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ORIGINAL RESEARCH

Impact of Intracoronary Imaging-Guided Percutaneous Coronary Intervention on Procedural Outcomes Among Complex Patient Groups

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BACKGROUND: Intracoronary imaging (ICI) has been shown to improve survival after percutaneous coronary intervention (PCI). Whether this prognostic benefit is sustained across different indications remains unclear.

METHODS AND RESULTS: All PCI procedures performed in England and Wales between April, 2014 and March 31, 2020, were retrospectively analyzed. The association between ICI use and in-hospital major acute cardiovascular and cerebrovascular events; composite of all-cause mortality, stroke, and reinfarction and mortality was examined using multivariable logistic regression analysis for different imaging-recommended indications as set by European Association for Percutaneous Cardiovascular Interventions consensus. Of 555 398 PCI procedures, 10.8% (n=59 752) were ICI-guided. ICI use doubled between 2014 (7.8%) and 2020 (17.5%) and was highest in left main PCI (41.2%) and lowest in acute coronary syndrome (9%). Only specific European Association for Percutaneous Cardiovascular Interventions imaging-recommended indications were associated with reduced major acute cardiovascular and cerebrovascular events and mortality, including left main PCI (odds ratio [OR], 0.45 [95% CI, 0.39–0.52] and 0.41 [95% CI, 0.35–0.48], respectively), acute coronary syndrome (OR, 0.76 [95% CI, 0.70–0.82] and 0.70 [95% CI, 0.63–0.77]), and stent length >60 mm (OR, 0.75 [95% CI, 0.59–0.94] and 0.72 [95% CI, 0.54–0.95]). Stent thrombosis and renal failure were associated with lower mortality (OR, 0.69 [95% CI, 0.52–0.91]) and major acute cardiovascular and cerebrovascular events (OR, 0.77 [95% CI, 0.60–0.99]), respectively.

CONCLUSIONS: ICI use has more than doubled over a 7-year period at a national level but remains low, with <1 in 5 procedures performed under ICI guidance. In-hospital survival was better with ICI-guided than angiography-guided PCI, albeit only for specific indications.

Key Words: acute coronary syndrome ■ consensus ■ percutaneous coronary intervention ■ prognosis ■ retrospective studies ■ stents ■ thrombosis

Invasive coronary angiography is commonly used to assess the severity of coronary artery disease and guide percutaneous coronary intervention (PCI). However, coronary angiography alone provides a 2-dimensional lumenogram, which limits the appreciation of the arterial internal dimensions, plaque characteristics, and vulnerability, as well as the assessment of strut apposition and stent expansion in the context of PCI.[1–4] This has led to an increased use of intracoronary imaging (ICI) over the past 2 decades, including intravascular ultrasound (IVUS) and optical coherence tomography, given its superior assessment of these procedural considerations.[1,5]

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CLINICAL PERSPECTIVE

What Is New?

- To our knowledge, this is the first study to systematically examine the rates and the prognostic utility of intracoronary imaging use during percutaneous coronary intervention across a wide range of procedural indications.
- Despite the increased uptake of intracoronary imaging use nationally, it remains significantly underused with <1 in 5 cases undergoing intracoronary imaging in 2020.
- In-hospital mortality was lower in imaging-guided than angiography-guided percutaneous coronary intervention but only for certain indications including left main stem percutaneous coronary intervention, acute coronary syndrome, stent length >60 mm, and stent thrombosis.

What Are the Clinical Implications?

- The present findings should prompt greater use of intracoronary imaging among interventionists especially in cases where it was shown to be of greater prognostic benefit.
- Further studies are warranted to evaluate prognostic differences in longer-term survival between different indications for intracoronary imaging.

Nonstandard Abbreviations and Acronyms

BVS	bioresorbable vascular scaffolds
ICI	intracoronary imaging
MACCE	major acute cardiovascular and cerebrovascular events

Previous studies have demonstrated improved postprocedural clinical outcomes with ICI compared with angiography guidance for PCI alone.[6–11] Given the limited adoption of ICI in contemporary practice, the European Association of Percutaneous Cardiovascular Interventions (EAPCI) published a consensus statement on the clinical use of ICI, which recommended its use in patients in whom a better appreciation of lesion characteristics, vascular anatomy, and stent deployment may improve clinical outcomes following PCI, including stent thrombosis, in-stent restenosis, renal failure, bioresorbable vascular scaffolds (BVS), stent length >60 mm, acute coronary syndrome (ACS) indications, chronic total occlusion and left main stem (LMS) intervention.[2] Similarly, recent guidelines from the American College of Cardiology/American Heart Association Joint Committee on coronary revascularization recommend the use of intravascular imaging to guide PCI.[12]

While these recommendations provide useful guidance for operators about patient groups who are more likely to benefit from ICI, they were based on limited evidence derived from small underpowered studies that may not be representative of the broader population being treated, as acknowledged by the authors.[2] Therefore, there remains a gap in evidence on whether these patient groups benefit, or whether those that fall outside these recommendations may also yield a similar benefit from ICI in terms of postprocedural outcomes.

The present study sought to compare in-hospital survival and postprocedural complications between patients undergoing angiography-guided and ICI-guided PCI, as well as between guideline recommendations for imaging as per expert consensus, in a national cohort of PCI procedures from England and Wales over a 7-year period.

METHODS

Data Source, Study Design, and Population

This study was derived from routinely collected audit data in England and Wales, which a exempt from institutional board review. Furthermore, informed consent is not required for pseudoanonymized audit data in England under Section 251 of the National Health Service Act 2006. The data used for the purpose of this study are only available to designated researchers and cannot be shared with other researchers. However, all efforts were made to describe the methods in detail.

Adult (aged ≥18 years) PCI procedures performed between April 1, 2014 and March 31, 2020, in England and Wales were retrospectively analyzed from the BCIS (British Cardiovascular Intervention Society) registry, stratified by use of ICI (IVUS/optical coherence tomography) and by individual imaging-recommended indication for imaging as per the EAPCI expert consensus on clinical use of ICI (stent thrombosis, in-stent restenosis, renal failure [defined as creatinine >200 μmoL/L and/or dialysis in our registry], BVS, length of stent >60 mm, ACS indication, chronic total occlusion, and LMS intervention).[2] The BCIS registry comprises clinical and procedural data, and in-hospital outcomes (death, bleeding, arterial complications) for all procedures undertaken in England and Wales.[13,14] The only exclusion criteria were missing data for death (n=10 006, 1.7% of the original cohort) and ICI use (n=17 628, 3.0% of the original cohort).

Outcomes

The main outcomes were in-hospital major adverse cardiovascular and cerebrovascular events (MACCE; composite of death, acute stroke/transient ischemic attack [TIA], and reinfarction) and all-cause mortality.

