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Intracoronary imaging in PCI for acute coronary syndrome: Insights from British Cardiovascular Intervention Society registry

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ABSTRACT

Background: While previous studies have demonstrated the superiority of ICI-guided PCI over an angiography-based approach, there are limited data on all-comer ACS patients.
This study aimed to identify the characteristics and in-hospital outcomes of patients undergoing intracoronary imaging (ICI) guided percutaneous coronary intervention (PCI) for acute coronary syndrome (ACS).
Methods: All patient undergoing PCI for ACS in England and Wales between 2006 and 2019 were retrospectively analyzed and stratified according to ICI utilization. The outcomes assessed were in-hospital all-cause mortality and major adverse cardiovascular and cerebrovascular events (MACCE) using multivariable logistic regression models.
Results: 598,921 patients underwent PCI for ACS, of which 41,716 (7.0 %) had ICI which was predominantly driven by IVUS use (5.6 %). ICI use steadily increased from 1.4 % in 2006 to 13.5 % in 2019. Adjusted odds of mortality (OR 0.69, 95%CI 0.58–0.83) and MACCE (OR 0.77, 95%CI 0.73–0.83) were significantly lower in the ICI group. The association between ICI and improved outcomes varied according to vessel treated with both left main stem (LMS) and LMS/left anterior descending (LAD) PCI associated with significantly lower odds of mortality (OR 0.34, 95%CI 0.27–0.44, OR 0.51 95%CI 0.45–0.56) and MACCE (OR 0.44 95%CI 0.35–0.54, OR 0.67 95%CI 0.62–0.72) respectively.
Conclusions: Although ICI use has steadily increased, less than one in seven patients underwent ICI-guided PCI. The association between ICI use and improved in-hospital outcomes was mainly observed in PCI procedures involving LMS and LAD.

Summary

Previous studies have demonstrated superior clinical outcomes with ICI-guided PCI compared to an angiography-based approach; however, there are limited contemporary data on ICI use in an all-comer ACS population. This national analysis demonstrates that the use of ICI in the setting of ACS remains low, despite increasing trends during the study period. The potential benefits of ICI seem to be mainly in LMS/LAD PCI procedures, with significantly lowers odd of in-hospital mortality and MACCE.

Abbreviations: ACS, Acute coronary syndromes; CI, Confidence interval; ICI, Intracoronary imaging; IVUS, Intravascular ultrasound; LAD, Left anterior descending; LMS, Left main stem; MACCE, Major adverse cardiovascular and cerebrovascular events; NHS, National Health Service; OCT, Optical coherence tomography; PCI, Percutaneous coronary intervention; OR, Odds ratio; SD, Standard deviation; STEMI, ST elevation myocardial infarction.

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1. Introduction

Invasive coronary angiography allows the identification and treatment of the culprit lesion in an acute coronary syndrome (ACS) setting. However, many ACS patients do not demonstrate significant obstructive coronary artery disease (CAD) or may have multiple culprit lesions [1,2]. In cases of diagnostic uncertainty, intra-coronary imaging (ICI) in the form of either intravascular ultrasound (IVUS) or optical coherence tomography (OCT) plays a pivotal role in the identification of the hallmarks of the culprit lesion, which may subsequently lead to an alternate non-stenting strategy. In those with plaque rupture events or significant coronary disease, ICI provides important additional information over angiography alone with more precise assessment of lesion characteristics, including distribution of calcium, lesion length, reference vessel diameter and stent expansion, thereby improving procedural outcomes [3,4].

Current European Association of Percutaneous Coronary Intervention (EAPCI) expert opinion advocates the adjunctive use of ICI in patients with ACS [5]. Previous studies have reported better clinical outcomes for ACS patients undergoing ICI-guided PCI compared to a conventional angiography-based approach [4,6–11]. A recent analysis of 13,104 patients with ACS showed that IVUS was associated with significantly lower target lesion failure at 3 years compared to an angiography-based approach [12]. However, limited contemporary data exist on the uptake of ICI, temporal trends and associated clinical outcomes in an all-comer national ACS cohort as previous studies have been limited to either an IVUS or OCT approach or focused predominantly on NSTEMI or STEMI only [4,7–10,13]. Furthermore, there is little data regarding whether any benefit of ICI-guided PCI varies according to the treated vessel.

This study aims to study the temporal growth in the use of ICI, clinical characteristics and angiographic profiles of ACS patients who underwent ICI-guided PCI. We investigated the associations between ICI utilization and clinical outcomes (in-hospital all-cause mortality and MACCE), and the impact of ICI on clinical outcomes in individual coronary vessels. In addition, we aim to assess the individual impact of IVUS and OCT on clinical outcomes compared to angiography-guided PCI.

