JACC: CARDIOVASCULAR INTERVENTIONS VOL. 11, NO. 7, 2018

PUBLISHED BY ELSEVIER

Burden of 30-Day Readmissions After Percutaneous Coronary Intervention in 833,344 Patients in the United States: Predictors, Causes, and Cost

Insights From the Nationwide Readmission Database

Chun Shing Kwok, MBBS, MSc, BSc,[a,b] Sunil V. Rao, MD,[c] Jessica E. Potts, MSc,[a] Evangelos Kontopantelis, PhD,[d] Muhammad Rashid, MBBS,[a] Tim Kinnaird, MD,[e] Nick Curzen, BM, PhD,[f] James Nolan, MD,[a,b] Rodrigo Bagur, MD, PhD,[g] Mamas A. Mamas, BMBCh, DPhil[a,b]

ABSTRACT

OBJECTIVES This study aimed to examine the 30-day unplanned readmissions rate, predictors of readmission, causes of readmissions, and clinical impact of readmissions after percutaneous coronary intervention (PCI).

BACKGROUND Unplanned rehospitalizations following PCI carry significant burden to both patients and the local health care economy and are increasingly considered as an indicator of quality of care.

METHODS Patients undergoing PCI between 2013 and 2014 in the U.S. Nationwide Readmission Database were included. Incidence, predictors, causes, and cost of 30-day unplanned readmissions were determined.

RESULTS A total of 833,344 patients with PCI were included, of whom 77,982 (9.3%) had an unplanned readmission within 30 days. Length of stay for the index PCI was greater (4.7 vs. 3.9 days) and mean total hospital cost ($23,211 vs. $37,524) was higher for patients who were readmitted compared with those not readmitted. The factors strongly independently associated with readmissions were index hospitalization discharge against medical advice (odds ratio [OR]: 1.91; 95% confidence interval [CI]: 1.65 to 2.22), transfer to short-term hospital for inpatient care (OR: 1.62; 95% CI: 1.38 to 1.90), discharge to care home (OR: 1.57; 95% CI: 1.51 to 1.64), and chronic kidney disease (OR: 1.50; 95% CI: 1.44 to 1.55). Charlson Comorbidity Index score (OR: 1.28; 95% CI: 1.27 to 1.29) and number of comorbidities (OR: 1.18; 95% CI: 1.17 to 1.18) were independently associated with unplanned readmission. The majority of readmissions were due to noncardiac causes (56.1%).

CONCLUSIONS Thirty-day readmissions after PCI are relatively common and relate to baseline comorbidities and place of discharge. More than one-half of the readmissions were due to noncardiac causes. (J Am Coll Cardiol Intv 2018;11:665–74) © 2018 by the American College of Cardiology Foundation.

Percutaneous coronary intervention (PCI) is the most common revascularization modality for the treatment of coronary disease, accounting for 3.6% of all invasive procedures in the United States in 2011 (1). As the mean in-hospital mortality after PCI is <1% (2), readmissions after PCI are increasingly recognized as an important post-discharge outcome. In addition, rate of readmission

From the [a]Centre for Prognosis Research, Institute for Primary Care and Health Sciences, Keele Cardiovascular Research Group, Keele University, Stoke-on-Trent, United Kingdom; [b]Royal Stoke University Hospital, Stoke-on-Trent, United Kingdom; [c]Department of Cardiology, Duke Clinical Research Institute, Durham, North Carolina; [d]University of Manchester, Manchester, United Kingdom; [e]Department of Cardiology, University Hospital of Wales, Cardiff, United Kingdom; [f]University Hospital Southampton NHS Foundation Trust & Faculty of Medicine, University of Southampton, Southampton, United Kingdom; and the [g]Division of Cardiology, Department of Medicine, London Health Sciences Centre, and Epidemiology and Biostatistics, Western University, London, Canada. Financial support was provided by the North Staffs Heart Committee. This work was conducted as a part of Dr. Kwok's PhD research, which was supported by Biosensors International. Dr. Curzen has received unrestricted research grant support from Boston Scientific, Haemonetics, Heartflow, and Philips Volcano; has received speaker fees from Boston Scientific and Heartflow; has received travel sponsorship from Edwards and Lilly/D-S; and has served as a consultant for Haemonetics. All other authors have reported that they have no relationships relevant to the contents of this paper to disclose.