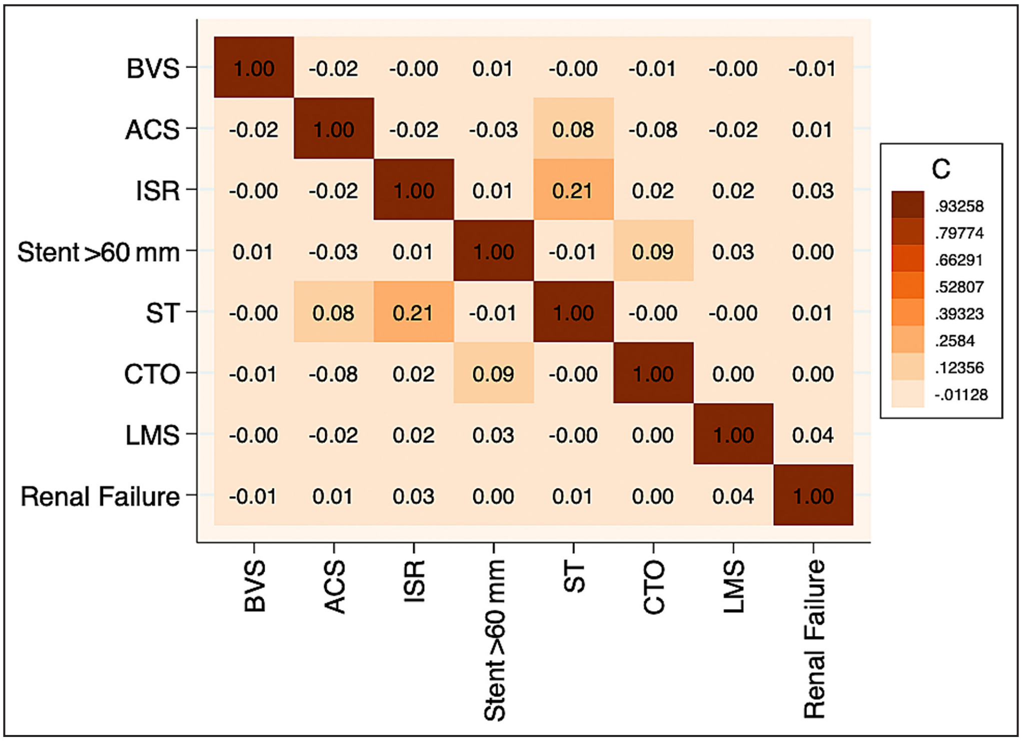

Figure 1. Correlation between the individual recommendations for intracoronary imaging.
ACS indicates acute coronary syndrome; BVS, bioresorbable vascular scaffold; CTO, chronic total occlusion; ISR, in-stent restenosis; LMS, left main stem; and ST, stent thrombosis.

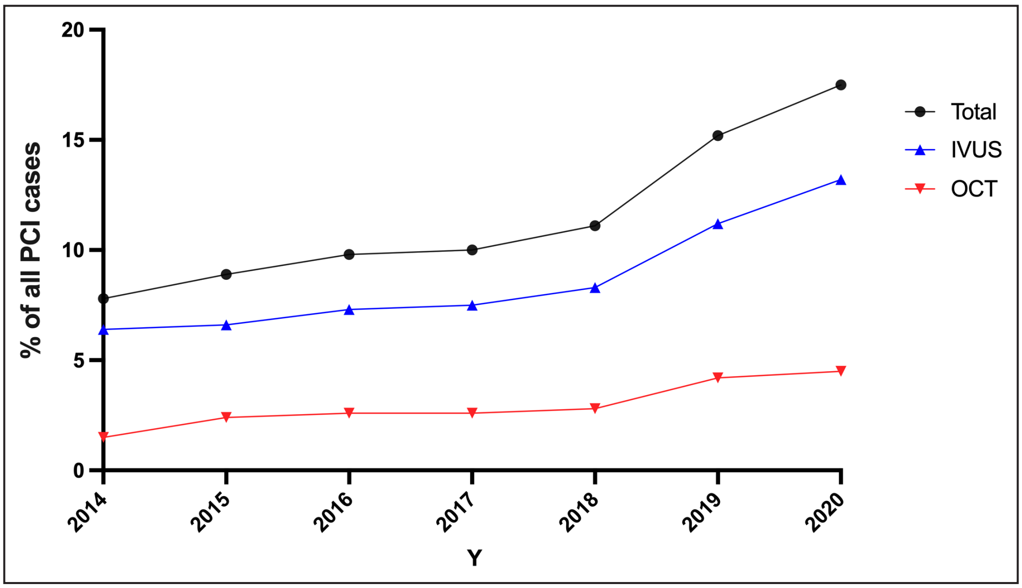

Figure 2. Use of intracoronary imaging among all percutaneous coronary intervention cases (2014–2020).
IVUS indicates intravascular ultrasound; OCT, optical coherence tomography; and PCI, percutaneous coronary intervention.

Secondary outcomes included the individual MACCE components as well as Bleeding Academic Research Consortium stage 3–5 bleeding, as per its previously published definition.[15]

Statistical Analysis

All statistical analyses were performed using Stata 16 MP (College Station, TX). For exploratory analysis, patient and procedural characteristics were compared

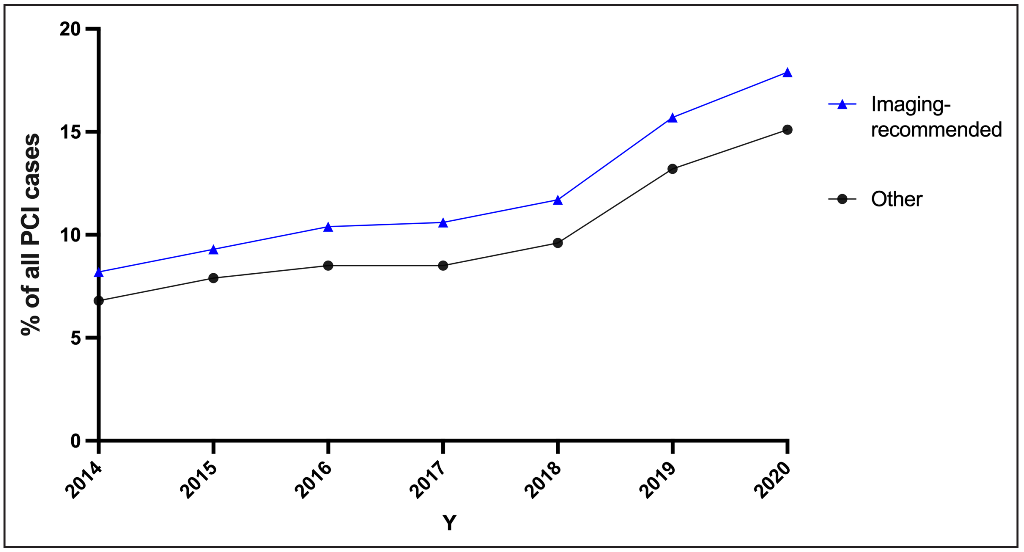

Figure 3. Use of intracoronary imaging according to presence of imaging-recommendation.
PCI indicates percutaneous coronary intervention.