2. Methods

We queried the British Cardiovascular Intervention Society (BCIS) PCI registry to include all patients aged>18 years undergoing PCI for ACS between 1st January 2006 to 31st December 2019. The registry collects information from all National Health Service (NHS) acute hospitals about co-morbidities, angiographic findings, procedural pharmacology, and in-hospital outcomes in patients undergoing PCI, constituting over 95 % of all PCI activity in the UK.[14] The encrypted and pseudonymized data are used for audit, research purposes and public reporting without formal individual patient consent under section 251 of NHS act 2006; therefore, the data was processed without individual identifiable information and did not require institutional review board ethical approval [14].

The use of ICI was defined as the use of any imaging modality such as intravascular ultrasound (IVUS), optical coherence tomography (OCT) and optical frequency domain imaging (OFDI). We excluded patients lacking information regarding age, in-hospital death, and ICI use. The final study cohort was then grouped into ICI versus non-ICI groups based on ICI utilization, with further subgroup analysis according to the type of vessel treated using ICI (Supplementary Fig. 1).

The primary outcome was in-hospital mortality, secondary outcomes were major adverse cardiovascular and cerebrovascular events (MACCE; composite of death, acute stroke/transient ischemic attack and reinfarction) and procedural complications as defined in the BCIS registry previously [14].

The patient profiles and procedural characteristics of the ICI group were compared with the non-ICI group. The *t*-test was used to compare continuous variables, normally distributed and presented as mean values with standard deviations (SD). Categorical variables were reported as numbers and percentages and compared using the Chi-squared test. The data were assumed to be missing at random and were accounted for by using multiple imputations with chained equations. The imputation models included linear regression for continuous variables, logistic regression for binary variables and multinomial models for nominal variables. A total of ten imputed datasets were generated before model fitting [15,16]. Rubin's rules were used to combine model estimates late [17]. Multivariable logistic regression models were performed to assess A) the association between ICI utilization and aforementioned outcomes (in-hospital mortality and MACCE) overall and then stratified according to the type of ICI modality used and type of vessel treated, B) the predictors of receipt of ICI in the overall cohort. Variables adjusted for in the models included: age, sex, ethnicity, clinical syndrome (ST-elevation myocardial infarction (STEMI) or non-STEMI),

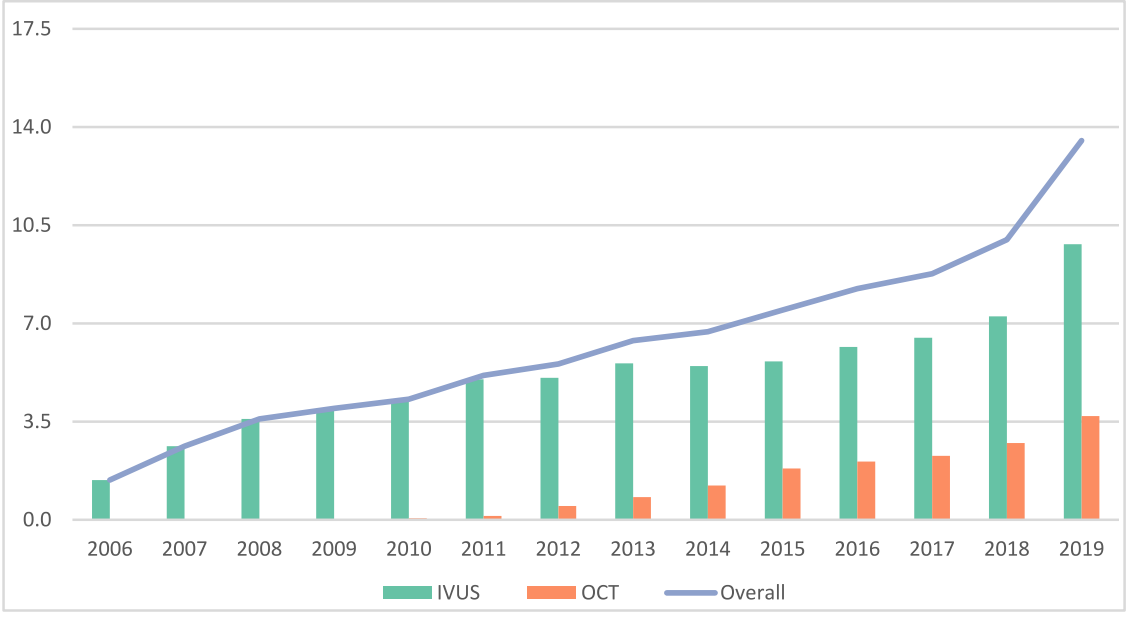

Fig. 1. ICI temporal trends - Temporal trends in the use of ICI between 2006 and 2019 in the overall cohort.

Table 1
Baseline characteristics of patients undergoing intracoronary imaging (ICI) guided PCI compared to no intracoronary imaging.