Manuscript received October 11, 2017; revised manuscript received December 18, 2017, accepted January 9, 2018.

ISSN 1936-8798/$36.00 https://doi.org/10.1016/j.jcin.2018.01.248

ABBREVATIONS AND ACRONYMS

CABG = coronary artery bypass grafting

CI = confidence interval

ICD-9 = International Classification of Diseases-9th Revision

NRD = Nationwide Readmissions Database

OR = odds ratio

PCI = percutaneous coronary intervention

TIA = transient ischemic attack

increasingly used as a quality-of-care indicator at the institutional level, in addition to being an important burden to patients and the local health care economy (3).

The nature and impact of readmissions is complex. Despite efforts to reduce early readmissions, readmissions rates after PCI have been reported to be between 4.7% and 15.6% (3). Hospital readmissions may act as a surrogate of the quality of care received from the initial hospitalization (4), as they may result from actions taken or omitted during the initial hospital stay (5), or they may be a consequence of incomplete treatment or failure of services to coordinate post-discharge care (6,7). Unplanned readmissions can also be considered an adverse outcome for patients. From the health service perspective, the financial impact of readmissions is significant, with a readmission within 30 days associated with financial penalties (8). Furthermore, in the United States, the Affordable Care Act includes financial penalties for hospitals that have risk-adjusted readmissions rates for specific conditions exceeding specific benchmarks (9), whereas in the United Kingdom, hospitals do not receive any additional payments for treatment if patients are readmitted within 30 days (10).

SEE PAGE 675

In this study, we aimed to examine: 1) the 30-day unplanned readmissions rate; 2) predictors of readmission including comorbidity burden; and 3) causes of readmissions after PCI using the Nationwide Readmissions Database (NRD), the largest all-payer database of hospital readmissions in the United States.

METHODS

PARTICIPANTS AND STUDY DESIGN. The NRD provides a nationally representative sample of all-age, all-payer discharges from U.S. nonfederal hospitals produced by the Healthcare Cost and Utilization Project of the Agency for Healthcare Research and Quality (11). This database is constructed from the discharge-level data of hospitalizations from 21 geographically dispersed participating states which represents 49.3% of the total U.S. population and 49.1% of all U.S. hospitalizations (12). Readmissions are determined through the deidentified unique patient linkage number assigned to each patient, which allows tracking of patients across hospitals within a state during a calendar year.

Individual patients in the NRD dataset are assigned up to 15 procedure codes for each admission to hospital. We defined patients with PCI with procedure code 0066 (PTCA OR: CORONARY ATHER), 3606 (INSERT CORON ART STENT), and 3607 (INSERT DRUGELUTING CRNRY AR). Only patients who were discharged alive after PCI were considered in the analysis. Planned readmissions were excluded, which were defined by readmissions within 30 days, which were classified as elective.

OUTCOMES AND MEASUREMENTS. The primary outcome was the rate of unplanned readmission within 30 days of hospitalization with PCI. We included patients who underwent PCI with discharge dates in 2013 and 2014 with 30-day follow up. We excluded patients admitted in December of both calendar years because they would have not 30-day follow-up and patients who had planned readmissions. Total cost of index admission and readmissions (where relevant) for each patient was determined by multiplying the hospital charges with the Agency for Healthcare Research and Quality's all-payer cost-to-charge ratios for each hospital.