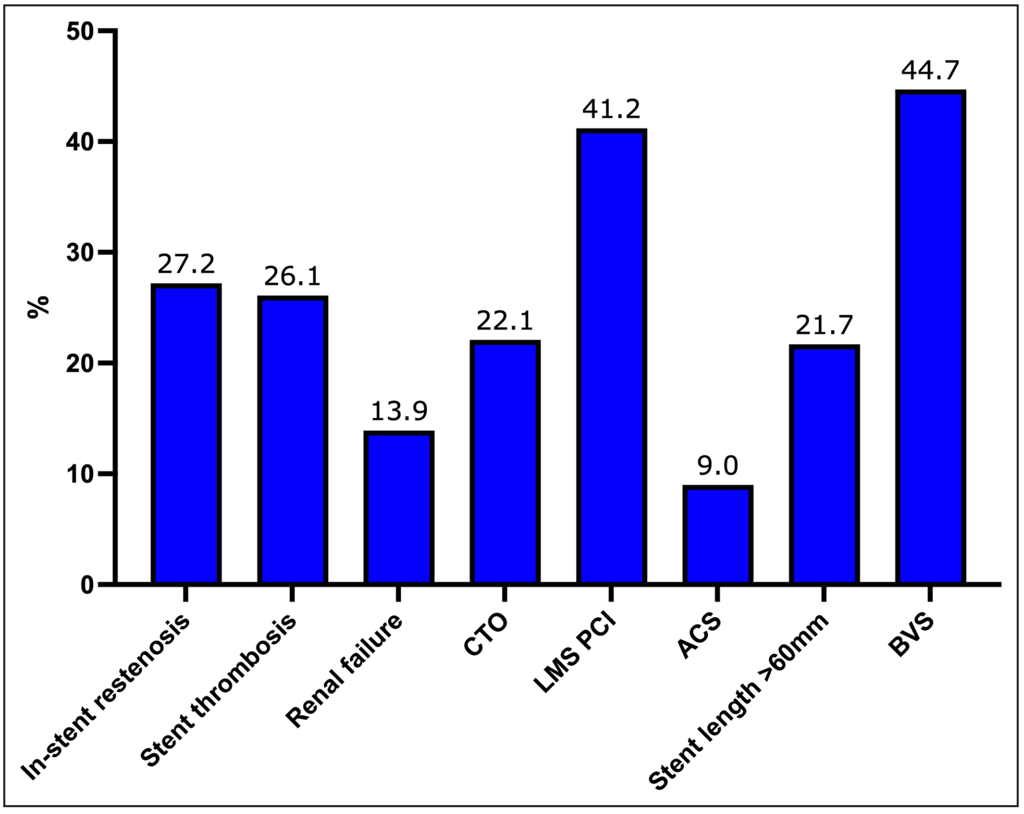

Figure 4. Rate of usage of intracoronary imaging per individual indication.
ACS indicates acute coronary syndrome; BVS, bioresorbable vascular scaffold; CTO, chronic total occlusion; LMS, left main stem; and PCI, percutaneous coronary intervention.

between the ICI and no ICI procedure groups with further comparisons according to the presence or absence of imaging-recommended indications for imaging in each of the procedure groups (ICI versus no ICI). Categorical variables are summarized as percentages and analyzed using the Chi-squared (X^2) test. Multivariable logistic regression modeling was performed to examine the association between ICI and

Table 1. Patient and Procedural Characteristics According to Intracoronary Imaging Use

	No ICI (n=495646)	ICI (n=59752)
Age, mean (SD)	65.9 (11.9)	65.3 (12.1)
Age groups, y, %		
<60	31.9	32.8
60–69	28.7	28.4
70–79	26.3	27.1
≥80	13.1	11.8
Men, %	74.0	75.9
Race or ethnicity, %		
White	83.1	80.9
Black	4.3	6.3
Asian	7.2	7.8
Other	5.4	5.1
Clinical syndrome, %		
Stable	36.4	47.3
NSTE-ACS	37.0	39.8
STEMI	26.6	12.9
Stent thrombosis	1.5	4.3
Previous MI, %	25.7	36.9
Previous PCI, %	26.4	42.8
Previous CABG, %	7.7	8.8
Previous CVA, %	3.8	4.4
Diabetes, %	23.2	25.5
Renal failure, %	2.4	3.2
Functioning renal transplant, %	0.3	0.4
Cardiac transplant, %	0.1	0.1
LV function (ejection fraction), %*		
Good (>50%)	69.2	71.0
Moderate (30%–50%)	28.0	25.5
Poor (<30%)	2.9	3.6
Hypercholesterolemia, %	51.1	54.7
Peripheral vascular disease, %	3.9	5.2
Hypertension, %	56.3	60.0
Current/Previous smoker, %	59.4	59.8
Valvular heart disease, %	2.0	2.7
Cardiogenic shock (pre-procedure), %	2.9	2.2
Out of hospital cardiac arrest, %	3.0	2.1
Mechanical ventilation, %	2.1	1.6
Mechanical circulatory support, %	1.6	1.8
Access route*		
Radial, %	83.2	84.8
Femoral, %	19.5	19.3
No. of vessels, %		
1	79.8	64.8
2	17.1	25.0
3	2.7	8.2
4	0.4	2.0

(Continued)

Table 1. Continued

	No ICI (n=495646)	ICI (n=59752)
No. of lesions, %		
1	71.9	61.7
2	21.9	26.4
3	4.9	9.0
4+	1.3	3.0
No. of stents, mean (SD)	1.3 (1)	1.5 (1.3)
DES, %	79.5	76.1
First generation DES, %†	38.1	35.8
Second/Third generation DES, %†	60.7	55.3
Drug-coated balloon, %	0.1	0.5
Fractional flow reserve, %	16.5	13.9
Calcium modification, %	3.2	7.8
LMS, %	3.4	20.1
LAD proximal, %	28.9	44.8
Grafts, %	2.8	1.6
Aspirin, %	89.0	91.3
Clopidogrel. %	53.7	59.2
Ticagrelor, %	33.2	30.4
Prasugrel, %	3.9	2.9
Warfarin, %	1.1	1.1
Glycoprotein 2b/3a inhibitor, %	13.6	12.3
Bivalirudin, %	1.1	0.4

CABG indicates coronary artery bypass graft; CVA, cerebrovascular accident; DES, drug-eluting stent; LAD, left anterior descending artery; LMS, left main stem; MI, myocardial infarction; PCI, percutaneous coronary intervention; NSTE-ACS, non-ST-elevation acute coronary syndrome (non-STEMI and unstable angina); and STEMI, ST-segment–elevation myocardial infarction.

*Patients had >1 access route in some cases.

†There was an overlap in stent generations in a subset of cases.

in-hospital outcomes (MACCE and all-cause mortality) in (1) the overall cohort as well as in (2) the imaging-recommended and non-imaging recommended subgroups, and (3) individual imaging-recommended indications, using the no ICI group as the reference category. For the latter, we assessed the correlations between individual indications as there is an inevitable overlap between imaging-recommended indications (e.g., renal failure and ACS), and these were found to be weak (Figure 1; values represent r^2 values). Further modeling was performed to look at predictors of receipt of ICI.

All associations are reported as odds ratios (OR) with corresponding 95% CI and were adjusted for the following variables: age, sex, race, previous acute myocardial infarction (MI), previous PCI, previous coronary artery bypass graft surgery, diabetes, cardiac transplant, left ventricular function category (good, moderate, poor), hypercholesterolemia, peripheral vascular disease, previous cerebrovascular accident (including stroke or transient ischemic attack), hypertension, smoking, valvular

Table 2. Patient and Procedural Characteristics According to Intracoronary Imaging Use and Imaging-Recommended Indication

