Journal of the American Heart Association

ORIGINAL RESEARCH

Clinical Characteristics and Outcomes Among Patients Undergoing High-Risk Percutaneous Coronary Interventions by Single or Multiple Operators: Insights From the Veterans Affairs Clinical Assessment, Reporting, and Tracking Program

Christopher P. Kovach, MD, MSc; Annika Hebbe, MS; Anna E. Barón, PhD; Aaron Strobel, MD; Mary E. Plomondon, MSPH, PhD; Javier A. Valle, MD, MSCS; Stephen W. Waldo, MD

BACKGROUND: High-risk percutaneous coronary intervention (HR-PCI) is increasingly common among contemporary patients with coronary artery disease. Experts have advocated for a collaborative 2-operator approach to support intraprocedural decision-making for these complex interventions. The impact of a second operator on patient and procedural outcomes is unknown.

METHODS AND RESULTS: Patients who underwent HR-PCI from 2015 to 2018 within the Veterans Affairs Healthcare System were identified. Propensity-matched cohorts were generated to compare the outcomes following HR-PCI performed by a single or multiple (≥2) operators. The primary end point was the 12-month rate of major adverse cardiovascular events. We identified 6672 patients who underwent HR-PCI during the study period; 6211 (93%) were treated by a single operator, and 461 (7%) were treated by multiple operators, with a nonsignificant trend toward increased multioperator procedures over time. A higher proportion of patients treated by multiple operators underwent left main (10% versus 7%, P=0.045) or chronic total occlusion intervention (11% versus 5%, P<0.001). Lead interventionalists participating in multioperator procedures practiced at centers with higher annual HR-PCI volumes (124±71.3 versus 111±69.2; standardized mean difference, 0.197; P<0.001) but otherwise performed a similar number of HR-PCI procedures per year (34.4±35.3 versus 34.7±30.7; standardized mean difference, 0.388; P=0.841) compared with their peers performing single-operator interventions. In a propensity-matched cohort, there was no significant difference in major adverse cardiovascular events (32% versus 30%, P=0.444) between patients who underwent single-operator versus multioperator HR-PCI. Adjusted analyses accounting for site-level variance showed no significant differences in outcomes.

CONCLUSIONS: Patients who underwent multioperator HR-PCI had similar outcomes compared with single-operator procedures. Further studies are needed to determine if the addition of a second operator offers clinical benefits to a subset of HR-PCI patients undergoing left main or chronic total occlusion intervention.

Key Words: high risk ■ multiple operator ■ outcomes research ■ percutaneous coronary intervention

See Editorial by Lee et al.

Correspondence to: Stephen W. Waldo, MD, Rocky Mountain Regional VA Medical Center, CART Program, VHA Office of Quality and Patient Safety, 1700 N Wheeling Street, Suite F2-114, Aurora, CO 80045. E-mail: stephen.waldo@va.gov

Supplementary Material for this article is available at https://www.ahajournals.org/doi/suppl/10.1161/JAHA.121.022131

For Sources of Funding and Disclosures, see page 11.

© 2021 The Authors. Published on behalf of the American Heart Association, Inc., by Wiley. This is an open access article under the terms of the Creative Commons Attribution-NonCommercial-NoDerivs License, which permits use and distribution in any medium, provided the original work is properly cited, the use is non-commercial and no modifications or adaptations are made.

JAHA is available at: www.ahajournals.org/journal/jaha

CLINICAL PERSPECTIVE

What Is New?

- This is the first study to compare the characteristics and outcomes of patients who underwent high-risk percutaneous coronary intervention (HR-PCI) by single or multiple operators in a national, integrated healthcare system.
- Patients undergoing multioperator HR-PCI had similar outcomes compared with single-operator procedures.
- A higher proportion of patients treated by multiple operators underwent left main or chronic total occlusion intervention at centers with higher annual HR-PCI volumes, suggesting selection bias.

What Are the Clinical Implications?

- Randomized studies are needed to determine if the addition of a second operator offers clinical benefits to a subset of HR-PCI patients undergoing left main or chronic total occlusion intervention.
- A more precise definition of HR-PCI is needed to appropriately stratify risk and describe outcomes of HR-PCI.

Nonstandard Abbreviations and Acronyms

CTO	chronic total occlusion
HR-PCI	high-risk percutaneous coronary intervention
MACE	major adverse clinical events
SMD	standardized mean difference
VA	Veterans Affairs

The management of coronary artery disease (CAD) has evolved over time to account for an increasingly medically and anatomically complex patient population.[1–3] Although coronary artery bypass grafting is traditionally associated with improved long-term mortality and reductions in cardiovascular events, contemporary patients with CAD with multiple comorbidities are not well represented in the landmark trials and are increasingly referred for high-risk percutaneous coronary intervention (HR-PCI) after being declined for surgical revascularization.[4–6] Advances in percutaneous coronary intervention (PCI) techniques and the advent of percutaneous mechanical circulatory support have provided new avenues to treat these challenging patients, at the price of increased procedural complexity and cost.[7–13] Although the overall morbidity and complexity of patients referred for percutaneous intervention has increased, there has been a concomitant decrease in PCI volumes, creating a challenge for today's operators. PCI is becoming more and more complex to treat a sicker population, but there is less case volume to support the development of operators' technical skills and experience.[14–16]

As a response to this dilemma, experts have advocated for a collaborative 2-operator approach, as pioneered in structural heart intervention, to provide technical support and augment real-time intraprocedural decision-making for these high-risk cases.[17–20] This team-based approach offers many potential advantages, including discussions of alternative approaches and techniques to achieve procedural success, assistance in operating complex devices, and management of unexpected complications. However, the potential impact of a second operator on clinical outcomes is unknown, and concerns about cost and reimbursement remain.[6] Here, we describe and compare the characteristics and outcomes of patients who underwent HR-PCI performed by a single versus multiple (≥2) operators within the Veterans Affairs (VA) Healthcare System, the largest integrated healthcare system in the United States.

METHODS

The data that support the findings of this study are available from the corresponding author upon reasonable request, though they will be subject to the stringent data privacy rules of the VA Healthcare Systema and US government.

Population

The VA Clinical Assessment Reporting and Tracking Program is a national quality and safety oversight organization for invasive cardiac procedures performed within the VA Healthcare System. As described previously, this mandatory program captures and compiles standardized patient and procedural data elements for invasive cardiac procedures.[21] The data elements surveyed are derived from previously established definitions from the National Cardiovascular Data Registry, and the data set is independently assessed for accuracy and validity on a routine basis.[22,23] This study identified all patients aged ≥18 years who underwent HR-PCI between 2015 and 2018. Prior studies have defined HR-PCI as a combination of patient comorbidities, adverse hemodynamics or depressed left ventricular function, and complex coronary anatomy, yet no formal consensus definition exists. Accordingly, HR-PCI was defined as the presence of at least 1 of the following criteria: (1) medical comorbidities resulting in >1.1% estimated periprocedural mortality by the

National Cardiovascular Data Registry CathPCI mortality model, (2) left ventricular ejection fraction ≤35%, or (3) VA synergy between percutaneous coronary intervention with taxus and cardiac surgery (SYNTAX) score ≥15, as previously published.[3,10,24] A multioperator procedure was defined as the participation of ≥2 attending operators. Patients undergoing PCI for cardiac arrest, ST-segment–elevation myocardial infarction, or other emergent indications were excluded to focus the analysis on cases with a conscious, premeditated decision for multioperator intervention. This analysis was approved by the Colorado Multiple Institutional Review Board with a waiver of informed consent.

Data Collection

Patient characteristics, laboratory studies, procedural details, and outcomes were obtained from the VA electronic health record. Angiographic severity of coronary stenoses was determined by the performing angiographer and recorded as previously described.[23] Mortality was ascertained from the VA Information Resource Center Vital Status File, which includes vital data from the Beneficiary Identification Record Locator Subsystem Death File, VA Medicare Vital Status File, and the Social Security Administration Death Master File. One year of follow-up data for the primary composite outcome was available for all subjects in the cohort.

Statistical Analysis

The cohort was divided into 2 groups based on treatment by a single or multiple (≥2) operators at the time of HR-PCI. Propensity-score matching was used to address differences between these groups. Variables used for matching included demographic information, comorbidities, laboratory studies, procedural indication and degree of urgency, coronary artery bypass grafting eligibility, National Cardiovascular Data Registry CathPCI mortality risk, and VA SYNTAX score. Using these variables for adjustment, a multivariable logistic regression was created to identify the propensity of a patient being treated by single or multiple operators at the time of intervention. The results of this model were used for 2-to-1 matching by a greedy matching algorithm with a caliper of >0.1.[25] Covariate balance of the matched cohort was assessed using standardized mean difference (SMD).[26]

Cox proportional hazards models were used to assess the relationship between treatment by single or multiple operators at the time of HR-PCI and major adverse cardiovascular events (MACE; death, myocardial infarction, repeat revascularization, and stroke) in the matched cohort. The proportional hazards assumption was violated for the outcome of 12-month mortality, and thus, secondary nonproportional hazards analyses using period-specific hazard ratios and a parametric accelerated failure time model were performed.[27,28] Period-specific hazard ratios for increasingly longer periods of follow-up of 0 to 4, 0 to 8, and 0 to 12 months were provided for each outcome. Accelerated failure time models using exponential, Weibull, log-logistic, log-normal, and generalized gamma distributions were compared using Akaike Information Criteria or likelihood ratio tests to identify the most accurate model.[29] For the outcomes of 12-month myocardial infarction and 12-month revascularization, the competing risk of mortality was accounted for by cause-specific Cox proportional hazards models and cause-specific accelerated failure time models. All models were adjusted for unbalanced covariates after matching. An adjusted analysis was performed to assess for the potential influence of clinical site on outcomes. Finally, to explore the potential impact of multioperator HR-PCI on the highest-risk patients, a sensitivity analysis was conducted by restricting the analysis to patients with 2 or more HR-PCI criteria. Data preparation, Cox regression models, and accelerated failure time models were generated using SAS software, version 9.4 (SAS Institute, Cary, NC). Descriptive and graphical analysis was performed with R version 3.5.3 (R Foundation for Statistical Computing, Vienna, Austria). A P value of <0.05 was considered statistically significant.

