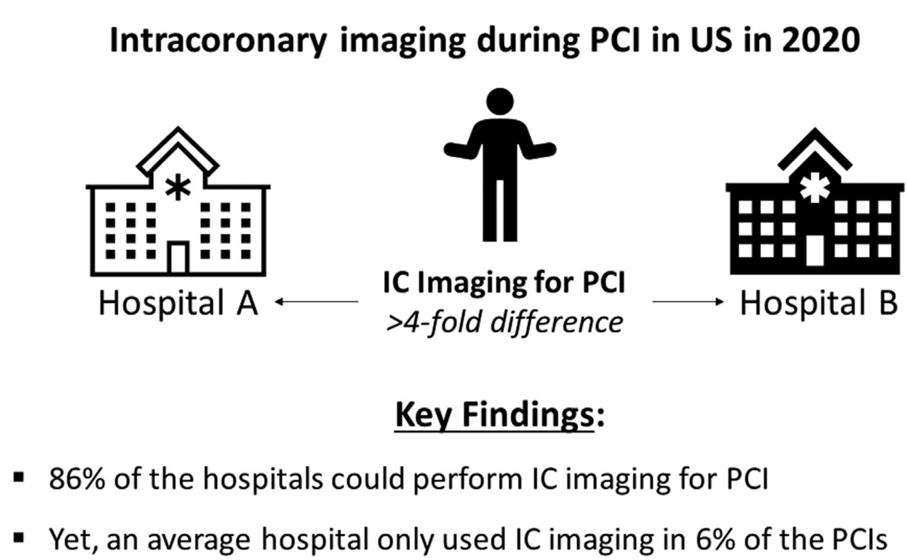
CTO, chronic total occlusion; MI, myocardial infarction; NA, not applicable; PCI, percutaneous coronary intervention.

2020. A counter-intuitive finding is that this overall low rate of IC imaging use persists even though >85% of hospitals did perform either IVUS or OCT for some proportion of PCIs in 2020, indicating that although hospitals can perform IC imaging, operators choose to do so in a small minority of cases. Overall, the rate of IC imaging use was highly variable. It was not utilized at all in some hospitals, whereas other hospitals had utilization rates >80%. There was a >4-fold difference in the odds of a patient having IC imaging during PCI at one hospital vs another, and this high degree of variability was not explained by procedural, patient, or hospital factors.

Our results extend previous analyses from nationwide samples in the United States that have shown very low utilization of IC imaging for PCI guidance. Elgendy et al[14] analyzed data from the National Inpatient Sample (2007-2013) and found the rates of IVUS use were 6.9% in 2007 and 8.8% in 2013. In a similar analysis of the National Inpatient Sample from 2016 to 2017, the rate of IVUS use was 5.5% in ST segment elevation myocardial infarction patients.[23] Interestingly, we observed no factors that accounted for the variability in IC imaging use, including procedural complexity, renal insufficiency, and hospital size. The lack of impact of these conventional factors, which are known to drive decision-making in other clinical contexts, suggests that the primary driver of IC imaging use may be operator preference.

Our analysis further supports the concept that operators, not hospitals, may be the primary driver of variability and low overall utilization. Reasons for operators to prefer IC imaging or no IC imaging remain unclear but may include time, familiarity, and procedural cost. Our results are in line with previous international surveys that have shown an impressive variability in utilization of IC imaging for PCI across operators from different countries.[24] Given that use of IC imaging to guide PCI has consistently been shown to improve procedural results and patient outcomes including cardiovascular death, target lesion revascularization, and myocardial infarction in multiple randomized clinical trials,[6–9] our results highlight a need for incentives to increase the use of IC imaging during PCI in the United States. An important aspect of increasing operator adoption of IC imaging is ensuring that operators are well trained and comfortable with the technology. There is no current requirement for IC imaging mastery-based learning as part of US training programs, and there are no standard pathways for operators to gain this skillset independently. The most recent recommendations from the American College of Cardiology Competency Management Committee have stipulated that trainees participate in at least 25 IC imaging procedures. Although this is a good start, more thorough curriculum and training guidelines along with other strategies to improve education around IC imaging modalities, image interpretation, and the application of these images to optimize PCI procedures are needed.[25]