	Imaging-recommended (n=388106)		No imaging-recommended (n=167292)	
	No ICI (n=343866)	ICI (44240)	No ICI (151780)	ICI (15512)
Age, mean (SD)	65.6 (12.4)	65.3 (12.4)	66.3 (10.7)	65.1 (11.2)
Age groups, y, %				
<60	33.6	32.9	28.2	32.3
60–69	27.3	27.5	32.0	30.9
70–79	24.9	27.0	29.3	27.5
≥80	14.2	12.7	10.5	9.4
Men, %	73.8	75.3	74.5	77.5
Race or ethnicity, %				
White	84.1	81.4	80.9	79.4
Black	4.1	6.4	4.6	6.1
Asian	7.1	7.7	7.5	8.0
Other	4.7	4.6	7.0	6.4
Clinical syndrome, %				
Stable	8.4	28.9	100	100
NSTE-ACS	53.3	53.7	…	…
STEMI	38.4	17.4	…	…
Stent thrombosis	2.1	5.8	…	…
Previous MI, %	23.0	37.3	31.9	35.9
Previous PCI, %	21.0	41.3	38.5	47.1
Previous CABG, %	7.8	9.5	7.4	6.9
Previous CVA, %	4.1	4.7	3.2	3.5
Diabetes, %	23.1	26.3	23.4	23.4
Renal failure, %	3.5	4.3	…	…
Functioning renal transplant, %	0.3	0.4	0.3	0.4
Cardiac transplant, %	0.1	0.2	0.1	0.3
LV function (ejection fraction), %*				
Good (>50%)	62.6	66.8	84.0	82.8
Moderate (30%–50%)	34.0	29.0	14.3	15.3
Poor (<30%)	3.4	4.2	1.7	1.9
Hypercholesterolemia, %	46.4	53.0	61.8	59.6
Peripheral vascular disease, %	4.1	5.7	3.3	3.8
Hypertension, %	53.4	59.3	63.1	61.8
Current/Previous smoker, %	61.3	61.2	55.0	55.8
Valvular heart disease, %	1.8	2.7	2.3	2.8
Cardiogenic shock (preprocedure), %	4.1	2.9	0.2	0.2
Out of hospital cardiac arrest, %	4.2	2.8	0.1	0.1
Mechanical ventilation, %	3.0	2.1	0.3	0.2
Mechanical circulatory support, %	2.2	2.3	0.2	0.4
Access route*				
Radial, %	83.2	84.4	83.3	86.2
Femoral, %	19.6	19.9	19.1	17.3
No. of vessels, %				
1	80.4	61.8	78.5	73.4
2	16.2	25.6	19.1	23.2
3	2.9	10.0	2.2	3.2

(*Continued*)

Table 2. Continued

	Imaging-recommended (n=388106)		No imaging-recommended (n=167292)	
	No ICI (n=343866)	ICI (44240)	No ICI (151780)	ICI (15512)
4	0.5	2.7	0.2	0.2
No. of lesions, %				
1	72.1	59.4	71.3	68.2
2	21.4	26.9	23.2	25.0
3	5.2	10.2	4.4	5.4
4+	1.4	3.5	1.0	1.5
No. of stents, mean (SD)	1.4 (1)	1.6 (1)	1.1 (1)	1.3 (1)
DES, %	83.6	77.7	70.2	71.5
First generation DES, %†	40.2	36.7	33.3	33.1
Second/Third generation DES, %†	63.8	57.3	53.6	49.7
Drug-coated balloon, %	0.1	0.5	0.1	0.2
Fractional flow reserve, %	8.8	9.9	34.0	25.4
Calcium modification, %	2.9	8.2	3.8	6.6
LMS, %	4.9	27.1	…	…
LAD proximal, %	28.2	44.9	30.4	44.8
Grafts, %	2.9	1.5	2.5	1.6
Chronic total occlusion, %	2.3	5.2	…	…
Aspirin, %	89.2	91.8	88.7	89.8
Clopidogrel. %	46.0	55.6	70.9	69.3
Ticagrelor, %	40.0	34.2	17.8	19.6
Prasugrel, %	4.9	3.1	1.6	2.1
Warfarin, %	0.9	1.0	1.4	1.5
Glycoprotein 2b/3a inhibitor, %	18.7	15.3	2.0	3.5
Bivalirudin, %	1.5	0.5	0.2	0.1

CABG indicates coronary artery bypass graft; CVA, cerebrovascular accident; DES, drug-eluting stent; LAD, left anterior descending artery; LMS, left main stem; LV, left ventricular; MI, myocardial infarction; NSTE-ACS, non-ST-elevation acute coronary syndrome (non-STEMI and unstable angina); PCI, percutaneous coronary intervention; and STEMI, ST-segment–elevation myocardial infarction.

*Patients had >1 access route in some cases.

†There was an overlap in stent generations in a subset of cases.

heart disease, out of hospital cardiac arrest, mechanical ventilation, circulatory support (intra-aortic balloon pump or left ventricular assist device), preoperative cardiogenic shock, vascular access (radial versus femoral), number of vessels and lesions attempted, number of stents, drug-eluting stent generation (first versus second/third generation), use of fractional flow reserve, calcium modification (rotablation, laser angioplasty), vessel attempted (proximal left anterior descending and grafts) and in-hospital pharmacotherapy (only for outcomes models), including aspirin, clopidogrel, ticagrelor, prasugrel, warfarin, glycoprotein IIb/IIIa inhibitor, bivalirudin.

Multiple imputation with chained equations was performed for variables with missing data (except ICI use and the outcome variables) before model fitting, with a total of 10 imputations. Combined estimates, using Rubin rules, were then used for analyses.[16] The frequency of missingness for each variable before imputation is presented in Table S1.

RESULTS

Of 555398 PCI procedures performed between April 1, 2014 and March 31, 2020, 10.8% (n=59752) involved ICI use. The rate of use of intravascular imaging more than doubled over the study period (2014: 7.8% to 2020: 17.5%; Figure 2), which was consistent for both IVUS and optical coherence tomography. The rate of intravascular imaging use was observed to increase regardless of the presence or absence of an imaging-recommended indication (Figure 3); only 44240 (11.4%) out of 388106 patients with an imaging-recommended indication underwent ICI as part of their PCI procedure. Overall, patients with an imaging-recommended indication represented 74% of those in receipt of ICI (n=59752). Among the imaging-recommended indications, the use of ICI was highest for BVS (44.7%) and LMS PCI (41.2%) and lowest in ACS (9%) (Figure 4).

Table 3. Unadjusted Rates of In-Hospital Adverse Outcomes According to Intracoronary Imaging Use

	No ICI (n=495 646)	ICI (n=59 752)	*P* value*
MACCE‡, %			
Overall	2.51	1.80	<0.001
Imaging-recommended†	3.43	2.25	<0.001
No imaging-recommended	0.38	0.40	0.550
All-cause mortality, %			
Overall	2.09	1.36	<0.001
Imaging-recommended†	2.93	1.76	<0.001
No imaging-recommended	0.12	0.15	0.416
Acute stroke/TIA, %			
Overall	0.43	0.42	0.693
Imaging-recommended†	0.50	0.47	0.369
No imaging-recommended	0.26	0.26	0.717
BARC 3–5 bleeding, %			
Overall	0.15	0.17	0.190
Imaging-recommended†	0.19	0.22	0.137
No imaging-recommended	0.07	0.04	0.140
Reinfarction, %			
Overall	0.06	0.07	0.193
Imaging-recommended†	0.08	0.09	0.493
No imaging-recommended	0.00	0.02	0.053

BARC indicates Bleeding Academic Research Consortium; and TIA, transient ischemic attack.

*Chi-squared test used.

†Includes stent thrombosis, in-stent restenosis, renal failure, bioresorbable vascular scaffold, length of stent >60mm, acute coronary syndrome indication, chronic total occlusion, left main stem intervention.

‡Major acute cardiovascular and cerebrovascular outcomes: composite of death, acute stroke/transient ischemic attack and reinfarction; Bleeding Academic Research Consortium.