RESULTS

Patient Characteristics

A total of 6672 patients who underwent HR-PCI were included in the analysis (Figure 1). Of these, 6211 patients (93%) were treated by a single operator, and 461 patients (7%) were treated by multiple operators. Baseline characteristics and medical comorbidities were similar between the 2 subpopulations (Table 1).

Operator and Site Characteristics

Three hundred four operators from 68 clinical sites were included in the analysis. There were significant differences in operator and site characteristics between groups (Table 2). In multioperator procedures, lead operators had more experience (7.8±5.1 versus 4.5±5.9; SMD, 0.601; P<0.001) and higher annual PCI (71.8±66.1 versus 29.8±35.1; SMD, 0.976; P<0.001) and HR-PCI volumes (34.4±35.3 versus 14.2±17.2; SMD, 0.919; P<0.001) compared with junior operators. Lead operators had similar annual HR-PCI volumes (34.4±35.3 versus 34.7±30.7; SMD, 0.388; P=0.841) and fewer years of experience (7.8±5.1 versus 8.9±5.7; SMD, 0.574; P<0.001) compared with single operators. Clinical sites hosting multioperator interventions had significantly higher HR-PCI volumes as compared with

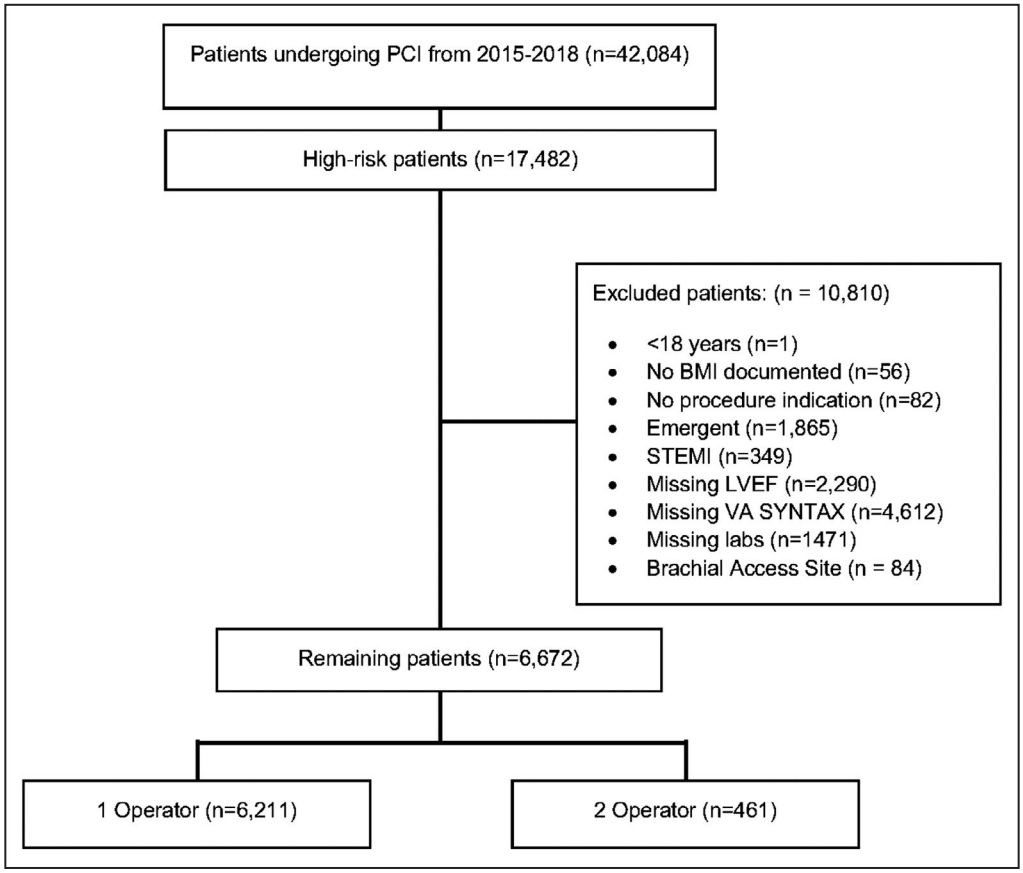

Figure 1. Eligible patient population and exclusion criteria.
BMI indicates body mass index; LVEF, left ventricular ejection fraction; PCI, percutaneous coronary intervention; STEMI, ST-segment–elevation myocardial infarction; and VA SYNTAX, Veterans Affairs SYNTAX score.

single-operator clinical sites (124±71.3 versus 111±69.2; SMD, 0.197; *P*<0.001). The system-wide proportion of HR-PCI procedures performed by multiple operators ranged from 5% to 10% during the study period, and there was a nonsignificant trend of increasing odds of multioperator procedures over time (Table S1).

Procedural Characteristics

Procedural indication and degree of procedural urgency were similar between groups (Table 3). A greater proportion of patients treated by multiple operators underwent left main intervention (10% versus 6%; SMD, 0.144; *P*<0.001), had calcific stenoses (36% versus 27%; SMD, 0.204; *P*<0.001), or chronic total occlusions (CTO) (11% versus 5%; SMD, 0.198; *P*<0.001). Procedures involving multiple arterial access (21% versus 6%; SMD, 0.422; *P*<0.001), intravascular imaging (17% versus 13%; SMD, 0.102; *P*=0.033), or atherectomy (9% versus 5%; SMD, 0.155; *P*<0.001) were more frequently associated with treatment by multiple operators as compared with a single operator. There was no significant difference in the prescription of dual antiplatelet therapy following single-operator or multioperator HR-PCI (94% versus 93%; SMD, 0.066; *P*=0.151).

Propensity Matching

A propensity-matched cohort was developed using 20% of the entire population. A total of 460 patients treated by multiple operators were successfully matched with 920 patients treated by a single operator (Table S2). Matching between groups was balanced, but significant differences in operator experience and operator and site annual HR-PCI volumes persisted (Tables 1 and 2). Intervention upon the left main coronary artery (10% versus 7%; SMD, 0.117; *P*=0.045), CTO interventions (11% versus 5%; SMD, 0.212; *P*<0.001), and calcific stenoses (36% versus 28%; SMD, 0.166; *P*=0.004), as well as the use of atherectomy (9% versus 6%; SMD, 0.138; *P*=0.017) and multiple arterial access (20% versus 7%; SMD, 0.388; *P*<0.001) continued to be more frequently associated with multioperator procedures after matching

Table 1. Baseline Characteristics

	Unmatched				Matched			
	1 operator, n=6211	2+ operators, n=461	SMD	*P* value	1 operator, n=920	2+ operators, n=460	SMD	*P* value
Demographics								
Age, y	70.1±8.9	70.6±8.7	0.055	0.261	70.4±9.1	70.6±8.7	0.022	0.699
Male sex	6135 (99)	457 (99)	0.035	0.649	914 (99)	456 (99)	0.025	0.911
Race/ethnicity								
White	5198 (84)	398 (86)	0.074	0.287	781 (85)	398 (87)	0.047	0.600
Black	901 (15)	58 (13)	0.056		131 (14)	57 (12)	0.054	
Other	112 (2)	5 (1)	0.060		8 (1)	5 (1)	0.022	
Non-Hispanic	5888 (95)	438 (95)	0.010	0.929	882 (96)	437 (95)	0.042	0.547
BMI	30.3±5.9	29.7±6.1	0.088	0.066	29.7±5.8	29.7±6.1	0.006	0.922
Comorbidities								
CVD	1660 (27)	120 (26)	0.016	0.786	239 (26)	120 (26)	0.002	1.00
Prior CVA	887 (14)	62 (13)	0.024	0.671	118 (13)	62 (13)	0.019	0.799
CAD								
1 vessel	1406 (23)	71 (15)	0.185	0.003	129 (14)	71 (15)	0.040	0.847
2 vessels	1916 (31)	145 (31)	0.013		298 (32)	144 (31)	0.023	
3 vessels	2805 (45)	238 (52)	0.120		482 (52)	238 (52)	0.013	
Nonobstructive	84 (1)	7 (2)	0.014		11 (1)	7 (2)	0.028	
Prior MI	3622 (58)	273 (59)	0.018	0.741	561 (61)	273 (59)	0.033	0.599
Prior PCI	3625 (58)	262 (57)	0.031	0.552	542 (59)	262 (57)	0.040	0.524
Prior CABG	2917 (47)	216 (47)	0.002	1.000	447 (49)	216 (47)	0.033	0.607
CHF	3284 (53)	249 (54)	0.023	0.671	464 (50)	248 (54)	0.070	0.245
LVEF	44.4±15.8	43.8±16.8	0.038	0.423	44.9±15.5	43.9±16.8	0.062	0.272
LVEF ≤35%	1609 (26)	125 (27)	0.027	0.606	223 (24)	124 (27)	0.062	0.303
NYHA class								
I	672 (11)	38 (8)	0.088	0.090	78 (8)	38 (8)	0.008	0.948
II	2285 (37)	167 (36)	0.012		348 (38)	167 (36)	0.031	
III	1317 (21)	94 (20)	0.020		191 (21)	94 (20)	0.008	
IV	169 (3)	8 (2)	0.067		13 (1)	8 (2)	0.026	
Unknown	1768 (28)	154 (33)	0.107		290 (32)	153 (33)	0.037	
Valvular disease	920 (15)	88 (19)	0.114	0.016	170 (18)	88 (19)	0.017	0.826
Prior valve surgery	230 (4)	17 (4)	0.001	1.00	32 (3)	17 (4)	0.012	0.959
PAD	2022 (33)	158 (34)	0.036	0.479	321 (35)	158 (34)	0.011	0.889
Hypertension	5942 (96)	444 (96)	0.033	0.590	891 (97)	443 (96)	0.030	0.711
Hyperlipidemia	5884 (95)	430 (93)	0.062	0.217	863 (94)	429 (93)	0.022	0.785
Atrial fibrillation	1402 (23)	115 (25)	0.056	0.265	211 (23)	115 (25)	0.048	0.433
Pulmonary hypertension	64 (1)	5 (1)	0.005	0.812	13 (1)	5 (1)	0.029	0.802
COPD	1978 (32)	143 (31)	0.018	0.752	281 (31)	142 (31)	0.007	0.951
OSA	2105 (34)	144 (31)	0.038	0.266	301 (33)	144 (31)	0.030	0.640
Obesity	2939 (47)	212 (46)	0.027	0.614	404 (44)	212 (46)	0.044	0.479
Diabetes	3798 (61)	278 (60)	0.017	0.757	554 (60)	278 (60)	0.004	0.984
Insulin therapy	1355 (22)	91 (20)	0.051	0.324	185 (20)	91 (20)	0.008	0.943
CKD	2312 (37)	159 (34)	0.057	0.261	332 (36)	159 (35)	0.032	0.691
Hemodialysis	392 (6)	29 (6)	0.001	1.00	71 (8)	29 (6)	0.055	0.398
Anemia	595 (10)	60 (13)	0.109	0.021	129 (14)	60 (13)	0.029	0.678
Tobacco use								