Standardizing care for PCI across hospitals has shown to improve the safety, efficiency, and value of these procedures. For example, streamlining administrative flow improved door-to-balloon-time for ST segment elevation myocardial infarction and markedly improved patient outcomes, including in-hospital mortality.[26] Similarly a multifaceted intervention targeting operator feedback and audits resulted in lower post-PCI acute kidney injury rates across multiple cardiac catheterization laboratories.[27] Importantly, the use of IC imaging does add complexity and cost to PCI procedures and requires adequate technical skills and experience. Imaging catheter-related complications have been reported, but these instances are rare (<1%).[28] These factors could dissuade some PCI operators and hospitals from using IC imaging. Hence although it is important to institute structural changes to increase utilization of IC imaging across hospitals that provide PCI, such efforts would need to be undertaken with a deeper understanding of clinical subtleties and hospital administrative context. Future efforts should focus on understanding operator and hospital perspectives to understand the hesitancy in utilization of IC imaging for PCI. This could identify actionable targets for intervention to increase the value of PCI procedures in the United States.



Central Illustration.
Intracoronary imaging (IC) use for percutaneous coronary intervention (PCI) in the United States for the year 2020.

Limitations

Our study should be interpreted in context of the following limitations. First, we used an administrative database that is not specifically designed for research purposes. Second, operator information is not captured in the NRD. Some of the hospital-level variability that we found in our analysis could be explained by operator characteristics (experience, age, training site, etc.), that we did not account for. Third, the NRD does not include several procedural aspects that may contribute to variability in IC imaging, such as treatment of in-stent restenosis, stent-thrombosis, bifurcation lesions, or left main coronary disease. These procedural characteristics are important, and hence, our results do not completely assess the relationship between lesion complexity and use of IC imaging. Fourth, the NRD includes only inpatient admissions, so PCI performed in an outpatient setting (same day discharge) would not be captured in this database. Fifth, we only analyzed data from 2016 to 2020, and more recent trends in the use of IC imaging for PCI in the United States are not known. Moreover, the American College of Cardiology/American Heart Association upgraded the recommendation of using IC imaging for PCI to class IIA in 2021. Our study does not assess the impact of this important change.[12] Finally, the NRD includes only patient information from hospitals participating in the Healthcare Cost and Utilization Project. It does not include patient information across all hospitals in the United States. Therefore, not all patients treated with PCI from 2016 to 2020 were included.

Conclusion

In summary, in a nationally representative sample of hospitals in the United States providing PCI services, we observed that the use of IC imaging increased significantly over time but remains seldom used. Although >85% of hospitals can perform IC imaging for PCI, IC imaging was used in about 1 in 15 PCI procedures overall in an average US hospital in 2020. Moreover, there was high variability in use of IC imaging during PCI among hospitals, with procedural, patient, and hospital-level factors not accounting for this variability. Given that IC imaging improves PCI results and long-term patient outcomes, our results highlight the need to improve adoption, training, and application of IC imaging to guide PCI procedures in the United States.

Declaration of competing interest

John Saxon is on the speakers' bureau and is a proctor for Edwards Lifesciences, Abbott Vascular, and Medtronic Inc. John Spertus is the principal investigator of an analytic contract from the American College of Cardiology Foundation to provide analytic services for the National Cardiovascular Data Registries. He provides consultative services on patient-reported outcomes and evidence evaluation to Alnylam, AstraZeneca, Bayer, Merck, Janssen, Bristol-Myers Squibb, Edwards Lifesciences, Kineksia, 4DT Medical, Terumo, Cytokinetics, Imbria, and United Healthcare. He holds research grants from Bristol-Myers Squibb and Janssen. He owns the copyright to the Seattle Angina Questionnaire, Kansas City Cardiomyopathy Questionnaire, and Peripheral Artery Questionnaire and serves on the Board of Directors for Blue Cross and Blue Shield of Kansas City. Adam Salisbury reports institutional research grants from Boston Scientific and Abiomed, and consulting/advisory services with Medtronic. Chetan Huded reports consulting services for Boston Scientific. Ali Malik, James Grantham, and Kevin Kennedy reported no financial interests.

Funding sources

This research was sponsored by the Society for Cardiovascular Angiography and Interventions (SCAI) and supported by an educational grant from Abbott. The views presented here represent those of the authors and do not necessarily reflect the official views of SCAI or Abbott.

Ethics statement and patient consent

The institutional review board at Saint Luke's Mid America Heart Institute approved the study and waived the requirement for informed consent because the study involved deidentified data. Moreover, our research activities were monitored by the institutional review board to ensure compliance to ethical standards.

Supplementary material

To access the supplementary material accompanying this article, visit the online version of the *Journal of the Society for Cardiovascular Angiography & Interventions* at 10.1016/j.jscai.2023.100973.

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