Table 4. Adjusted Odds Ratio* and 95% CI of In-Hospital Adverse Outcomes in Patients Undergoing Intracoronary Imaging

	OR (95% CI)	*P* value
MACCE		
Overall	0.78 (0.72–0.84)	<0.001
Imaging-recommended†	0.75 (0.69–0.81)	<0.001
No imaging-recommended	0.85 (0.64–1.13)	0.259
All-cause mortality		
Overall	0.70 (0.64–0.78)	<0.001
Imaging-recommended†	0.69 (0.63–0.76)	<0.001
No imaging-recommended	0.87 (0.53–1.42)	0.570

*Reference is no intravascular imaging use; adjusted for the following variables: age, sex, race, previous acute myocardial infarction, previous percutaneous coronary intervention, previous coronary artery bypass graft surgery, diabetes, cardiac transplant, left ventricular function category (good, moderate, poor), hypercholesterolemia, peripheral vascular disease, previous cerebrovascular accident (including stroke or transient ischemic attack), hypertension, smoking, valvular heart disease, out of hospital cardiac arrest, mechanical ventilation, circulatory support (intra-aortic balloon pump or left ventricular assist device), preoperative cardiogenic shock, vascular access (radial vs femoral), number of vessels and lesions attempted, number of stents, drug-eluting stent generation (first vs second/third generation), use of fractional flow reserve, calcium modification (rotablation, laser angioplasty), vessel attempted (proximal left anterior descending and grafts) and in-hospital pharmacotherapy: aspirin, clopidogrel, ticagrelor, prasugrel, warfarin, glycoprotein IIb/IIIa inhibitor, bivalirudin.

†Includes: stent thrombosis, in-stent restenosis, renal failure, bioresorbable vascular scaffold, length of stent >60mm, acute coronary syndrome indication, chronic total occlusion, left main stem intervention.

Patient Characteristics

Patients in receipt of ICI were generally younger (65.3 versus 65.9years), more likely to be men (75.9% versus 74.0%), White race (83.1% versus 80.9%), and undergoing PCI for a stable angina (47.3% versus 36.4%) or stent thrombosis (4.3% versus 1.5%) indication (Table 1). Furthermore, patients in receipt of ICI had a higher prevalence of previous MI, PCI, coronary artery bypass graft surgery, and cerebrovascular accident as well as diabetes, hypertension, and renal failure. They were also more likely to undergo PCI for multivessel disease (single vessel: 64.8% versus 79.8%), with a greater mean number of stents used (1.5 versus 1.3, $P<0.001$) compared with those without receipt of ICI. Furthermore, procedures with coronary imaging were more likely to be for LMS (20.1% versus 3.4%) and proximal left anterior descending (44.8% versus 28.9%) interventions and to involve calcium modification therapies (7.8% versus 3.2%).

Patients with an imaging-recommended indication for ICI were older, more likely to be men, with a greater prevalence of previous MI, PCI, and coronary artery bypass graft surgery, and moderate-poor left ventricular function, irrespective of whether they underwent ICI or not (Table 2). Furthermore, patients with an imaging-recommended indication for ICI were more critically unwell with a higher prevalence of preprocedure cardiogenic shock, mechanical ventilation, and circulatory support, more so among those who did not undergo ICI.

In-Hospital Outcomes

Overall, the crude rates of MACCE and all-cause mortality were generally lower in patients undergoing ICI (1.8% versus 2.5% and 1.3% versus 2.1%, respectively, Table 3) while no difference in acute stroke/transient ischemic attack, Bleeding Academic Research Consortium 3–5 bleeding and reinfarction between ICI and no ICI groups. When stratified by imaging-recommended indication, MACCE and all-cause mortality was only lower in patients with an imaging-recommended indication (ICI versus no ICI: MACCE: 2.3% versus 3.4%, all-cause mortality: 1.8% versus 2.9%) (Table 3).

After adjustment for baseline patient and procedural characteristics, ICI use was associated with reduced odds of in-hospital MACCE and all-cause mortality (OR, 0.78 [95% CI, 0.72–0.84] and 0.70 [95% CI, 0.64–0.78], respectively) overall, but this reduction was only

Table 5. In-Hospital Rates of Adverse Outcomes According to Intracoronary Imaging Use and Individual Guideline-Recommended Indication

	No ICI (n=495646)	ICI (n=59752)	*P* value*
MACCE, %†			
In-stent restenosis	2.5	1.8	<0.001
Stent thrombosis	6.4	4.4	<0.001
Renal failure	7.8	5.8	0.002
CTO	3.7	1.4	<0.001
LMS PCI	9.5	3.2	<0.001
ACS	3.7	2.8	<0.001
Stent length >60mm	3.4	1.9	<0.001
BVS	1.1	0.5	0.158
All-cause mortality, %			
In-stent restenosis	2.1	1.5	<0.001
Stent thrombosis	5.9	3.5	<0.001
Renal failure	7.3	5.4	0.002
CTO	3.2	1.0	<0.001
LMS PCI	8.7	2.7	<0.001
ACS	3.2	2.3	<0.001
Stent length >60mm	2.7	1.4	<0.001
BVS	0.4	0.5	0.764

ACS indicates acute coronary syndrome; BVS, bioresorbable vascular scaffold; CTO, chronic total occlusion; LMS, left main stem; and MACCE, major acute cardiovascular and cerebrovascular outcomes.

*Chi-squared test used.

†Major acute cardiovascular and cerebrovascular outcomes: composite of death, acute stroke/transient ischemic attack, and reinfarction.

observed in the imaging-recommended groups for receipt of ICI (MACCE: OR, 0.75 [95% CI, 0.69–0.81]; all-cause mortality: OR, 0.69 [95% CI, 0.63–0.76]) and not in the non-guideline recommended group (MACCE: OR, 0.85 [95% CI, 0.64–1.13]; all-cause mortality: OR, 0.87 [95% CI, 0.53–1.42]) (Table 4).

Among the individual imaging-recommended indications, unadjusted rates of MACCE and all-cause mortality were lower in patients who underwent coronary imaging for all indications except BVS (Table 5). However, after adjustment for baseline differences, only certain imaging-recommended indications were associated with reduced odds of MACCE and/or all-cause mortality; specifically, ICI use in LMS PCI, ACS, and stent length >60mm was associated with reduced odds of both MACCE and all-cause mortality (LMS PCI: OR, 0.45 [95% CI, 0.39–0.52] and OR, 0.41 [95% CI, 0.35–0.48], respectively; ACS OR, 0.76 [95% CI, 0.70–0.82] and OR, 0.70 [95% CI, 0.63–0.77]; stent length >60mm: OR, 0.75 [95% CI, 0.59–0.94]) and (OR, 0.72 [95% CI, 0.54–0.95]) while stent thrombosis was only associated with lower mortality (OR, 0.69 [95% CI, 0.52–0.91]), and renal failure was associated

Table 6. Adjusted Odds* of In-Hospital Adverse Outcomes in Patients Undergoing Intracoronary Imaging Per Individual Imaging-Recommended Indication

	OR (95% CI)	*P* value
MACCE		
In-stent restenosis	0.78 (0.60–1.00)	0.054
Stent thrombosis	0.82 (0.64–1.07)	0.147
Renal failure	0.77 (0.60–0.99)	0.047
CTO	0.80 (0.52–1.23)	0.314
LMS PCI	0.45 (0.39–0.52)	<0.001
ACS	0.76 (0.70–0.82)	<0.001
Stent length >60mm	0.75 (0.59–0.94)	0.016
BVS	2.66 (0.24–28.93)	0.422
All-cause mortality		
In-stent restenosis	0.76 (0.57–1.02)	0.070
Stent thrombosis	0.69 (0.52–0.91)	0.014
Renal failure	0.76 (0.58–0.99)	0.042
CTO	0.79 (0.46–1.33)	0.372
LMS PCI	0.41 (0.35–0.48)	<0.001
ACS	0.70 (0.63–0.77)	<0.001
Stent length >60mm	0.72 (0.54–0.95)	0.020
BVS	…	…

ACS indicates acute coronary syndrome; BVS, bioresorbable vascular scaffold; CTO, chronic total occlusion; LMS, left main stem; MACCE, major acute cardiovascular and cerebrovascular outcomes; and PCI, percutaneous coronary intervention.