(*Continued*)

Table 1. Continued

	Unmatched				Matched			
	1 operator, n=6211	2+ operators, n=461	SMD	*P* value	1 operator, n=920	2+ operators, n=460	SMD	*P* value
Never	990 (16)	67 (15)	0.038	0.006	134 (15)	67 (15)	<0.001	0.329
Current	1529 (25)	93 (20)	<0.001		215 (23)	92 (20)	<0.001	
Former	2363 (38)	172 (37)	0.015		349 (38)	172 (37)	0.011	
Unknown	1331 (21)	129 (28)	0.152		222 (24)	129 (28)	0.089	
Alcohol use	243 (4)	15 (3)	0.035	0.560	26 (3)	14 (3)	0.013	0.955
Substance use	283 (5)	15 (3)	0.067	0.234	24 (3)	15 (3)	0.039	0.605
Laboratory values								
Creatinine	2.83±14.7	1.73±5.47	0.100	0.108	1.69±2.84	1.73±5.48	0.008	0.869
GFR	67.6±27.2	68.1±27.4	0.010	0.684	67.6±28.0	68.1±27.4	0.016	0.778
Hemoglobin	12.9±2.1	12.7±2.1	0.085	0.075	12.6±2.2	12.7±2.1	0.043	0.454
INR	1.12±0.36	1.16±0.45	0.079	0.067	1.14±0.47	1.16±0.45	0.027	0.636

Numbers are presented as n (%) or mean±SD with standardized mean difference (SMD) and *P* values. BMI indicates body mass index; CABG, coronary artery bypass graft; CAD, coronary artery disease; CHF, congestive heart failure; CKD, chronic kidney disease; COPD, chronic obstructive pulmonary disease; CVA, cerebrovascular accident; CVD, cerebrovascular disease; GFR, glomerular filtration rate; INR, international normalized ratio; LVEF, left ventricular ejection fraction; MI, myocardial infarction; NYHA, New York Heart Association; OSA, obstructive sleep apnea; PAD, peripheral artery disease; and PCI, percutaneous coronary intervention.

The participants self-identified as Other.

(Table 3). Radiation exposure was significantly higher in patients treated by 2 or more operators (61.6±96.3 versus 31.7±49.3 mGy cm^2; SMD, 0.391; *P*=0.004), but there were no significant differences in contrast use (116±83.4 versus 109±90 mL; SMD, 0.107; *P*=0.191) or procedural time (24±83.9 versus 31.2±106 minutes; SMD, 0.076; *P*=0.2).

Outcomes

In the propensity-matched analysis, there was no significant difference in MACE (32% versus 30%; SMD, 0.047; *P*=0.444) or their components between multioperator and single operator HR-PCI at 12 months (Figure 2, Table 4). There were no significant differences in acute kidney injury (6% versus 5%; SMD, 0.37; *P*=0.594), hospital length of stay (2.70±4.58 versus 2.41±5.16 days; SMD, 0.043; *P*=0.307), or 30-day readmission (28% versus 25%; SMD, 0.061; *P*=0.298) between multioperator and single-operator procedures. The proportional hazards assumption was violated for the outcome of 12-month mortality (Figure S1). Period-specific Cox proportional hazards models showed no significant difference in MACE or their components at 4, 8, or 12 months (Table 5). Accelerated failure time models for 12-month MACE and their components showed no differences between multioperator and single-operator procedures (Table S3). There were no interactions between outcomes and procedural duration by period-specific Cox proportional hazards or accelerated failure time models (Tables S4 and S5). No significant differences in outcomes were observed in adjusted analyses performed to account for variation by clinical site (Table S6).

Table 2. Operator and Site Characteristics

	1 operator, n=6211	2+ operators, n=461	SMD	*P* value	1 operator, n=920	2+ operators, n=460	SMD	*P* value
Operator								
Annual PCI	74.2±58.5	50.8±37.9	0.468	<0.001	76.3±61.1	50.8±35	0.509	<0.001
Annual HR-PCI	34.7±30.7	24.2±20.9	0.388	<0.001	35.7±31.8	24.3±20.9	0.415	<0.001
Experience, y	8.9±5.7	6.2±3.6	0.574	<0.001	8.9±5.7	6.2±3.6	0.565	<0.001
Site								
Annual PCI	240±119	267±131	0.216	<0.001	246±125	267±131	0.162	0.004
Annual HR-PCI	111±69.2	124±71.3	0.197	<0.001	113±70.2	125±71.4	0.159	0.005

Numbers are presented as mean±SD with standardized mean difference (SMD) and *P* values. Operator experience for 2+ operator procedures is presented as the mean of the participants. HR indicates high-risk; and PCI, percutaneous coronary intervention.

Table 3. Procedural Indications, Anatomic Characteristics, and Intervention Details

	Unmatched				Matched			
	1 operator, n=6211	2+ operators, n=461	SMD	*P* value	1 operator, n=920	2+ operators, n=460	SMD	*P* value
Indication								
Stable angina	1721 (28)	140 (30)	0.018	0.349	281 (31)	140 (30)	<0.001	0.750
Unstable angina	1468 (24)	115 (25)	0.018		226 (25)	115 (25)	<0.001	
NSTEMI	1927 (31)	125 (27)	0.086		262 (28)	125 (27)	0.029	
Other	1065 (17)	81 (18)	0.020		170 (19)	80 (17)	0.030	
Urgency								
Elective	3660 (59)	276 (60)	0.019	0.050	563 (61)	275 (60)	0.029	0.23
Urgent	2543 (41)	182 (39)	0.030		335 (39)	182 (40)	0.020	
Salvage	8 (0)	3 (1)	0.083		2 (0)	3 (1)	0.066	
CABG eligible	37 (1)	3 (1)	0.007	0.754	4 (0)	3 (1)	0.030	0.692
NCDR CathPCI risk score	22.8 (11.0)	23.4 (12.2)	0.056	0.222	23.1 (11.6)	23.4 (12.3)	0.025	0.664
Anatomy								
VA SYNTAX score	19.9±11.4	20.9±10.4	0.087	0.082	21.1±10.9	20.9±10.4	0.016	0.783
Multivessel CAD	4911 (79)	372 (81)	0.041	0.442	750 (82)	371 (81)	0.076	0.662
Left main disease	982 (16)	87 (19)	0.081	0.096	150 (16)	86 (19)	0.062	0.312
In-stent restenosis	801 (13)	52 (11)	0.049	0.357	110 (12)	52 (11)	0.020	0.790
Calcification	1653 (27)	166 (36)	0.204	<0.001	261 (28)	166 (36)	0.166	0.004
Bifurcation	789 (13)	70 (16)	0.072	0.144	116 (13)	70 (15)	0.075	0.210
CTO	329 (5)	49 (11)	0.198	<0.001	46 (5)	49 (11)	0.212	<0.001
SVG disease	788 (13)	54 (12)	0.030	0.593	132 (14)	54 (12)	0.078	0.210
PCI details								
Primary access								
Radial	2078 (33)	143 (31)	0.054	0.294	291 (32)	142 (31)	0.017	0.811
Femoral	4054 (65)	313 (68)	0.054		618 (67)	313 (68)	0.017	
Multiple access	393 (6)	94 (21)	0.422	<0.001	67 (7)	94 (20)	0.388	<0.001
Vessels treated								
LM	377 (6)	46 (10)	0.144	0.001	62 (7)	46 (10)	0.117	0.045
LAD	2435 (39)	189 (41)	0.037	0.477	355 (39)	189 (41)	0.048	0.429
LCx	1900 (31)	162 (35)	0.097	0.047	280 (31)	162 (35)	0.100	0.090
RI	209 (3)	15 (3)	0.006	1.000	30 (3)	15 (3)	0.001	1.000
RCA	1710 (28)	113 (25)	0.069	0.177	254 (28)	113 (25)	0.071	0.240
No. of vessels treated	1.56±0.839	1.66±0.912		0.010	1.59±0.848	1.66±0.913	0.086	0.126
No. of stents placed	1.57±1.07	1.87±1.37	0.239	<0.001	1.58±1.12	1.87±1.37	0.228	<0.001

(*Continued*)

Table 3. Continued

	Unmatched				Matched			
	1 operator, n=6211	2+ operators, n=461	SMD	*P* value	1 operator, n=920	2+ operators, n=460	SMD	*P* value
Stent length	23.5±41.3	24.4±8.69	0.031	0.643	23.3±15.3	24.4±8.70	0.087	0.175
FFR/iFR use	498 (8)	27 (6)	0.085	0.116	60 (7)	27 (6)	0.027	0.725
IVUS/OCT use	837 (13)	79 (17)	0.102	0.033	126 (14)	79 (17)	0.096	0.103
Atherectomy	319 (5)	42 (9)	0.155	<0.001	51 (6)	42 (9)	0.138	0.017
MCS use	73 (1)	10 (2)	0.078	0.101	20 (2)	10 (2)	<0.001	1.00
Contrast, mL	155±139	164±130	0.106	0.172	109±90.3	116±83.4	0.107	0.191
Radiation								
mGy cm^2	43.8±79.3	61.6±96.3	0.202	0.055	31.7±49.3	61.6±96.3	0.391	0.004
Air kerma, mGy	1790±3340	2310±1780	0.193	0.275	1600±1390	2310±1780	0.443	0.014
Duration, min	36.9±123	23.9±83.8	0.123	0.026	31.2±106	24.0±83.9	0.076	0.200
DAPT	5866 (94)	428 (93)	0.066<	0.151	854 (90)	427 (93)	<0.001	1.000

Numbers are presented as n (%) or mean±SD with standardized mean difference (SMD) and *P* values. CABG indicates coronary artery bypass graft; CAD, coronary artery disease; CTO, chronic total occlusion; DAPT, dual antiplatelet therapy; FFR, fractional flow reserve; iFR, instantaneous wave-free ratio; IVUS, intravascular ultrasound; LAD, left anterior descending; LCx, left circumflex; LM, left main; MCS, mechanical circulatory support; NCDR, National Cardiovascular Data Registry; NSTEMI, non–ST-segment–elevation myocardial infarction; OCT, optical coherence tomography; PCI, percutaneous coronary intervention; RCA, right coronary artery; RI, ramus intermedius; SVG, saphenous vein graft; and VA, Veterans Affairs.