Variable	No ICI group	ICI group	*p*-value
Number of patients	557,205	41,716	
Age (mean (SD))	64.91 (12.51)	64.66 (12.89)	<0.001
BMI (mean (SD))	28.06 (5.26)	28.21 (5.42)	<0.001
Female, No. (%)	148,416 (26.6)	10,901 (26.1)	0.025
BAME	61,100 (14.0)	4830 (16.9)	<0.001
Left Ventricular Ejection Fraction			
Good (LVEF ≥ 50 %)	463,821 (83.2)	33,046 (79.2)	<0.001
Moderate (LVEF 30 %–49 %)	73,337 (13.2)	6619 (15.9)	
Poor (LVEF ≤ 29 %)	20,047 (3.6)	2051 (4.9)	
Indication			
NSTEMI	324,040 (58.2)	31,381 (75.2)	<0.001
STEMI	233,165 (41.8)	10,335 (24.8)	
Smoking			
Non-smoker	179,021 (35.7)	13,851 (36.4)	<0.001
Current smoker	155,302 (30.9)	9570 (25.1)	
Ex-smoker	167,827 (33.4)	14,666 (38.5)	
Co-morbidities			
Prior PCI	84,843 (15.7)	14,485 (35.4)	<0.001
Prior MI	115,243 (21.8)	14,421 (36.2)	<0.001
Prior CABG	38,829 (7.2)	3083 (7.5)	0.005
Diabetes	107,671 (19.9)	9840 (24.1)	<0.001
Hypertension	273,472 (51.0)	22,600 (56.7)	<0.001
Hypercholesterolemia	282,403 (52.7)	21,643 (54.3)	<0.001
Family history of heart disease	196,128 (39.8)	14,559 (39.7)	0.713
Renal disease	13,342 (2.5)	1573 (3.9)	<0.001
Peripheral vascular disease	23,224 (4.3)	2385 (6.0)	<0.001
Prior cerebrovascular accident	22,210 (4.1)	2136 (5.4)	<0.001
Procedural Data			
GPIIb/IIIa inhibitor	144,357 (28.0)	9378 (24.4)	<0.001
Warfarin	4435 (0.9)	336 (0.9)	0.973
No stents used	34,924 (7.5)	3817 (12.7)	<0.001
Pressure Wire	25,951 (4.7)	2778 (6.7)	<0.001
In-stent restenosis	15,369 (3.6)	4263 (15.4)	<0.001
Cardiogenic shock (pre-procedure)	21,808 (4.1 %)	1478 (3.6 %)	<0.001
Number of lesions treated (%)			
1	342,096 (72.5)	18,448 (61.2)	<0.001
2	98,182 (20.8)	7899 (26.2)	
≥3	31,299 (6.6)	3819 (12.7)	
Number of vessels treated (%)			
1	457,459 (82.9)	28,215 (68.4)	<0.001
2	80,277 (14.5)	9311 (22.6)	
≥3	14,334 (2.6)	3736 (9.1)	
Number of stents used			<0.001
1	262,863 (56.2)	12,686 (42.2)	
2	114,981 (24.6)	7634 (25.4)	
3	54,668 (11.7)	5943 (19.8)	
Radial access	356,497 (67.6)	30,591 (78.6)	<0.001
Atherectomy devices use	11,519 (2.4)	4414 (12.8)	<0.001
Target vessel for PCI			
Graft	17,060 (3.1)	737 (1.8)	<0.001
LMS	16,588 (3.0)	8828 (21.4)	<0.001
LAD	252,850 (46.1)	25,615 (62.2)	<0.001
LCX	132,089 (24.1)	9700 (23.6)	0.018
RCA	207,895 (37.9)	10,384 (25.2)	<0.001
Multiple Vessel	98,187 (17.9)	14,525 (35.3)	<0.001
Stent Length (mean (SD))	25.38 (13.24)	29.78 (17.86)	<0.001
Stent Diameter (mean (SD))	3.32 (0.58)	3.81 (0.70)	<0.001
Procedural complications			
Side branch occlusion	3075 (0.6)	317 (0.8)	<0.001
No flow/ slow flow	7364 (1.4)	502 (1.3)	0.04
Coronary dissection	6498 (1.2)	1085 (2.7)	<0.001
Re-intervention PCI	2590 (0.5)	209 (0.5)	0.290
Re-intervention angiography	721 (0.1)	78 (0.2)	0.002
Outcomes			
In-hospital MACCE	21,108 (3.8)	1395 (3.3)	<0.001
In-hospital mortality	13,641 (2.4)	708 (1.7)	<0.001

BMI: Body Mass Index, CABG: Coronary artery bypass graft, BAME: Black, asian and minority ethnic, GPIIb/IIIa: Glycoprotein IIb/IIIa, IABP: Intra-aortic balloon pump, ICI: intracoronary imaging, LAD: Left anterior descending, LCX: Left circumflex, LMS: Left main stem, LVEF: Left Ventricular Ejection Fraction, MACCE: Major adverse cardiovascular and cerebrovascular events, MI: Myocardial Infarction, NSTEMI: Non-ST Elevation Myocardial Infarction, PCI: Percutaneous Coronary Intervention, RCA: Right coronary artery, SD: Standard deviation, STEMI: ST Elevation Myocardial Infarction.