*Reference is no intravascular imaging use, adjusted for the same variables as Table 4.

with reduced MACCE (OR, 0.77 [95% CI, 0.60–0.99]) but not mortality (Table 6, Figure 5).

Predictors of Receipt of Intracoronary Imaging

Factors associated with increased odds of ICI use included previous MI and PCI, out of hospital cardiac arrest, greater number of stents implanted, the use of calcium modifying devices and proximal left anterior descending PCI, and this was observed in the overall cohort as well as in those with an imaging-recommended indication (Table 7). In contrast, previous coronary artery bypass graft surgery or graft PCI procedure, advanced age (>60years), moderate-poor left ventricular function, and greater number of vessels or lesions treated were negative predictors of ICI use, even in those with an imaging-recommended indication.

DISCUSSION

To our knowledge, this is the first study to systematically study whether EAPCI recommendations for use of ICI identifies patients who have most to gain from its usage. We compared the association between

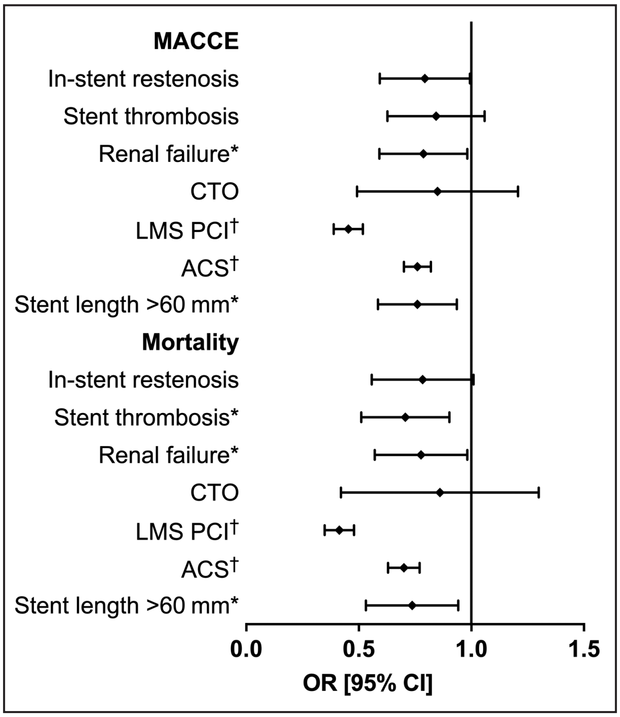

Figure 5. Adjusted odds of in-hospital outcomes associated with intracoronary imaging use according to individual recommendation.

ACS indicates acute coronary syndrome; CTO, chronic total occlusion; LMS, left main stem; MACCE, major acute cardiovascular and cerebrovascular outcomes; OR, odds ratio; and PCI, percutaneous coronary intervention. *P<0.05; †P<0.00.

imaging-guided PCI and outcome across a wide range of indications for ICI in a national cohort of >500000 PCI procedures in England and Wales. The use of ICI more than doubled over a 7-year period (7.8% in 2014 to 17.5% in 2020) but remained significantly underused, with <1 in 5 patients receiving imaging as part of their procedure. Even in those with a recommendation for ICI according to expert consensus, the use of imaging ranged between 9% and 44.7%. Nevertheless, the majority of ICI undertaken in England and Wales (74%) was in those patients with an EAPCI imaging-recommended indication. We found that ICI use was associated with lower in-hospital mortality but not postprocedural complications including acute stroke/transient ischemic attack, Bleeding Academic Research Consortium 3–5 bleeding, and reinfarction in PCI procedures undertaken with an EAPCI imaging-recommended indication, but not those without.

ICI, including IVUS and optical coherence tomography, has previously been shown to improve postprocedural outcomes, including mortality.[6–9,17] However, the current evidence is based on randomized trials that recruit highly selected cohorts as well as observational studies with relatively small cohorts. Given the limited adoption of intracoronary imaging in contemporary practice, the EAPCI published a consensus statement on the clinical use of ICI, which recommended its use in patients among whom it may be of greatest benefit.[2] There has been no previous systematic assessment of the role of ICI in this patient group and whether they yield a greater benefit with ICI than patients for which no recommendations were made.

Most studies to date have either examined the impact of ICI on procedural outcomes in totality or for specific indications. For example, a meta-analysis of randomized trials examining the impact of IVUS on drug-eluting stent implantation outcomes in 3276 patients with complex coronary lesions, including long coronary lesions or those requiring ≥4 stents, small vessels, bifurcation lesions, and chronic total occlusion reported lower target lesion revascularization (relative risk [RR], 0.62 [95% CI, 0.45–0.86]) and TVR (RR, 0.60 [95% CI, 0.42–0.87]) with IVUS-guided PCI compared with angiography-guided PCI but no difference between strategies in terms of cardiac or all-cause mortality. However, their findings were based on relatively small sample sizes from randomized studies that are less representative of the target population, and did not stratify outcomes according to different imaging indications.

While some previous studies have looked at the impact of ICI on procedural outcomes in totality or for specific indications, there are limited data stratifying outcomes based on EAPCI criteria. In a meta-analysis of 6480 patients undergoing PCI specifically for left main coronary disease, IVUS use was associated with a significant reduction of cardiac death (RR, 0.47 [95% CI, 0.33–0.66]), target lesion revascularization (RR, 0.43, 95% CI, 0.25–0.73) and stent thrombosis (stent thrombosis; RR, 0.28 [95% CI, 0.12–0.67]).[8] Similarly, a recent study by Choi et al only examined procedural outcomes in ACS and demonstrated lower mortality with IVUS use compared with angiography alone in a multicenter observational registry.[9] A substudy from the ULTIMATE (Intravascular Ultrasound Guided Drug Eluting Stents Implantation in “All-Comers” Coronary Lesions) randomized trial demonstrated lower target vessel failure (TVF) (hazard ratio [HR], 0.12 [95% CI, 0.02–0.93]) and target vessel MI (HR, 0.12 [95% CI, 0.02–0.93]) with IVUS use compared with angiography guided PCI among 349 patients with chronic kidney disease.[18] However, the hazards for other outcomes, including mortality, were either insignificant or incalculable because of their small sample size. While our findings suggest that ICI was associated with lower in-hospital mortality in cases with an EAPCI imaging-recommended indication, this was only the case with certain indications including renal failure, stent thrombosis, LMS PCI, ACS indication, and stent length >60 mm. The greatest reduction in odds of mortality (59%) was among patients undergoing LMS PCI, which