Sensitivity Analysis

A sensitivity analysis restricted to patients who had 2 or more high-risk criteria was performed, whereby 148 patients who underwent multioperator HR-PCI were successfully matched with 296 patients who underwent a single-operator procedure (Table S7). Baseline and procedural characteristics are listed in Table S8. Compared with the primary analysis, this subgroup had higher mean National Cardiovascular Data Registry mortality risk (30±12 versus 23±12) and VA SYNTAX scores (23±10 versus 21±11), and a greater proportion of patients had left ventricular ejection fraction ≤35% (57% versus 28%). Rates of left main (11% versus 8%) and CTO interventions (9% versus 7%) and the use of intravascular imaging (18% versus 15%), atherectomy (7% versus 7%), and mechanical circulatory support (4% versus 2%) were similar between the sensitivity cohort and the primary cohort. Within this subgroup, no significant difference in MACE or their components at 4, 8, or 12 months was observed after adjusting for VA SYNTAX score, 3-vessel CAD, 2-vessel CAD, tobacco use, substance use, and depression (Table 6, Figure S2). Additionally, there were no significant differences in acute kidney injury (12% versus 6%; SMD, 0.12; *P*=0.281), hospital length of stay (2.02±6.35 versus 2.38±5.91 days; SMD, 0.104; *P*=0.296), or 30-day readmission (32% versus 26%; SMD, 0.135; *P*=0.216) between multioperator and single-operator procedures within this subgroup.

DISCUSSION

Here, we report the first study to compare the characteristics and outcomes of patients who underwent HR-PCI by single or multiple operators in a national, integrated healthcare system. In a propensity-matched analysis, we found no significant differences in MACE or their components between the single or multiple operator groups at 4, 8, or 12 months. No significant differences in postprocedural acute kidney injury, hospital length of stay, or 30-day readmission between groups was observed. The results of a sensitivity analysis restricted to patients with multiple high-risk criteria were unchanged.

Contemporary CAD patients with multiple comorbidities and complex anatomy referred for HR-PCI using advanced PCI adjuncts represent a unique challenge for interventional cardiologists.[2,3,6] The demands imposed by complex procedural tasks, such as HR-PCI, may strain the cognitive and technical capacity of operators, leading to conditions that may negatively impact procedural safety and increase the risk of patient harm.[30–33] Experts at high-volume HR-PCI centers have advocated for a 2-operator approach to support dynamic intraprocedural decision-making and early recognition and management of complications

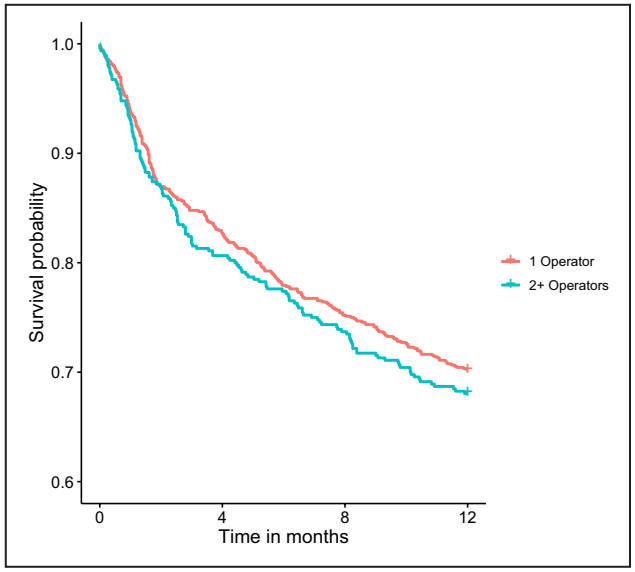

Figure 2. Kaplan-Meier analysis of major adverse cardiac events in the matched cohort.

during these high-risk procedures to avoid negative patient outcomes and reduce costs.[17,18,34,35] Patients included in this analysis were representative of contemporary patients with CAD referred for HR-PCI; they had significant medical comorbidities, complex coronary anatomy as reflected by high VA SYNTAX scores, and prevalence of prior coronary artery bypass grafting, and a substantial proportion had left ventricular ejection fraction ≤35%. The analysis observed a trend toward increased multioperator HR-PCI over time, and found that a significantly higher proportion of patients treated by multiple operators underwent left main intervention, CTO intervention, or had calcific stenoses. Notably, interventionalists participating in multioperator procedures worked at centers with higher annual PCI and HR-PCI volumes compared with their peers performing single-operator interventions. However, an adjusted analysis accounting for site-level variance showed no significant differences in outcomes.

There are several potential explanations for the lack of observed benefit for multioperator HR-PCI in this analysis. First, although the definition of HR-PCI has not been formally defined, the patients included in our study had significant medical comorbidities, left ventricular systolic dysfunction, and/or anatomically complex disease that correlated with a 28% incidence of MACE and an 11% mortality rate over 12 months of follow-up.[6] However, the rates of left main intervention, CTO intervention, and use of intravascular imaging, atherectomy, and/or mechanical circulatory support in this study were relatively low. Thus, it could be argued that the analyzed cohort is not representative of the patients treated by high-volume HR-PCI programs advocating for multioperator intervention.[17,36] Second, patients who underwent multioperator HR-PCI in the propensity-matched cohort had higher rates of left main intervention, CTO intervention, calcific disease, and use of atherectomy and multiple arterial access compared with single-operator procedures, and there was a trend toward increased multioperator procedures over time. These observations suggest a selection bias for a multioperator treatment paradigm based on these factors, which may have contributed to different baseline risk of MACE between the analyzed cohorts that was not captured by this analysis. Third, the rates of left main and CTO intervention have increased over time.[37,38] Recent studies have shown that a hybrid antegrade/retrograde approach to CTO intervention, a mainstay of HR-PCI operators, can be successfully adopted by a single operator with excellent early procedural success despite a lack of prior CTO-PCI experience.[39,40] Moreover, studies of operator volumes and long-term outcomes in the United Kingdom have shown conflicting results for HR-PCI overall as compared with a smaller subset of left main intervention procedures.[41,42] Physicians performing HR-PCI in this study had an average of 9 years of experience after fellowship, and although interventionalists using a multioperator strategy worked at centers with higher annual HR-PCI volumes, lead operators performed a similar number of HR-PCI procedures per year compared with their single-operator peers. These observations suggest that operators in this study may

Table 4. Clinical Outcomes at 12 Months

	Unmatched				Matched			
	1 operator, n=6211	2+ operators, n=461	SMD	*P* value	1 operator, n=920	2+ operators, n=460	SMD	*P* value
MACE	1716 (28)	147 (32)	0.093	0.056	274 (30)	147 (32)	0.047	0.444
Death	682 (11)	59 (13)	0.056	0.262	105 (11)	59 (13)	0.043	0.499
MI	373 (6)	19 (4)	0.095	0.119	58 (6)	19 (4)	0.036	0.125
Revascularization	963 (16)	88 (19)	0.086	0.049	163 (18)	88 (19)	0.098	0.570
Stroke	51 (1)	4 (1)	0.005	0.790	3 (0)	4 (1)	0.071	0.231

Numbers are presented as n (%) with standardized mean difference (SMD) and *P* values. MACE indicates major adverse cardiovascular events; and MI, myocardial infarction.

Table 5. Cox Proportional Hazards Analysis of Outcomes in the Propensity-Matched Cohort

	0–4 mo			0–8 mo			0–12 mo		
	1 OP	2+ OP	HR (95% CI)	1 OP	2+ OP	HR (95% CI)	1 OP	2+ OP	HR (95% CI)
MACE	157	89	1.15 (0.89–1.40)	226	121	1.09 (0.87–1.34)	274	147	1.09 (0.90–1.34)
Death	53	27	1.03 (0.65–1.63)	83	42	1.02 (0.70–1.48)	105	59	1.13 (0.82–1.56)
MI	22	8	0.73 (0.33–1.64)	39	16	0.82 (0.46–1.47)	58	19	0.66 (0.39–1.10)
Revascularization	98	60	1.25 (0.91–1.73)	137	79	1.18 (0.89–1.55)	163	88	1.11 (0.85–1.43)
Stroke	1	0	…	3	2	…	3	4	…

HR indicates hazard ratio; MACE, major adverse cardiovascular events; MI, myocardial infarction; and OP, operator.

have developed a substantial body of experience with complex PCI, potentially negating the benefits of a second operator.[15] Lastly, lead interventionalists in multioperator procedures had significantly more experience and higher volumes compared with junior operators, suggesting that in some cases a multioperator approach may have been chosen to support the development of a junior operator's technical skills and experience rather than to meet the procedural challenges presented by the patient.