previous AMI, previous PCI, prior coronary artery bypass graft surgery (CABG), diabetes mellitus, chronic renal failure, family history of ischemic heart disease (IHD), left ventricular (LV) function, hypercholesterolemia, peripheral vascular disease (PVD), previous cerebrovascular accident, hypertension, smoking, out of hospital cardiac arrest (OHCA), mechanical ventilation, circulatory support, vascular access (radial vs femoral), number of vessels and lesions attempted, number of stents, the drug-eluting stent (DES), use of fractional flow reserve (FFR), or calcium modification (rotablation, cutting balloon, laser angioplasty), and in-hospital pharmacotherapy (Clopidogrel, ticagrelor, prasugrel, warfarin, glycoprotein IIb/IIIa inhibitor (GP-2b3a)). All associations are reported as odds ratios (OR) with corresponding 95 % confidence intervals (CI). All statistical analyses were performed using Stata 16 MP (College Station, Texas, US).

3. Results

A total of 598,921 patients underwent PCI for ACS during the study period, of which 41,716 (7.0 %) had ICI performed. Amongst those undergoing ICI, 36772 (5.6 %) and 8044 (1.4 %) underwent IVUS and OCT, respectively. The percentage of ICI undertaken for an ACS indication steadily increased from 1.4 % in 2006 to 13.5 % in 2019, with a steady increase in the use of both IVUS and OCT (Fig. 1).

Patients in the ICI group were younger (mean age 64.6 years vs 64.9 years, $p < 0.001$) and had a higher prevalence of poor LV impairment (4.9 % vs 3.5 %, $p < 0.001$), prior MI (36.2 % vs 21.8 %, $p < 0.001$), prior PCI (35.4 vs 15.7 %, $p < 0.001$), diabetes (24.1 % vs 19.9 %, $p < 0.001$), hypertension (56.7 % vs 51.0 %, $p < 0.001$), renal disease (3.9 % vs 2.5 %, $p < 0.001$), peripheral vascular disease (6.0 % vs 4.3 %, $p < 0.001$) and cerebrovascular disease (5.4 % vs 4.1 %, $p < 0.001$) (Table 1). ICI was more commonly used in patients with in-stent restenosis (15.4 % vs 3.6 %, $p < 0.001$) and those with increased disease complexity, such as patients with a greater number of lesions (≥3) (12.7 % vs 6.6 %, $p < 0.001$) and number of vessels (≥3) treated (9.1 % vs 2.6 %, $p < 0.001$). Stent sizes in both length (29.8 mm vs 25.3 mm, $p < 0.001$) and diameter (3.8 mm vs 3.3 mm, $p < 0.001$) were significantly larger in the ICI group compared to the non-ICI group. There was a higher incidence of PCI in the LMS (21.4 % vs 3.0 %, $p < 0.001$) and LAD (62.2 % vs 46.1 %, $p < 0.001$) in the ICI group (Table 1).

When stratified by mode of ICI, the use of IVUS was significantly higher than OCT in patients undergoing LMS PCI (24.5 % vs 8.5 %, $p < 0.001$), multi-vessel PCI (37.5 % vs 25.6 %, $p < 0.001$) and those with renal disease (4.4 % vs 2.1 %, $p < 0.001$). OCT use was slightly greater than IVUS in the setting of STEMI presentation (26.3 % vs 24.4 %, $p < 0.001$) and in-stent restenosis (18.7 % vs 14.7 %, $p < 0.001$). IVUS use was associated with longer stent length (30.1 vs 28.2 mm, $p < 0.001$) and diameter (3.84 vs 3.65 mm, $p < 0.001$) when compared to OCT (Table 2).

Further stratification by EAPCI recommendations for ICI revealed that the uptake of ICI was consistently higher in the NSTEMI group for all indications compared to the STEMI group (Fig. 2).