Table 7. Predictors of Receipt of Intravascular Imaging

	Overall		Imaging-recommended indication		No imaging-recommended indication	
	OR [95% CI]	*P* value	OR [95% CI]	*P* value	OR [95% CI]	*P* value
Age, y						
<60	ref	ref	ref	ref	ref	ref
60–70	0.86 [0.84–0.88]	<0.001	0.85 [0.82–0.89]	<0.001	0.86 [0.83–0.88]	<0.001
70–80	0.82 [0.80–0.84]	<0.001	0.81 [0.77–0.84]	<0.001	0.82 [0.79–0.84]	<0.001
80+	0.67 [0.65–0.69]	<0.001	0.74 [0.69–0.79]	<0.001	0.62 [0.60–0.65]	<0.001
Male sex	0.99 [0.97–1.01]	0.500	1.09 [1.04–1.13]	<0.001	0.95 [0.93–0.98]	<0.001
Race or ethnicity						
White	ref	ref	ref	ref	ref	ref
Black	1.44 [1.38–1.50]	<0.001	1.34 [1.25–1.44]	<0.001	1.48 [1.41–1.55]	<0.001
Asian	1.02 [0.99–1.06]	0.268	1.06 [1.00–1.13]	0.072	0.99 [0.95–1.04]	0.776
Other	0.90 [0.87–0.94]	<0.001	0.91 [0.85–0.98]	0.011	0.89 [0.84–0.94]	<0.001
Previous MI	1.04 [1.02–1.07]	0.001	0.95 [0.91–0.99]	0.019	1.09 [1.06–1.13]	<0.001
Previous PCI	1.59 [1.55–1.63]	<0.001	1.56 [1.50–1.62]	<0.001	1.60 [1.55–1.66]	<0.001
Previous CABG	0.66 [0.64–0.69]	<0.001	1.11 [1.03–1.19]	0.006	0.55 [0.53–0.58]	<0.001
Previous CVA	1.06 [1.01–1.11]	0.019	1.11 [1.01–1.22]	0.028	1.05 [0.99–1.10]	0.100
Diabetes	0.97 [0.95–0.99]	0.005	0.99 [0.95–1.03]	0.511	0.95 [0.93–0.98]	<0.001
Functioning renal transplant	1.26 [1.08–1.46]	0.003	1.52 [1.16–1.99]	0.002	1.16 [0.96–1.40]	0.119
Cardiac transplant	2.03 [1.58–2.61]	<0.001	3.77 [2.63–5.42]	<0.001	1.18 [0.82–1.70]	0.367
LV ejection fraction						
Good (>50%)	ref	ref	ref	ref	ref	ref
Moderate (30%–50%)	0.93 [0.91–0.95]	<0.001	0.99 [0.94–1.04]	0.680	0.92 [0.89–0.94]	<0.001
Poor (<30%)	0.92 [0.88–0.97]	0.003	1.10 [0.97–1.25]	0.130	0.90 [0.85–0.95]	<0.001
Hypercholesterolemia	0.92 [0.90–0.94]	<0.001	0.92 [0.89–0.95]	<0.001	0.92 [0.90–0.94]	<0.001
Peripheral vascular disease	1.11 [1.06–1.16]	<0.001	1.20 [1.10–1.31]	<0.001	1.09 [1.03–1.14]	0.002
Hypertension	0.97 [0.95–0.99]	0.002	0.98 [0.94–1.01]	0.218	0.97 [0.94–0.99]	0.006
Smoking	1.02 [1.00–1.04]	0.020	1.02 [0.99–1.06]	0.176	1.02 [0.99–1.04]	0.183
Valvular heart disease	1.14 [1.07–1.21]	<0.001	1.31 [1.18–1.46]	<0.001	1.06 [0.99–1.14]	0.122
Cardiogenic shock (preprocedure)	0.70 [0.65–0.75]	<0.001	1.07 [0.73–1.58]	0.727	0.72 [0.66–0.78]	<0.001
Out of hospital cardiac arrest	1.21 [1.13–1.30]	<0.001	0.88 [0.52–1.51]	0.652	1.25 [1.16–1.34]	<0.001
Ventilated	0.89 [0.81–0.97]	0.006	0.91 [0.62–1.33]	0.632	0.88 [0.81–0.97]	0.007
Circulatory support	1.10 [1.02–1.19]	0.017	2.13 [1.61–2.81]	<0.001	1.10 [1.01–1.19]	0.029
Radial	1.47 [1.41–1.54]	<0.001	1.46 [1.33–1.59]	<0.001	1.46 [1.38–1.54]	<0.001
Femoral	1.15 [1.10–1.20]	<0.001	1.28 [1.18–1.39]	<0.001	1.09 [1.03–1.15]	0.001
No. of vessels						
1	ref	ref	ref	ref	ref	ref
2	0.96 [0.93–0.99]	0.010	0.92 [0.87–0.97]	0.002	0.98 [0.95–1.02]	0.322
3	0.83 [0.78–0.87]	<0.001	0.85 [0.75–0.95]	0.006	0.84 [0.79–0.90]	<0.001
4	0.61 [0.56–0.68]	<0.001	0.60 [0.41–0.88]	0.009	0.66 [0.59–0.73]	<0.001
No. of lesions						
1	ref	ref	ref	ref	ref	ref
2	0.93 [0.91–0.96]	<0.001	0.90 [0.86–0.95]	<0.001	0.94 [0.91–0.98]	0.001
3	0.89 [0.85–0.93]	<0.001	0.82 [0.75–0.91]	<0.001	0.92 [0.87–0.96]	0.001
4+	0.83 [0.77–0.90]	<0.001	0.81 [0.68–0.96]	0.013	0.85 [0.78–0.93]	<0.001

(*Continued*)

Table 7. Continued

	Overall		Imaging-recommended indication		No imaging-recommended indication	
	OR [95% CI]	*P* value	OR [95% CI]	*P* value	OR [95% CI]	*P* value
No. of stents	1.17 [1.16–1.19]	<0.001	1.27 [1.24–1.30]	<0.001	1.13 [1.12–1.15]	<0.001
DES	0.84 [0.81–0.86]	<0.001	0.96 [0.91–1.02]	0.201	0.74 [0.71–0.77]	<0.001
First generation DES	0.98 [0.96–1.00]	0.083	1.03 [0.99–1.07]	0.183	0.98 [0.96–1.00]	0.087
Newer generation DES	0.77 [0.76–0.79]	<0.001	0.71 [0.68–0.74]	<0.001	0.79 [0.77–0.82]	<0.001
Drug coated balloon	1.06 [0.90–1.24]	0.521	1.15 [0.77–1.73]	0.491	1.02 [0.85–1.22]	0.874
Calcium modification	1.70 [1.63–1.76]	<0.001	1.78 [1.66–1.92]	<0.001	1.61 [1.53–1.69]	<0.001
Proximal LAD PCI	1.94 [1.90–1.98]	<0.001	1.98 [1.91–2.06]	<0.001	1.94 [1.89–1.99]	<0.001
Grafts	0.84 [0.78–0.91]	<0.001	0.79 [0.68–0.90]	0.001	0.88 [0.81–0.97]	0.006
Year	1.16 [1.15–1.17]	<0.001	1.15 [1.14–1.17]	<0.001	1.17 [1.16–1.18]	<0.001
Clinical syndrome						
Stable	ref	ref			ref	ref
NSTE-ACS	0.90 [0.88–0.92]	<0.001			0.73 [0.71–0.76]	<0.001
STEMI	0.39 [0.38–0.41]	<0.001			0.32 [0.31–0.34]	<0.001
Stent thrombosis	2.84 [2.69–3.00]	<0.001			2.75 [2.60–2.90]	<0.001
Renal failure	1.11 [1.05–1.17]	<0.001			1.06 [1.00–1.12]	0.040
LMS	8.63 [8.35–8.92]	<0.001			8.29 [7.98–8.61]	<0.001
CTO	1.47 [1.39–1.54]	<0.001			1.29 [1.22–1.37]	<0.001
ISR	2.39 [2.31–2.48]	<0.001			2.16 [2.08–2.24]	<0.001
Stent length >60 mm	1.74 [1.68–1.81]	<0.001			1.72 [1.65–1.79]	<0.001
BVS	10.05 [9.09–11.11]	<0.001			9.58 [8.63–10.64]	<0.001