These results do not support the routine use of multiple operators for HR-PCI as defined in the present study. However, this analysis does not address whether the addition of a second operator improves procedural outcomes for patients undergoing procedures in the highest stratum of complexity such as coronary atherectomy, left main intervention, and CTO-PCI with mechanical circulatory support. Multioperator HR-PCI may also offer benefits for the operators, such as reduced cognitive burden and intraprocedural stress, which are not readily quantifiable. The finding that patients with the highest complexity of disease underwent multioperator intervention at sites with higher clinical volumes suggests that interventionalists at lower volume centers may select a lower risk subset within the overall population of HR-PCI and refer their most complex patients to more experienced centers. These findings underscore a growing sentiment that HR-PCI may be defined too broadly in current practice and that a more precise definition is needed to appropriately stratify risk and describe outcomes in this uniquely challenging patient population.[41]

The results must be interpreted in the context of the study's limitations. This study benefits from its large size and detailed patient data derived from a nationally integrated medical system. However, this study depends on accurate data entry by treating physicians across the VA Healthcare System. In cases of improper or inadequate documentation, the fidelity of the analysis may be compromised. The possibility of residual or unmeasured confounding is inherent to the study's observational design. Robust statistical methodologies, including propensity matching, were used to limit these potential influences. However, after matching, there were significant differences in the complexity of interventions performed and the use of PCI adjuncts between groups that may have impacted the observed results. Although this analysis reflects the largest comparison of multioperator and single-operator HR-PCI to date, the study is limited by moderate sample size and may not be powered to detect small, yet clinically relevant, differences between the 2 treatment strategies. Some secondary outcomes, such as myocardial infarction and stroke, occurred infrequently and were not amenable to statistical analysis. Significant variation in institutional HR-PCI volumes could explain discrepancies in clinical outcomes, but a site-adjusted secondary analysis was consistent with our primary results. This study cannot comment on the potential impact of a second operator in emergent procedures or ST-segment–elevation myocardial infarction, which were

Table 6. Cox Proportional Hazards Analysis of Outcomes in the Propensity-Matched Cohort Restricted to Patients With Multiple High-Risk Criteria (Sensitivity Analysis)

	0–4 mo			0–8 mo			0–12 mo		
	1 OP	2+ OP	HR (95% CI)	1 OP	2+ OP	HR (95% CI)	1 OP	2+ OP	HR (95% CI)
MACE	69	33	0.94 (0.62–1.42)	100	45	0.90 (0.63–1.28)	114	53	0.93 (0.67–1.28)
Death	36	10	0.54 (0.27–1.09)	56	17	1.03 (1.01–1.06)	65	26	1.03 (1.01–1.06)
MI	8	5	…	15	8	…	21	9	…
Revascularization	29	21	1.41 (0.80–2.48)	39	26	1.34 (0.81–2.21)	46	26	1.13 (0.70–1.84)
Stroke	2	0	…	3	2	…	3	2	…

HR indicates hazard ratio; MACE, major adverse cardiovascular events; MI, myocardial infarction; and OP, operator.

intentionally excluded to focus the analysis on a premeditated decision for multiple operators. Moreover, it is possible that some procedures included in this study were performed ad hoc by a single operator despite a preference for multioperator intervention in settings where a second interventionalist was not available, but we suspect this to be a rare circumstance that would not significantly influence the results. There were no differences in the prescription of dual antiplatelet therapy following HR-PCI, but we did not incorporate data on other postprocedure therapies, and thus, unmeasured differences in the quality of follow-up medical care may have impacted the results. Finally, this analysis is limited to the VA Healthcare System and may not be representative of other centers' clinical volumes or expertise.

CONCLUSIONS

Patients who underwent multioperator HR-PCI had similar outcomes compared with single-operator procedures. There was a nonsignificant trend toward increased multioperator procedures over time, and a higher proportion of patients treated by multiple operators underwent left main or chronic total occlusion intervention by interventionalists at centers with higher annual HR-PCI volumes compared with their peers. The analysis may have been limited by residual confounding, and thus, randomized studies are needed to determine if the addition of a second operator offers clinical benefits to a subset of HR-PCI patients undergoing left main or chronic total occlusion intervention.

ARTICLE INFORMATION

Received April 19, 2021; accepted July 26, 2021.

Affiliations

Division of Cardiology, Department of Medicine (C.P.K., A.S., J.A.V., S.W.W.) and Department of Biostatistics and Informatics (A.H., A.E.B.), University of Colorado, Aurora, CO; CART Program, Office of Quality and Patient Safety, Veterans Health Administration, Washington, DC (A.H., M.E.P., S.W.W.); and Department of Medicine, Michigan Heart and Vascular Institute, Ann Arbor, MI (J.A.V.).

Sources of Funding

None.

Disclosures

The views expressed in this article are those of the authors and do not necessarily reflect the position or policy of the Department of Veterans Affairs or the US government. Dr Waldo has received grants from the National Institutes of Health and VA Health Services Research and investigator-initiated research support to the Denver Research Institute from Abiomed, Cardiovascular Systems Incorporated, and Janssen Pharmaceuticals; and serves as the National Director of the VA Clinical Assessment, Reporting, and Tracking Program, the national quality and safety oversight organization for invasive cardiac procedures within the VA Healthcare System. Dr Valle has received unrelated consulting fees from Philips Medical, Medtronic, and Cardiovascular Systems Incorporated. Dr Barón has received grants from VA Health Services Research. The remaining authors have no disclosures to report.

Supplementary Material

Tables S1–S8
Figures S1–S2

REFERENCES

1. Huang HW, Brent BN, Shaw RE. Trends in percutaneous versus surgical revascularization of unprotected left main coronary stenosis in the drug-eluting stent era: a report from the American College of Cardiology-National Cardiovascular Data Registry (ACC-NCDR). *Catheter Cardiovasc Interv*. 2006;68:867–872. doi: 10.1002/ccd.20886
2. Waldo SW, Gokhale M, O'Donnell CI, Plomondon ME, Valle JA, Armstrong EJ, Schofield R, Fihn SD, Maddox TM. Temporal trends in coronary angiography and percutaneous coronary intervention: insights from the VA clinical assessment, reporting, and tracking program. *JACC Cardiovasc Interv*. 2018;11:879–888. doi: 10.1016/j.jcin.2018.02.035
3. Valle JA, Glorioso TJ, Bricker R, Barón AE, Armstrong EJ, Bhatt DL, Rao SV, Plomondon ME, Serruys PW, Keppetein AP, et al. Association of coronary anatomical complexity with clinical outcomes after percutaneous or surgical revascularization in the veterans affairs clinical assessment reporting and tracking program. *JAMA Cardiol*. 2019;4:727–735. doi: 10.1001/jamacardio.2019.1923
4. Garcia S, Sandoval Y, Roukoz H, Adabag S, Canoniero M, Yannopoulos D, Brilakis ES. Outcomes after complete versus incomplete revascularization of patients with multivessel coronary artery disease: a meta-analysis of 89,883 patients enrolled in randomized clinical trials and observational studies. *J Am Coll Cardiol*. 2013;62:1421–1431. doi: 10.1016/j.jacc.2013.05.033
5. Waldo SW, Secemsky EA, O'Brien C, Kennedy KF, Pomerantsev E, Sundt TM III, McNulty EJ, Scirica BM, Yeh RW. Surgical ineligibility and mortality among patients with unprotected left main or multivessel coronary artery disease undergoing percutaneous coronary intervention. *Circulation*. 2014;130:2295–2301. doi: 10.1161/CIRCULATIONAHA.114.011541
6. Kirtane AJ, Doshi D, Leon MB, Lasala JM, Ohman EM, O'Neill WW, Shroff A, Cohen MG, Palacios IF, Beohar N, et al. Treatment of higher-risk patients with an indication for revascularization: evolution within the field of contemporary percutaneous coronary intervention. *Circulation*. 2016;134:422–431. doi: 10.1161/CIRCULATIONAHA.116.022061
7. Riley RF, Henry TD, Mahmud E, Kirtane AJ, Brilakis ES, Goyal A, Grines CL, Lombardi WL, Maran A, Rab T, et al. SCAI position statement on optimal percutaneous coronary interventional therapy for complex coronary artery disease. *Catheter Cardiovasc Interv*. 2020;96:346–362. doi: 10.1002/ccd.28994
8. van Nunen LX, Zimmermann FM, Tonino PAL, Barbato E, Baumbach A, Engstrøm T, Klauss V, MacCarthy PA, Manoharan G, Oldroyd KG, et al. Fractional flow reserve versus angiography for guidance of PCI in patients with multivessel coronary artery disease (FAME): 5-year follow-up of a randomised controlled trial. *Lancet*. 2015;386:1853–1860. doi: 10.1016/S0140-6736(15)00057-4
9. Riley RF, McCabe JM, Kalra S, Lazkani M, Pershad A, Doshi D, Kirtane AJ, Nicholson W, Kearney K, Demartini T, et al. Impella-assisted chronic total occlusion percutaneous coronary interventions: a multicenter retrospective analysis. *Catheter Cardiovasc Interv*. 2018;92:1261–1267. doi: 10.1002/ccd.27679
10. Bricker RS, Glorioso TJ, Jawaid O, Plomondon ME, Valle JA, Armstrong EJ, Waldo SW. Temporal trends and site variation in high-risk coronary intervention and the use of mechanical circulatory support: insights from the Veterans Affairs clinical assessment reporting and tracking (CART) program. *J Am Heart Assoc*. 2019;8:e014906. doi: 10.1161/JAHA.119.014906
11. Barrett C, Warsavage T, Kovach C, McGuinn E, Plomondon ME, Armstrong EJ, Waldo SW. Comparison of rotational and orbital atherectomy for the treatment of calcific coronary lesions: insights from the VA clinical assessment reporting and tracking (CART) program. *Catheter Cardiovasc Interv*. 2021;97:E219–E226. doi: 10.1002/ccd.28971
12. Gada H, Whitlow PL, Marwick TH. Establishing the cost-effectiveness of percutaneous coronary intervention for chronic total occlusion in