Crude in-hospital mortality (3.8 % vs 3.3 %, $p < 0.001$) and in-hospital MACCE (2.4 % vs 1.7 %, $p < 0.002$) were significantly higher in the non-ICI compared to the ICI group. The procedural complications rates were similar in both groups, although slightly higher rates of coronary dissection (2.7 % vs 1.2 %, $p < 0.001$) were observed in the ICI group. After adjustment of case-mix differences, the use of ICI was associated with reduced in-hospital mortality (odds ratio [OR] 0.69 95%CI 0.58–0.83) and in-hospital MACCE (OR 0.77 95%CI 0.73–0.83) (Table 3). When ICI outcomes were stratified by the vessel treated, lower odds of in-hospital mortality and MACCE were observed both in those who underwent LMS PCI (in-hospital mortality OR 0.34 95%CI 0.27–0.44, MACCE OR 0.44 95%CI 0.35–0.54 respectively) or LMS/LAD PCI (in-hospital mortality OR 0.51 95%CI 0.45–0.56, MACCE; OR 0.67 95%CI 0.62–0.72). In contrast, ICI in non-LAD/LMS PCI procedures was not associated with decreased odds of in-hospital mortality (OR 0.82 95%CI 0.68–1.0) or MACCE (OR 1.10 95%CI 0.98–1.24) compared to the non-ICI group (Table 4)

Table 2
Baseline characteristics of patients undergoing PCI with no intracoronary imaging (ICI) compared to IVUS or OCT guided PCI.

Variable	IVUS group N (%)	OCT group N (%)	p-value
Number of patients	33,672 (5.6)	8044 (1.3)	
Age (mean (SD))	65.33 (12.86)	61.86 (12.64)	<0.001
BMI (mean (SD))	28.17 (5.43)	28.37 (5.38)	<0.001
Female sex	8894 (26.4)	2007 (25.0)	0.002
BAME	3931 (17.4)	899 (15.2)	<0.001
Left Ventricular Ejection Fraction	<0.001		
Good (LVEF ≥ 50 %)	26,414 (78.4)	6632 (82.4)	
Moderate (LVEF 30 %–49 %)	5511 (16.4)	1108 (13.8)	
Poor (LVEF ≤ 29 %)	1747 (5.2)	304 (3.8)	
Indication			<0.001
NSTEMI	25,455 (75.6)	5926 (73.7)	<0.001
STEMI	8217 (24.4)	2118 (26.3)	
Smoking			<0.001
Non-smoker	11,168 (36.3)	2683 (36.7)	
Current smoker	7476 (24.3)	2094 (28.6)	
Ex-smoker	12,128 (39.4)	2538 (34.7)	
Co-morbidities			
Prior PCI	11,320 (34.3)	3165 (40.1)	<0.001
Prior MI	11,549 (36.1)	2872 (36.5)	<0.001
Prior CABG	2652 (8.0)	431 (5.4)	<0.001
Diabetes	8080 (24.6)	1760 (22.2)	<0.001
Hypertension	18,397 (57.3)	4203 (54.0)	<0.001
Hypercholesterolemia	17,642 (55.0)	4001 (51.4)	<0.001
Family history of heart disease	11,751 (40.0)	2808 (38.5)	0.072
Renal disease	1412 (4.4)	161 (2.1)	<0.001
Peripheral vascular disease	2058 (6.4)	327 (4.2)	<0.001
Prior cerebrovascular accident	1849 (5.8)	287 (3.7)	<0.001
Procedural data			
GPIIb/IIIa inhibitor	7694 (24.6)	1684 (23.6)	<0.001
Warfarin	286 (0.9)	50 (0.7)	0.220
Pressure Wire	2240 (6.7)	538 (6.7)	<0.001
In-stent restenosis	3416 (14.7)	847 (18.7)	<0.001
Cardiogenic shock (pre-procedure)	1293 (3.9 %)	185 (2.8 %)	<0.001
Number of lesions treated (%)	<0.001		
1	14,984 (59.2)	3464 (71.1)	
2	6836 (27.0)	1063 (21.8)	
≥3	3471 (13.7)	348 (7.1)	
Number of vessels treated (%)	<0.001		
1	21,976 (65.9)	6239 (78.9)	
2	7975 (23.9)	1336 (16.9)	
≥3	3403 (10.2)	333 (4.2)	
Radial access	23,840 (71.8)	6751 (86.8)	<0.001
Target vessel for PCI			
Graft	633 (1.9)	104 (1.3)	<0.001
LMS	8162 (24.5)	666 (8.5)	<0.001
LAD	20,620 (61.9)	4995 (63.7)	<0.001
LCX	8148 (24.4)	1552 (19.8)	<0.001
RCA	8342 (25.0)	2042 (26.0)	<0.001
Multiple Vessel	12,515 (37.5)	2010 (25.6)	<0.001
Stent Length (mean (SD))	30.07 (18.28)	28.24 (15.39)	<0.001
Stent Diameter (mean (SD))	3.84 (0.70)	3.65 (0.64)	<0.001
Procedural complications			
Side branch occlusion	281 (0.9)	36 (0.5)	<0.001
No flow/ slow flow	425 (1.3)	77 (1.0)	0.010
Coronary dissection	946 (3.0)	139 (1.8)	<0.001
Re-intervention PCI	174 (0.5)	35 (0.4)	0.360
Re-intervention angiography	67 (0.2)	11 (0.1)	0.003
In-hospital MACCE	1213 (3.6)	182 (2.3)	<0.001
In-hospital mortality	627 (1.9)	81 (1.0)	<0.001