ACS indicates acute coronary syndrome; BVS, bioresorbable vascular scaffold; CABG, coronary artery bypass graft; CTO, chronic total occlusion; CVA, cerebrovascular accident; DES, drug-eluting stent; ISR, in-stent restenosis; LAD, left anterior descending artery; LMS, left main stem; LV, left ventricular; MI, myocardial infarction; OR, odds ratio; PCI, percutaneous coronary intervention; NSTE-ACS, non-ST-elevation acute coronary syndrome (non-STEMI and unstable angina); and STEMI, ST-segment–elevation myocardial infarction.

is in keeping with previous reports.[17] Several reasons could explain the better survival among these patient groups. ICI allows for better plaque characterization and arterial/lumen measurements than angiography alone, meaning that calcified lesions (such as in chronic kidney disease) as well as plaque erosions/superficial ulcerations and vasospasm, which are frequently observed in ACS, are visualized in greater detail before PCI, thereby influencing the treatment strategy.[2,4,19] This also applies to stent thrombosis cases in whom the mechanism of stent failure such as underexpansion, malapposition, delayed endothelialization, and neoatherosclerosis can guide the treatment strategy.[2,20–22] Similarly, the use of ICI in patients with renal failure minimizes their exposure to higher volumes of contrast and subsequent risk of contrast-induced nephropathy, which is independently associated with higher mortality and MACE, as well as minimizes their risk of future stent failure.[18,23]

The low rate of use of ICI in the real world as highlighted by our study is concerning given the mounting evidence around its prognostic benefit. Although the rate of ICI use has doubled over our 7-year follow-up, it was used in less than half of cases with an imaging recommended indication (9%–44.7%), with the highest use observed in patients with BVS (44.7%) and those undergoing LMS PCI (41.2%), and the lowest in those with ACS (9%). The latter is important given the survival benefit associated with ICI use among those with ACS cases as demonstrated in our analysis as well as in previous studies. The recent study by Choi et al supports our findings, with a reported lower 1-year cardiac mortality (HR, 0.785 [95% CI, 0.643–0.959], *P*=0.018) in their multicenter registry analysis of 10 719 patients with ACS undergoing PCI with IVUS guidance versus angiography alone.[9] However, this benefit was not sustained beyond 1 year in their analysis (HR cardiac death, 0.883 [95% CI, 0.706–1.104], *P*=0.274). This could possibly be because of lack of sufficient power in their analysis, which was derived form a smaller and more outdated cohort (2004 to 2014) that included older stent generations and, therefore, may be less reflective of contemporary practice.

The underuse of ICI could be attributed to several factors including time constraints, as this prolongs the procedure time, as well as operator skill and experience or familiarity with interpretation of images.[5] Previous data from the ULTIMATE randomized trial have suggested that the benefit of imaging is restricted to those patients in whom optimal PCI was achieved, defined as

(1) MLA in the stented segment >5.0 mm^2 or 90% of the MLA at the distal reference segments, (2) plaque burden 5-mm proximal or distal to the stent edge is <50%, and (3) no edge dissection involves media with a length >3 mm, rather than use of imaging per se.[24] In fact, use of imaging did not significantly impact on 1-year outcomes (compared with angiography) in cases where an optimal PCI was not achieved in their analysis. However, among those with optimal PCI, the hazard of target lesion failure at 3-year follow up was significantly lower in certain groups including ACS (HR, 0.64 [95% CI, 0.43–0.93]), chronic kidney disease (HR, 0.49 [95% CI, 0.26–0.93]), bifurcation PCI (HR, 0.48 [95% CI, 0.27–0.87]), multivessel disease (HR, 0.55 [95% CI, 0.35–0.88]), and lesions with moderate–severe calcification (HR, 0.51 [95% CI, 0.29–0.91]) or length >25 mm (HR, 0.61 [95% CI, 0.39–0.96]).[25] In an era where health care resources are scarce, our study highlights the patient groups in which imaging is likely to be of greatest benefit and supports the EAPCI consensus statement around the types of lesions that are most likely to benefit from ICI.

Limitations

There are several limitations to the present study. First, the observational nature of this study means that our findings should be viewed as associations that are not necessarily suggestive of causality and should be interpreted within this context. Second, while the BCIS data set captures a wide range of patient and procedural characteristics, it does not include whether the results of the imaging were acted upon, and whether an optimal PCI result was obtained; therefore, there may be an element of residual confoundment. Furthermore, no adjustments were made for multiplicity. Finally, we only report in-hospital outcomes and do not identify cardiac-specific mortality, and differences between imaging-indication groups may become more pronounced on longer follow-up as shown in the ULTIMATE trial, albeit for some but not all indication groups.[25]

CONCLUSIONS

In a national procedural cohort, we found that intracoronary imaging was underused, even in patients with an EAPCI imaging-recommended indication, with <1 in 5 patients in receipt of imaging-guided PCI. Intracoronary imaging was associated with better in-hospital survival, in patient groups where imaging has been recommended by the EAPCI, particularly those with renal failure, PCI for stent thrombosis, LMS disease or ACS, and stent length >60 mm.

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None.

Supplemental Material

Table S1

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SUPPLEMENTAL MATERIAL

Table S1. Frequency of missing and imputed variables

Variable	Missing/Imputed, n (%)
Males	1376 (0.2)
Race	128834 (23.2)
Clinical syndrome	2974 (0.5)
Previous MI	11753 (2.1)
Previous PCI	10124 (1.8)
Previous CABG	8338 (1.5)
Diabetes	12588 (2.3)
Renal failure	4834 (0.9)
Family history of CAD	55152 (9.9)
Smoking	52302 (9.4)
Bivalirudin	57902 (10.4)
Aspirin	57902 (10.4)
Clopidogrel	57902 (10.4)
Ticagrelor	57902 (10.4)
Prasugrel	57902 (10.4)
Heparin	57902 (10.4)
Warfarin	57902 (10.4)
Nitrates	57902 (10.4)
GB23a inhibitors	62237 (11.2)
Rotational	26551 (4.8)
Directional	26551 (4.8)
Cutting Balloon	26551 (4.8)
Laser angioplasty	26551 (4.8)
Drug eluting balloon	26551 (4.8)
shockwave	26551 (4.8)
Hypercholesterolaemia	11488 (2.1)
Hypertension	11488 (2.1)
PVD	11488 (2.1)
Previous CVA	11488 (2.1)
Cardiac transplant	11488 (2.1)
Valvular heart disease	11488 (2.1)
Non-coronary surgery	11488 (2.1)
Cardiogenic shock pre-procedure	80533 (14.5)
Pre-op ventilation	34032 (6.1)
OHCA	123485 (22.2)
Radial access	11842 (2.1)
Femoral access	11842 (2.1)
LVEF category	118300 (21.3)
BARC3 to 5 bleeding	109969 (19.8)
LMS	41490 (7.5)
LAD proxinal	41490 (7.5)
LAD other	41490 (7.5)

LCx	41490 (7.5)
RCA	41490 (7.5)
Grafts	41490 (7.5)