stable angina: a decision-analytic model. *Heart*. 2012;98:1790–1797. doi: 10.1136/heartjnl-2012-302581
13. Fearon WF, Shilane D, Pijls NH, Boothroyd DB, Tonino PA, Barbato E, Jüni P, De Bruyne B, Hlatky MA. Cost-effectiveness of percutaneous coronary intervention in patients with stable coronary artery disease and abnormal fractional flow reserve. *Circulation*. 2013;128:1335–1340. doi: 10.1161/CIRCULATIONAHA.113.003059
14. Fanaroff AC, Zakroysky P, Dai D, Wojdyla D, Sherwood MW, Roe MT, Wang TY, Peterson ED, Gurm HS, Cohen MG, et al. Outcomes of PCI in relation to procedural characteristics and operator volumes in the United States. *J Am Coll Cardiol*. 2017;69:2913–2924. doi: 10.1016/j.jacc.2017.04.032
15. Fanaroff AC, Zakroysky P, Wojdyla D, Kaltenbach LA, Sherwood MW, Roe MT, Wang TY, Peterson ED, Gurm HS, Cohen MG, et al. Relationship between operator volume and long-term outcomes after percutaneous coronary intervention. *Circulation*. 2019;139:458–472. doi: 10.1161/CIRCULATIONAHA.117.033325
16. Virani SS, Alonso A, Benjamin EJ, Bittencourt MS, Callaway CW, Carson AP, Chamberlain AM, Chang AR, Cheng S, Delling FN, et al. Heart disease and stroke statistics-2020 update: a report from the American Heart Association. *Circulation*. 2020;141:e139–e596. doi: 10.1161/CIR.0000000000000757
17. Karmpaliotis D, Lembo N, Kalynych A, Carlson H, Lombardi WL, Anderson CN, Rinehart S, Kirkland B, Shemwell KC, Kandzari DE. Development of a high-volume, multiple-operator program for percutaneous chronic total coronary occlusion revascularization: procedural, clinical, and cost-utilization outcomes. *Catheter Cardiovasc Interv*. 2013;82:1–8. doi: 10.1002/ccd.24387
18. Riley RF. Complex, higher-risk, and indicated PCI (CHIP) fellowship: putting training into practice. *J Am Coll Cardiol*. 2020;75:980–984. doi: 10.1016/j.jacc.2020.01.025
19. Bavaria JE, Prager RL, Naunheim KS, Allen MS, Higgins RSD, Thourani VH, MacGillivray TE, Boden N, Sabik JF III. Surgeon involvement in transcatheter aortic valve replacement in the United States: a 2016 Society of Thoracic Surgeons Survey. *Ann Thorac Surg*. 2017;104:1088–1093. doi: 10.1016/j.athoracsur.2017.03.055
20. Kirtane AJ. RESPONSE: CHIP training: thinking beyond the numbers. *J Am Coll Cardiol*. 2020;75:983–984. doi: 10.1016/j.jacc.2020.01.026
21. Maddox TM, Plomondon ME, Petrich M, Tsai TT, Gethoffer H, Noonan G, Gillespie B, Box T, Fihn SD, Jesse RL, et al. A national clinical quality program for Veterans Affairs catheterization laboratories (from the Veterans Affairs clinical assessment, reporting, and tracking program). *Am J Cardiol*. 2014;114:1750–1757. doi: 10.1016/j.amjcard.2014.08.045
22. Brindis RG, Fitzgerald S, Anderson HV, Shaw RE, Weintraub WS, Williams JF. The American College of Cardiology-National Cardiovascular Data Registry (ACC-NCDR): building a national clinical data repository. *J Am Coll Cardiol*. 2001;37:2240–2245. doi: 10.1016/S0735-1097(01)01372-9
23. Byrd JB, Vigen R, Plomondon ME, Rumsfeld JS, Box TL, Fihn SD, Maddox TM. Data quality of an electronic health record tool to support VA cardiac catheterization laboratory quality improvement: the VA clinical assessment, reporting, and tracking system for cath labs (CART) program. *Am Heart J*. 2013;165:434–440. doi: 10.1016/j.ahj.2012.12.009
24. Peterson ED, Dai D, DeLong ER, Brennan JM, Singh M, Rao SV, Shaw RE, Roe MT, Ho KKL, Klein LW, et al. Contemporary mortality risk prediction for percutaneous coronary intervention: results from 588,398 procedures in the National Cardiovascular Data Registry. *J Am Coll Cardiol*. 2010;55:1923–1932. doi: 10.1016/j.jacc.2010.02.005
25. Rosenbaum PR. Overt bias in observational studies. *Observational Studies: Springer Series in Statistics*. Springer; 2002:71–104. doi: 10.1007/978-1-4757-3692-2_3
26. Greenland S, Rothman KJ, Lash TL. Measures of effect and measures of association. In: Rothman KJ, Greenland S, Lash TL, eds. *Modern Epidemiology*. Lippincott Williams & Wilkins; 2008:51–70.
27. Gregson J, Sharples L, Stone GW, Burman CF, Öhrn F, Pocock S. Nonproportional hazards for time-to-event outcomes in clinical trials: JACC review topic of the week. *J Am Coll Cardiol*. 2019;74:2102–2112. doi: 10.1016/j.jacc.2019.08.1034
28. Hernán MA. The hazards of hazard ratios. *Epidemiology*. 2010;21:13–15. doi: 10.1097/EDE.0b013e3181c1ea43
29. Moghimi-Dehkordi B, Safaee A, Pourhoseingholi MA, Fatemi R, Tabeie Z, Zali MR. Statistical comparison of survival models for analysis of cancer data. *Asian Pac J Cancer Prev*. 2008;9:417–420.
30. Shappell S, Detwiler C, Holcomb K, Hackworth C, Boquet A, Wiegmann DA. Human error and commercial aviation accidents: an analysis using the human factors analysis and classification system. *Hum Factors*. 2007;49:227–242. doi: 10.1518/001872007X312469
31. Chrouser KL, Xu J, Hallbeck S, Weinger MB, Partin MR. The influence of stress responses on surgical performance and outcomes: literature review and the development of the surgical stress effects (SSE) framework. *Am J Surg*. 2018;216:573–584. doi: 10.1016/j.amjsurg.2018.02.017
32. Merkle F, Kurtovic D, Starck C, Pawelke C, Gierig S, Falk V. Evaluation of attention, perception, and stress levels of clinical cardiovascular perfusionists during cardiac operations: a pilot study. *Perfusion*. 2019;34:544–551. doi: 10.1177/0267659119828563
33. Suliburk JW, Buck QM, Pirko CJ, Massarweh NN, Barshes NR, Singh H, Rosengart TK. Analysis of human performance deficiencies associated with surgical adverse events. *JAMA Netw Open*. 2019;2:e198067. doi: 10.1001/jamanetworkopen.2019.8067
34. Doll JA, Hira RS, Kearney KE, Kandzari DE, Riley RF, Marso SP, Grantham JA, Thompson CA, McCabe JM, Karmpaliotis D, et al. Management of percutaneous coronary intervention complications: algorithms from the 2018 and 2019 Seattle percutaneous coronary intervention complications conference. *Circ Cardiovasc Interv*. 2020;13:e008962. doi: 10.1161/CIRCINTERVENTIONS.120.008962
35. Salisbury AC, Karmpaliotis D, Grantham JA, Sapontis J, Meng Q, Magnuson EA, Gada H, Lombardi W, Moses J, Li H, et al. In-hospital costs and costs of complications of chronic total occlusion angioplasty: insights from the OPEN-CTO registry. *JACC Cardiovasc Interv*. 2019;12:323–331. doi: 10.1016/j.jcin.2018.10.025
36. Konstantinidis NV, Werner GS, Deftereos S, Di Mario C, Galassi AR, Buettner JH, Avran A, Reifart N, Goktekin O, Garbo R, et al. Temporal trends in chronic total occlusion interventions in Europe. *Circ Cardiovasc Interv*. 2018;11:e006229. doi: 10.1161/CIRCINTERVENTIONS.117.006229
37. Valle JA, Tamez H, Abbott JD, Moussa ID, Messenger JC, Waldo SW, Kennedy KF, Masoudi FA, Yeh RW. Contemporary use and trends in unprotected left main coronary artery percutaneous coronary intervention in the United States: an analysis of the National Cardiovascular Data Registry Research to Practice Initiative. *JAMA Cardiol*. 2019;4:100–109. doi: 10.1001/jamacardio.2018.4376
38. Othman H, Seth M, Zein R, Rosman H, Lalonde T, Yamasaki H, Alaswad K, Menees D, Mehta RH, Gurm H, et al. Percutaneous coronary intervention for chronic total occlusion-the Michigan experience: insights from the BMC2 registry. *JACC Cardiovasc Interv*. 2020;13:1357–1368. doi: 10.1016/j.jcin.2020.02.025
39. Vo MN, McCabe JM, Lombardi WL, Ducas J, Ravandi A, Brilakis ES. Adoption of the hybrid CTO approach by a single non-CTO operator: procedural and clinical outcomes. *J Invasive Cardiol*. 2015;27:139–144.
40. Shammas NW, Shammas GA, Robken J, Harris T, Madison A, Dinklenburg C, Shammas AN, Harb C, Jerin M. The learning curve in treating coronary chronic total occlusion early in the experience of an operator at a tertiary medical center: the role of the hybrid approach. *Cardiovasc Revasc Med*. 2016;17:15–18. doi: 10.1016/j.carrev.2015.09.004
41. Kinnaird T, Gallagher S, Spratt JC, Ludman P, de Belder M, Copt S, Anderson R, Walsh S, Hanratty C, Curzen N, et al. Complex high-risk and indicated percutaneous coronary intervention for stable angina: does operator volume influence patient outcome? *Am Heart J*. 2020;222:15–25. doi: 10.1016/j.ahj.2019.12.019
42. Kinnaird T, Gallagher S, Anderson R, Sharp A, Farooq V, Ludman P, Copt S, Curzen N, Banning A, Mamas M. Are higher operator volumes for unprotected left main stem percutaneous coronary intervention associated with improved patient outcomes? A survival analysis of 6724 procedures from the British Cardiovascular Intervention Society national database. *Circ Cardiovasc Interv*. 2020;13:e008782. doi: 10.1161/CIRCINTERVENTIONS.119.008782

Supplemental Material

Table S1. **HR-PCI volumes by year.**

	2015	2016	2017	2018
1 Operator	1232 (89.9)	1770 (94.5)	1682 (93.9)	1527 (93.3)
2+ Operator	139 (10.1)	104 (5.5)	109 (6.1)	109 (6.7)
OR (95% CI)		0.52 0.39-0.67	1.10 0.83-1.45	1.10 0.83-1.45

All numbers presented as N (%) except as otherwise noted. Odds ratios (OR) with 95% confidence intervals (95% CI) reflect the odds of a multi-operator procedure in the year specified as compared to the prior year.

Table S2. Standardized Mean Differences for Matching Variables in the Propensity-Matched Cohort.