BMI: Body Mass Index, CABG: Coronary artery bypass graft, BAME: Black, asian and minority ethnic, GPIIb/IIIa: Glycoprotein IIb/IIIa, IABP: Intra-aortic balloon pump, ICI: intracoronary imaging, IVUS: Intravascular Ultrasound, LAD: Left anterior descending, LCX: Left circumflex, LMS: Left main stem, LVEF: Left Ventricular Ejection Fraction, MACCE: Major adverse cardiovascular and cerebrovascular events, MI: Myocardial Infarction, NSTEMI: Non-ST Elevation Myocardial Infarction, OCT: Optical Coherence Tomography, PCI: Percutaneous Coronary Intervention, RCA: Right coronary artery, SD: Standard deviation, STEMI: ST Elevation Myocardial Infarction.

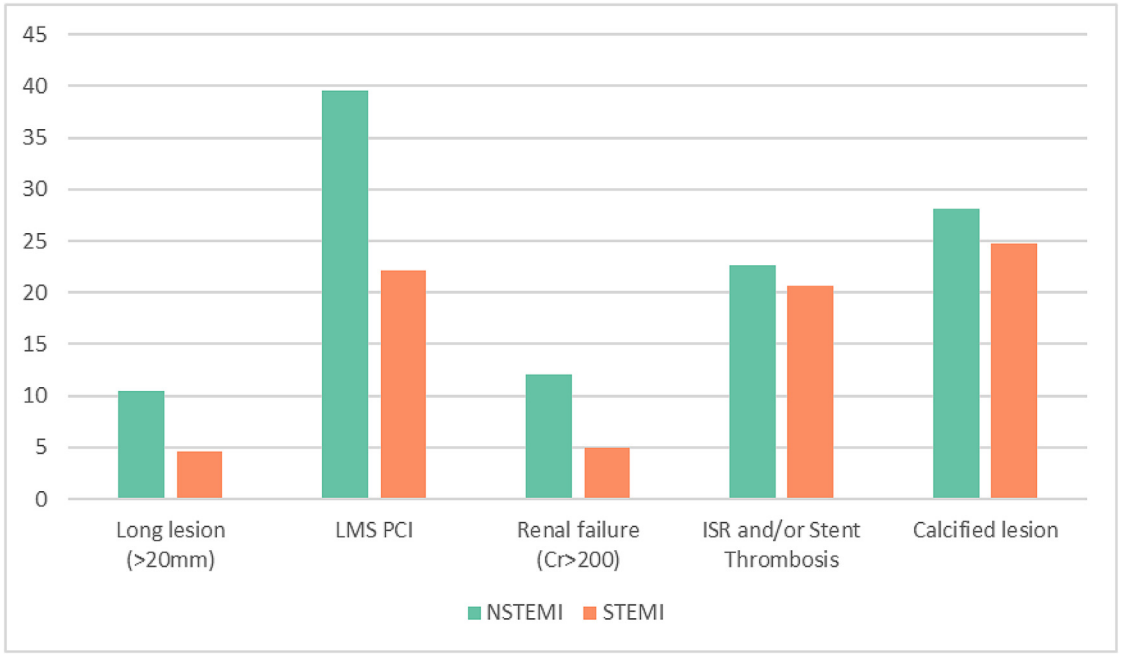

Fig. 2. ICI use in subgroups - Use of ICI as per EAPCI guidelines recommendations in different patient groups
EAPCI: European Association of Percutaneous Coronary Intervention, CR: Creatinine, ISR: In-stent restenosis, LMS PCI: Left main stem, PCI: Percutaneous coronary intervention.

When analyzed separately, both IVUS and OCT were associated with lower odds of in-hospital mortality (IVUS; OR 0.54 95%CI 0.40–0.48, OCT; OR 0.47 95%CI 0.39–0.56) and MACCE (IVUS; OR 0.65 95%CI 0.61–0.69, OCT; OR 0.55 95%CI 0.47–0.65) respectively, compared to an angiography-based PCI approach (Table 3).

The independent predictors of ICI are reported in Table 5. Use of rotational atherectomy (OR 4.05 95 % CI 3.81–4.29), LMS PCI (OR 4.1 95 % CI 4.02–4.34), larger stent diameters (OR 3.15 95 % CI 3.08–3.23) and previous PCI (OR 2.38 95 % CI 2.31–2.46) were independent predictors of ICI use.

4. Discussion

This national report from an all-comer national PCI registry demonstrates that the use of ICI in ACS patients has gradually increased more than ten-fold over the study period. However, even by 2019 less than one in seven patients receive ICI-guided PCI. ICI utilization was predominantly driven by IVUS use, although OCT use was more common in patients presenting with STEMI, previous PCI, and in-stent restenosis. OCT and IVUS use were consistently associated with significantly better clinical outcomes than the non-ICI group. The association between use of ICI and lower odds of in-hospital mortality and MACCE appeared to be only evident in PCI procedures undertaken in LMS/LAD.