	Unmatched	Matched
Age	0.055	0.022
Male sex	0.035	0.025
Race		
White	0.074	0.047
Black	0.056	0.054
Other	0.060	0.022
Non-Hispanic	0.010	0.042
BMI	0.088	0.006
CVD	0.016	0.002
Prior CVA	0.024	0.019
Coronary artery disease		
1 vessel	0.185	0.040
2 vessels	0.013	0.023
3 vessels or LM	0.120	0.013
Non-obstructive	0.014	0.028
Prior MI	0.018	0.033
Prior PCI	0.031	0.040
Prior CABG	0.002	0.033
CHF	0.023	0.070
LVEF	0.038	0.062
LVEF ≤35%	0.027	0.062
NYHA class		
I	0.088	0.008
II	0.012	0.031
III	0.020	0.008
IV	0.067	0.026
Valvular disease	0.114	0.017
Prior valve surgery	0.001	0.012
PAD	0.036	0.011
Hypertension	0.033	0.030
Hyperlipidemia	0.062	0.022
Atrial fibrillation	0.056	0.048
Pulmonary HTN	0.005	0.029
COPD	0.018	0.007
OSA	0.038	0.030
Obesity	0.027	0.044
Diabetes	0.017	0.004
Insulin therapy	0.051	0.008
Chronic Kidney Disease	0.057	0.032
Hemodialysis	0.001	0.055
Cr	0.100	0.008
GFR	0.010	0.016
Anemia	0.109	0.029
Hemoglobin	0.085	0.043
INR	0.079	0.027
PTSD	0.019	0.029
Depression	0.110	<0.001
Tobacco use		
Never	0.038	<0.001
Current	<0.001	<0.001
Former	0.015	0.011
Alcohol use	0.035	0.013
Substance use	0.067	0.039
PCI indication		
ACS	0.124	0.033
Aortic valve disease	0.044	<0.001
Arrhythmia	0.051	<0.001
Asymptomatic ischemia	0.031	<0.001
Asymptomatic	0.088	0.012
Cardiogenic shock	<0.001	<0.001
Cardiomyopathy	0.019	0.022
Chest pain	0.067	0.022
Heart failure	0.021	<0.001
NSTEMI	0.086	0.029
Positive functional test	0.020	0.030
Preop evaluation	0.062	<0.001

s/p cardiac transplant	0.018	<0.001
Stable angina	0.018	<0.001
Syncope	0.048	0.002
Transplant evaluation	0.018	<0.001
Unstable angina	0.018	<0.001

Abbreviations: ACS, acute coronary syndrome; BMI, body mass index; CABG, coronary artery bypass graft; CAD, coronary artery disease; CHF, congestive heart failure; CKD, chronic kidney disease; COPD, chronic obstructive pulmonary disease; Cr, creatinine; CVA, cerebrovascular accident; CVD, cerebrovascular disease; GFR, glomerular filtration rate; HTN, hypertension; INR, international normalized ratio; LM, left main; LVEF, left ventricular ejection fraction; NSTEMI, non-ST-elevation MI; MI, myocardial infarction; NYHA, New York Heart Association; OSA, obstructive sleep apnea; PAD, peripheral artery disease; PCI, percutaneous coronary intervention; PTSD, post-traumatic stress disorder.

Table S3. Accelerated Failure Time Analysis of 12-Month Outcomes in the Propensity-Matched Cohort.

	Acceleration Factor (95% CI)
MACE	0.84 (0.59-1.18)
Death	0.81 (0.47-1.40)
MI	1.54 (0.91-2.60)
Revascularization	0.85 (0.57-1.25)
Stroke	-

Abbreviations: MACE, major adverse cardiovascular event; MI, myocardial infarction. Accelerated failure time models using a Weibull distribution for MACE and log-normal distributions for MACE components is presented. Estimate shown is the acceleration factor (e.g., utilizing multiple operators as compared to a single operator accelerates time to MACE by a factor of 1.20 (i.e., 1/0.84).

Table S4. Interaction between Outcomes and Procedural Duration in the Propensity-Matched Cohort by Period-Specific Cox Proportional Hazards.

		0-4 months		0-8 months		0-12 months	
		HR (95% CI)	p-value	HR (95% CI)	p-value	HR (95% CI)	p-value
MACE	2+ OP	1.15 (0.89-1.40)	0.28	1.09 (0.87-1.34)	0.38	1.09 (0.90-1.34)	1.26
	HR-PCI Duration	1.00 (0.99-1.00)	0.67	1.00 (0.99-1.00)	0.57	1.00 (0.99-1.00)	0.90
	Interaction	1.00 (0.99-1.00)	0.79	1.00 (0.99-1.00)	0.53	1.00 (0.99-1.00)	0.34
Death	2+ OP	1.03 (0.65-1.63)	0.80	1.02 (0.70-1.48)	0.87	1.13 (0.82-1.56)	0.35
	HR-PCI Duration	1.00 (0.99-1.00)	0.88	1.00 (0.99-1.00)	0.70	1.00 (0.99-1.00)	0.46
	Interaction	1.00 (0.99-1.00)	0.62	1.00 (0.99-1.00)	0.75	1.00 (0.99-1.00)	0.52
MI	2+ OP	0.73 (0.33-1.64)	0.35	0.82 (0.46-1.47)	0.68	0.66 (0.39-1.10)	0.10
	HR-PCI Duration	0.99 (0.98-1.01)	0.29	1.00 (0.99-1.00)	0.54	1.00 (0.99-1.00)	0.32
	Interaction	1.00 (0.99-1.03)	0.53	1.00 (0.99-1.01)	0.49	1.00 (0.99-1.01)	0.79
Revasc	2+ OP	1.25 (0.91-1.73)	0.20	1.18 (0.89-1.55)	0.26	1.11 (0.85-1.43)	0.45
	HR-PCI Duration	1.00 (0.99-1.00)	0.74	1.00 (0.99-1.00)	0.62	1.00 (0.99-1.00)	0.44
	Interaction	1.00 (0.99-1.00)	0.94	1.00 (0.99-1.00)	0.87	1.00 (0.99-1.00)	0.84

Abbreviations: CI, confidence interval; HR, hazard ratio; HR-PCI, high-risk PCI; MACE, major adverse cardiovascular event; MI, myocardial infarction; OP, operator; Revasc, revascularization. There were insufficient events for the outcome of stroke to be included in this analysis.

Table S5. Interaction between Outcomes and Procedural Duration in the Propensity-Matched Cohort by Accelerate Failure Time.

	2+ OP		HR-PCI Duration		Interaction	
	AF (95% CI)	p-value	AF (95% CI)	p-value	AF (95% CI)	p-value
MACE	0.84 (0.59-1.18)	0.26	1.00 (0.99-1.00)	0.91	1.00 (0.99-1.01)	0.33
Death	0.81 (0.47-1.40)	0.30	1.00 (0.99-1.00)	0.70	1.00 (0.99-1.01)	0.50
MI	1.54 (0.91-2.60)	0.10	1.00 (0.99-1.01)	0.29	1.00 (0.99-1.01)	0.79
Revascularization	0.85 (0.57-1.25)	0.41	1.00 (0.99-1.00)	0.43	1.00 (0.99-1.01)	0.84

Abbreviations: AF, acceleration factor; CI, confidence interval; MACE, major adverse cardiovascular event; MI, myocardial infarction. Accelerated failure time models using a Weibull distribution for MACE and log-normal distributions for MACE components is presented.

Table S6. Site-Adjusted Cox Proportional-Hazards Analysis of Outcomes in the Propensity-Matched Cohort.

	0-4 months		0-8 months		0-12 months	
	HR (95% CI)	Median HR	HR (95% CI)	Median HR	HR (95% CI)	Median HR
MACE	1.09 (0.82-1.45)	1.45	1.08 (0.85-1.37)	1.32	1.07 (0.86-1.32)	1.26
Death	1.07 (0.66-1.73)	1.47	1.10 (0.74-1.63)	1.60	1.16 (0.83-1.62)	1.43
MI	0.73 (0.33-1.64)	1.01	0.81 (0.45-1.46)	1.35	0.66 (0.39-1.10)	1.01
Revascularization	1.10 (0.77-1.57)	1.82	1.13 (0.84-1.52)	1.42	1.05 (0.80-1.05)	1.32
Stroke	-		-		-	

Abbreviations: CI, confidence interval; HR, hazard ratio; MACE, major adverse cardiovascular event; MI, myocardial infarction.

Table S7. Standardized Mean Differences for Matching Variables in the Propensity-Matched Cohort Restricted to Patients with Multiple High-Risk Criteria (Sensitivity Analysis).

	Unmatched	Matched
Age	0.105	
Male sex	0.137	<0.001
Race		
White	0.009	0.028
Black	0.026	0.047
Other	0.046	0.067
Non-Hispanic	0.060	0.016
BMI	0.014	0.085
CVD	0.102	0.052
Prior CVA	0.167	<0.001
Coronary artery disease		
1 vessel	0.076	0.080
2 vessels	0.058	0.128
3 vessels or LM	0.017	0.167
Non-obstructive	0.069	<0.001
Prior MI	0.089	0.049
Prior PCI	0.102	0.034
Prior CABG	0.120	0.074
CHF	0.020	0.068
LVEF	0.071	0.043
LVEF ≤35%	0.139	0.007
NYHA class		
I	0.118	0.023
II	0.055	0.071
III	0.003	0.047
IV	0.055	0.033
Valvular disease	0.014	0.025
Prior valve surgery	0.097	0.036
PAD	0.021	0.041
Hypertension	0.107	0.019
Hyperlipidemia	0.078	0.017
Atrial fibrillation	0.038	<0.001
Pulmonary HTN	0.053	<0.001
COPD	0.066	0.028
OSA	0.300	0.043
Obesity	0.017	0.041
Diabetes	0.057	0.028
Insulin therapy	0.053	0.008
Chronic Kidney Disease	0.103	0.027
Hemodialysis	0.056	<0.001
Cr	0.062	0.084
GFR	0.110	0.003
Anemia	0.046	0.086
Hemoglobin	0.086	0.075
INR	0.075	0.043
PTSD	0.011	0.018
Depression	0.049	0.117
Tobacco use		
Never	0.043	<0.001
Current	0.095	0.069
Former	0.035	0.159
Alcohol use	0.048	<0.001
Substance use	0.001	0.108
PCI indication		
ACS	0.144	0.052
Aortic valve disease	0.050	<0.001
Arrhythmia	0.050	<0.001
Asymptomatic ischemia	<0.001	0.048
Cardiogenic shock	0.092	<0.001
Cardiomyopathy	0.055	0.067
Chest pain	0.143	<0.001
Heart failure	0.071	<0.001
NSTEMI	0.050	0.014
Positive functional test	0.035	<0.001
Stable angina	0.069	0.041

Unstable angina	0.013	0.041
Valvular heart disease	0.019	<0.001
Elective intervention		
Elective	0.019	0.029
Urgent	0.030	0.020
Salvage	0.084	0.066
CABG eligible	0.057	0.017
CathPCI risk	0.012	0.005
VA SYNTAX score	0.088	0.100

Abbreviations: ACS, acute coronary syndrome; BMI, body mass index; CABG, coronary artery bypass graft; CAD, coronary artery disease; CHF, congestive heart failure; CKD, chronic kidney disease; COPD, chronic obstructive pulmonary disease; Cr, creatinine; CVA, cerebrovascular accident; CVD, cerebrovascular disease; GFR, glomerular filtration rate; HTN, hypertension; INR, international normalized ratio; LM, left main; LVEF, left ventricular ejection fraction; NSTEMI, non-ST-elevation MI; MI, myocardial infarction; NYHA, New York Heart Association; OSA, obstructive sleep apnea; PAD, peripheral artery disease; PCI, percutaneous coronary intervention; PTSD, post-traumatic stress disorder.