ICI utilization has previously been reported at <15 % for all comer PCI in the UK [18]. In the setting of ACS, we found this was around 7 %, although there was a temporal increase from 1.4 % to 13.5 % during the study period. This is lower than other national reports; a recent Korean study reported IVUS utilization in myocardial infarction at 21.0 %.[12] Similarly, a Japanese report on ICI use in the ACS setting quoted 60 % uptake [19]. The results from our study demonstrate low volumes in the context of accumulating evidence for the benefits of ICI [4,12,19,20]. Potential explanations for this may be time pressures, lack of operator experience in using and interpreting ICI, and concerns around the risk of downstream embolization of thrombus due to increased instrumentation, particularly in STEMI patients. Although ICI is associated with a high up-front cost, in the UK National Health Service (NHS), operators do not have to seek reimbursement meaning this is less of an issue compared to other countries globally [21]. Interestingly, ICI has been shown to be cost-saving in ACS patients and may be more economical than a non-ICI-guided approach at longer term [22].

Table 3
Adjusted odds ratios (OR) and 95 % confidence intervals (CI) of in-hospital outcomes in the intracoronary imaging (ICI) groups (vs. no imaging).

Outcome	IVUS use Odds ratio (95%CI)	OCT use Odds ratio (95%CI)	Overall ICI use Odds ratio (95%CI)
In-hospital mortality	0.54 (0.40–0.68)	0.47 (0.39–0.56)	0.69 (0.58–0.83)
In-hospital MACCE	0.65 (0.61–0.69)	0.55 (0.47–0.65)	0.77 (0.73–0.83)
STEMI			
In-hospital mortality	0.53 (0.47–0.51)	0.36 (0.26–0.50)	0.62 (0.53–0.74)
In-hospital MACCE	0.68 (0.61–0.75)	0.52 (0.41–0.67)	0.78 (0.69–0.89)
NSTEMI			
In-hospital mortality	0.57 (0.50–0.65)	0.57 (0.41–0.79)	0.60 (0.50–0.71)
In-hospital MACCE	0.83 (0.76–0.90)	0.74 (0.61–0.91)	0.83 (0.74–0.92)

CI: Confidence Interval, ICI: intracoronary imaging, IVUS: Intravascular Ultrasound, MACCE: Major adverse cardiovascular and cerebrovascular events, NSTEMI: Non-ST Elevation Myocardial Infarction, OCT: Optical Coherence Tomography, STEMI: ST Elevation Myocardial Infarction.

Table 4
Adjusted odds ratios (OR) and 95 % confidence intervals (CI) of in-hospital outcomes in the intracoronary imaging (ICI) groups (vs. no imaging) stratified by vessel.

	Reference group	Odds Ratio (95 % CI)
LMS		
In-hospital mortality	No imaging group	0.34 (0.27–0.44)
In-hospital MACCE	No imaging group	0.44 (0.35–0.54)
LMS/LAD		
In-hospital mortality	No imaging group	0.51 (0.45–0.56)
In-hospital MACCE	No imaging group	0.67 (0.62–0.72)
Any other vessel[a]		
In-hospital mortality	No imaging group	0.82 (0.68–1.0)
In-hospital MACCE	No imaging group	1.10 (0.98–1.24)

CI: Confidence Interval, LAD: Left anterior descending, LMS: Left main stem, MACCE: Major adverse cardiovascular and cerebrovascular events.
[a] Any other vessel = left circumflex, right coronary artery, vein graft.

Table 5
Independent predictors of use of intracoronary imaging.

Independent predictors	Odds Ratio (95%CI)
Age per year	0.98 (0.97–0.98)
Female Sex	0.95 (0.71–1.15)
STEMI indication	0.53 (0.51–0.54)
Ex smoker	0.82 (0.80–0.85)
Current smoker	1.09 (1.05–1.13)
Previous PCI	2.38 (2.31–2.46)
Previous AMI	1.13 (1.04–1.13)
Diabetes	0.99 (0.95–1.03)
Hypertension	1.01 (0.98–1.04)
Hypercholesterolemia	0.89 (0.87–0.91)
Renal disease	1.04(0.96–1.13)
Previous CVA	1.08 (1.02–1.14)
GPI use	1.22 (1.18–1.26)
Rotational atherectomy	4.05 (3.81–4.29)
LMS PCI	4.1 (4.02–4.34)
BAME ethnicity	1.15 (1.11–1.19)
Stent Diameter per mm	3.15 (3.08–3.23)
Stent length per mm	1.01 (1.00–1.01)
Body mass Index	0.98 (0.97–0.98)
Radial access	1.37 (1.32–1.42)
Multi vessel PCI	1.38 (1.32–1.43)
Year (per year)	1.087 (1.081–1.093)

AMI: Acute myocardial infarction, BAME: Black, asian and minority ethnic, CI: Confidence Interval, CVA: Cerebrovascular accident, GPI: Glycoprotein Inhibitor IIa/IIIB, LMS: Left main stem, PCI: Percutaneous coronary intervention, STEMI: ST Elevation Myocardial Infarction,

Whilst previous registry data has provided evidence of benefit for ICI in LMS PCI, [23,24] this is the first report to demonstrate that the association between ICI and better outcomes in ACS appears to be mainly in PCI procedures undertaken in the LMS/LAD. The LMS and LAD subtend the largest area of the myocardium, and it is plausible that the most significant prognostic benefit from ICI will come when treating these vessels. Furthermore, ICI aids in identifying areas of high plaque burden requiring specific treatment and assessment of LMS vessel size, which is challenging to assess angiographically due to the lack of a proximal reference vessel [23].

Overall, there was a higher use of IVUS compared to OCT (5.6 % vs 1.3 %), which may be due to the higher rates of IVUS use in patients with LMS PCI, multi-vessel PCI, ostial disease and renal disease. The requirement for blood clearance along with contrast use reduces the applicability of OCT in these patient groups [5]. Between 2006 and 2010, there was minimal OCT use likely due to it being a newer ICI method and suggestive of a lag in operators' availability/learning curve. The use of OCT was more prevalent in the setting of STEMI and in-stent restenosis. The strongest predictors of stent thrombosis/restenosis are small luminal areas due to stent under expansion and reference segment disease, including edge dissections and untreated plaque burden [25–27]. The best modality to identify and treat these issues is ICI, with OCT being the most sensitive technique [5]. Nevertheless, both OCT and IVUS were associated with reduced in-hospital mortality and MACCE compared to the non-ICI group across the entire ACS population.

ICI enables accurate lesion sizing and morphological characterization, which improves procedural planning, i.e., correct balloon/stent sizing, calcium modification, and aspiration thrombectomy. It allows for treatment of angiographically unapparent high-risk plaque within and in close proximity to stented segments, thereby reducing the chance of future in-stent restenosis or acute stent thrombosis. Lastly, it allows for the treatment of under-expansion, mal-apposition, significant edge dissections and marked plaque burden at the stent edges which are the main causes of stent failure. Indeed, ICI criteria of suboptimal stent expansion have been shown to be associated with an increased risk of MACCE [28–30].

Given the study's observational nature, we could not adjust for variables not collected in the original database. The study does not report on outcome measures such as target vessel repeat revascularization, recurrent MI or MACCE beyond the index hospital admission that would enable us to assess the prognostic benefit of ICI beyond the hospital stay. The BCIS database does not capture the raw IVUS/OCT measurement data, and we could not provide details of the minimal luminal/stent area and correlate these with the outcomes noted in the ICI group. Furthermore, as this information is unavailable, we could not distinguish between upfront imaging use or use later in the procedure. Although there was a clear trend to reduce MACCE with ICI use, the improved outcomes may be confounded by operators' experience and equipment improvement.

This contemporary national report of an all-comer ACS population undergoing PCI shows that less than one in seven patients presenting with ACS undergo ICI-guided PCI despite increasing temporal trends. Although the uptake of ICI was predominantly driven by IVUS use, IVUS and OCT were associated with improved in-hospital mortality and MACCE compared to stand-alone angiography-guided PCI. There was a trend towards greater benefit of ICI-guided PCI in LMS/LAD PCI, which was less evident in PCI to other coronary vessels.

CRediT authorship contribution statement

Mahvash Zaman: Conceptualization, Methodology, Formal analysis, Writing – Original Draft, Review and Editing, Visualization.

Chris Stevens: Methodology, Software, Validation, Formal analysis, Investigation.

Peter Ludman: Data curation, resources.

Harinda C Wijeysundera: Writing – review and editing.

Zbigniew Siudak: Writing – review and editing.

Andrew SP Sharp: Writing – review and editing.

Tim Kinnaird: Writing – review and editing.

Mohamed O Mohamed: Writing – review and editing.

Javed M Ahmed: Writing – review and editing.

Muhammad Rashid: Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Writing – Original Draft, Review and Editing, Visualization, Supervision.

Mamas A Mamas: Conceptualization, Methodology, Writing – Original Draft, Visualization, Supervision.

Declaration of competing interest

Andrew Sharp is a Consultant to Medtronic, Philips, Boston Scientific, Recor Medical, Penumbra. NIHR funds MR for his academic clinical lecturer post, and the views expressed are those of the author(s) and not necessarily those of the NHS, the NIHR, or the Department of Health. Mamas A Mamas is in receipt of unrestricted educational grants from Abbott Vascular and Terumo. The remaining authors have no conflicts of interest to declare.

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Appendix A. Supplementary data

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