Table S8. Baseline Characteristics, Procedural Indications, Anatomic Characteristics, and Intervention Details in the Propensity-Matched Cohort Restricted to Patients with Multiple High-Risk Criteria (Sensitivity Analysis.)

	1 Operator N=296	2+ Operator N=148	SMD	p value
Demographics				
Age	72.1±9.4	72.0±9.2	0.042	0.940
Male sex	296 (100)	248 (100)	<0.001	-
Race				
White	247 (83)	125 (84)	0.028	
Black	47 (16)	21 (14)	0.047	0.697
Other	2 (1)	2 (1)	0.067	
Non-Hispanic	283 (96)	141 (95)	0.016	1.000
BMI	29.7±6.5	29.2±6.6	0.085	0.396
Comorbidities				
CVD	81 (27)	44 (30)	0.052	0.682
Prior CVA	40 (14)	20 (14)	<0.001	1.000
CAD				
1 vessel	25 (8)	16 (11)	0.080	
2 vessels	75 (25)	46 (31)	0.128	0.401
3 vessels	192 (65)	84 (57)	0.167	
Non-obstructive	4 (1)	2 (1)	<0.001	
Prior MI	195 (66)	94 (64)	0.049	0.699
Prior PCI	173 (58)	89 (60)	0.034	0.811
Prior CABG	155 (52)	72 (49)	0.074	0.524
CHF	234 (79)	121 (82)	0.068	0.586
LVEF	34.1±14.8	33.4±16.1	0.043	0.663
LVEF ≤35%	169 (57)	85 (57)	0.007	1.000
NYHA class				
I	28 (9)	13 (9)	0.023	
II	108 (36)	49 (33)	0.071	
III	70 (24)	38 (26)	0.047	0.931
IV	14 (5)	6 (4)	0.033	
Unknown	76 (26)	42 (28)	0.006	
Valvular disease	59 (20)	31 (21)	0.025	0.900
Prior valve surgery	12 (4)	5 (3)	0.036	0.800
PAD	138 (47)	66 (45)	0.041	0.762
Hypertension	87 (97)	143 (97)	0.019	1.000
Hyperlipidemia	285 (96)	142 (96)	0.017	1.000
Atrial fibrillation	94 (32)	47 (32)	<0.001	1.000
Pulmonary HTN	6 (2)	3 (2)	<0.001	1.000
COPD	118 (40)	57 (39)	0.028	0.864
OSA	104 (35)	49 (33)	0.043	0.751
Obesity	130 (44)	62 (42)	0.041	0.761
Diabetes	192 (65)	94 (64)	0.028	0.861
Insulin therapy	67 (23)	34 (23)	0.008	1.00
CKD	154 (52)	75 (51)	0.027	0.867
Hemodialysis	32 (11)	16 (11)	<0.001	1.000
Anemia	62 (21)	26 (18)	0.086	0.474
Tobacco use				
Never	52 (18)	30 (20)	<0.001	
Current	129 (44)	53 (36)	0.069	0.414
Former	46 (16)	23 (16)	0.159	
Unknown	69 (23)	42 (28)	0.077	
Alcohol use	0 (0)	0 (0)	<0.001	-
Substance use	5 (2)	5 (3)	0.108	0.312
Creatinine	1.97±3.40	2.57±9.45	0.084	0.333
GFR	58.5±27.6	58.5±29.4	0.003	0.979
Hemoglobin	11.9±2.3	12.1±2.0	0.075	0.471

	1 Operator N=296	2+ Operator N=148	SMD	p value
Indication				
Stable angina	67 (23)	31 (21)	0.041	
Unstable angina	67 (23)	31 (21)	0.041	0.932
NSTEMI	122 (41)	60 (41)	0.014	
Other	55 (19)	24 (16)	0.065	
Urgency				
Elective	132 (45)	70 (47)	0.054	
Urgent	1 (0)	1 (1)	0.048	0.625
Salvage	163 (55)	77 (52)	0.061	
CABG eligible	0 (0)	1 (1)	0.017	0.330
CathPCI risk	30.3±13.0	30.3±11.3	0.005	0.963
Anatomy				
VA SYNTAX score	23.7±10.6	22.7±9.5	0.100	0.329
Multivessel CAD	266 (90)	130 (87)	0.090	0.452
Left main disease	59 (20)	36 (24)	0.100	0.375
In-stent restenosis	28 (9)	15 (10)	0.023	0.955
Calcification	93 (31)	63 (43)	0.232	0.027
Bifurcation	41 (14)	25 (17)	0.084	0.479
CTO	20 (7)	19 (13)	0.206	0.050
SVG disease	47 (16)	18 (12)	0.098	0.367
PCI Details				
Primary access				
Radial	91 (31)	48 (32)	0.024	0.872
Femoral	197 (67)	98 (66)	0.024	
Multiple access	29 (10)	41 (28)	0.430	0.061
Vessels treated				
LM	29 (10)	20 (13)	0.101	0.327
LAD	128 (43)	61 (41)	0.049	0.697
LCx	92 (31)	63 (42)	0.231	0.027
RI	11 (4)	6 (4)	<0.001	1.000
RCA	79 (27)	35 (23)	0.076	0.527
# vessels treated	1.59±0.85	1.74±0.93	0.112	0.094
# stents placed	1.59±1.14	1.97±1.47	0.267	0.003
Stent length	23.6±8.63	25.0±8.48	0.162	0.118
FFR/iFR use	23 (8)	10 (7)	0..039	0.849
IVUS/OCT use	57 (19)	21 (14)	0.136	0.234
Atherectomy	19 (6)	13 (9)	0.089	0.475
MCS use	10 (3)	6 (4)	0.036	0.928
Contrast (mL)	182±94.5	220±106	0.138	<0.001
Radiation				
mGy-cm^2	31.7±49.3	61.6±96.3	0.194	0.004
Air kerma (mGy)	1600±1390	2310±1780	0.477	0.014
Duration (min)	22.4±77.5	30.6±84.2	0.001	0.309
DAPT	267 (90)	138 (93)	0.111	0.286

INR	1.20±0.43	1.22±0.46	0.043	0.664

Abbreviations: BMI, body mass index; CABG, coronary artery bypass graft; CAD, coronary artery disease; CHF, congestive heart failure; CKD, chronic kidney disease; COPD, chronic obstructive pulmonary disease; Cr, creatinine; CTO, chronic total occlusion; CVA, cerebrovascular accident; CVD, cerebrovascular disease; DAPT, dual anti-platelet therapy; FFR, fractional flow reserve; GFR, glomerular filtration rate; Hgb, hemoglobin; HTN, hypertension; iFR, instantaneous wave-free ratio; INR, international normalized ratio; IVUS, intravascular ultrasound; LAD, left anterior descending; LCx, left circumflex; LM, left main; LVEF, left ventricular ejection fraction; MCS, mechanical circulatory support; MI, myocardial infarction; NSTEMI, non-ST-elevation myocardial infarction; NYHA, New York Heart Association; OCT, optical coherence tomography; OSA, obstructive sleep apnea; PAD, peripheral artery disease; PCI, percutaneous coronary intervention. RCA, right coronary artery; RI, ramus intermedius; SVG, saphenous vein graft. All numbers presented as N (%) or mean±SD with standardized mean difference (SMD) and p-values.

Figure S1. Kaplan-Meier Analysis of Death in the Matched Cohort.

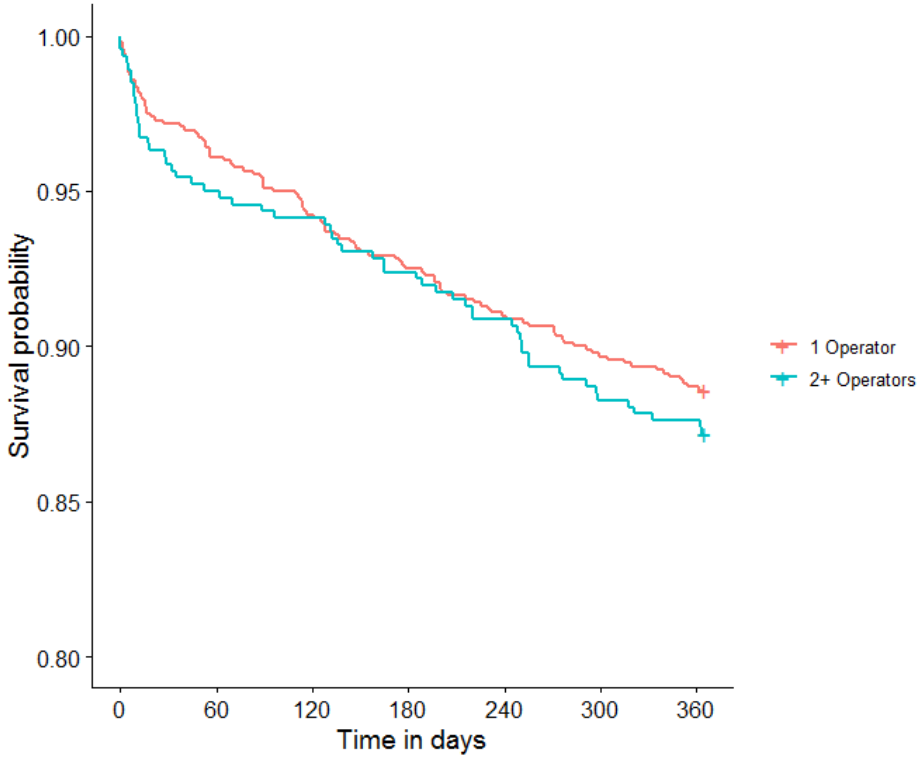

Figure S2. Kaplan-Meier Analysis of Major Adverse Cardiac Events in the Matched Cohort Restricted to Patients with Multiple High-Risk Criteria (Sensitivity Analysis).