We used International Classification of Diseases-9th Revision (ICD-9) codes to define clinical variables including smoking status, dyslipidemia, coronary artery disease, previous myocardial infarction, previous PCI, previous coronary artery bypass grafting (CABG), previous stroke or transient ischemic attack (TIA), atrial fibrillation, dementia, and receipt of circulatory support. The other comorbidity variables in the analysis were available via the Elixhauser comorbidities (13), which included alcohol misuse, chronic lung disease, heart failure, diabetes, valvular heart disease, peptic ulcer disease, hypertension, renal failure, obesity, cancer, fluid and electrolyte disorders, depression, peripheral vascular disease, hypothyroidism, liver disease, anemia, and coagulopathy. The paralysis variable from the Elixhauser comorbidities was used as a surrogate for hemiplegia, connective tissue disease, and leukemia where defined by Clinical Classifications Software codes 210, 211, and 39, respectively. Combining these variables enabled us to compute the Charlson Comorbidity Index. The number of comorbidities was the sum of the comorbidities included in the analysis. Procedural ICD-9 codes were used to define multivessel disease, bifurcation disease, circulatory support, vasopressor use, intra-aortic balloon pump use, fractional flow reserve use, intravascular ultrasound, and drug-eluting stent use. Diagnostic ICD-9 codes were used to define in-hospital outcomes including complete heart block, TIA or stroke, cardiogenic shock, cardiac arrest, acute kidney injury, major bleeding, blood transfusion, vascular complication, and emergency

TABLE 1 Baseline Characteristics and In-Hospital Outcomes From Index Admission for PCI Patients According to 30-Day Readmission Status

	30-Day Readmission		
	No (n = 755,362)	Yes (n = 77,982)	p Value
Age, yrs	64.5 ± 12.3	67.3 ± 12.8	<0.001
Women	31.3	39.4	<0.001
Elective	13.2	9.5	<0.001
Weekend admission	22.3	22.8	0.016
Diagnosis of acute myocardial infarction	58.4	56.1	<0.001
Primary expected payer			<0.001
Medicare	51.8	65.0	
Medicaid	7.9	9.5	
Private	30.2	18.2	
Uninsured	5.7	3.7	
No charge	0.9	0.7	
Other	3.5	2.9	
Median household income			<0.001
0–25th percentile	27.6	30.4	
26–50th percentile	27.0	27.2	
51–75th percentile	24.0	22.8	
76–100th percentile	21.3	19.6	
Comorbidities			
Smoking	43.9	41.2	<0.001
Alcohol misuse	2.9	3.0	0.55
Dyslipidemia	71.8	68.3	<0.001
Hypertension	75.0	78.8	<0.001
Diabetes mellitus	36.8	46.0	<0.001
Obesity	17.5	17.4	0.85
Heart failure	1.6	2.7	<0.001
Known CAD	93.0	93.0	0.56
Previous MI	14.3	16.2	<0.001
Previous PCI	20.9	22.2	<0.001
Previous CABG	7.3	9.0	<0.001
Previous valve disease	0.5	0.8	<0.001
Atrial fibrillation	11.9	19.5	<0.001
Previous TIA/stroke	7.0	10.5	<0.001
Peripheral vascular disease	11.1	16.3	<0.001
Pulmonary circulatory disorder	0.3	0.5	<0.001
Peptic ulcer disease	0.02	0.03	0.38
Chronic lung disease	16.7	25.3	<0.001
Chronic kidney disease	13.7	25.6	<0.001
Liver disease	1.3	2.2	<0.001
Hypothyroidism	9.5	12.2	<0.001
Fluid and electrolyte disorders	14.0	21.5	<0.001
Anemia	10.5	20.2	<0.001
Cancer	1.8	2.9	<0.001
Depression	6.9	9.7	<0.001
Dementia	1.9	3.7	<0.001
Charlson Comorbidity Index	1.3 ± 1.4	1.9 ± 1.7	<0.001
Mean number of comorbidities	4.9 ± 2.1	5.7 ± 2.3	<0.001
Hospital characteristics			
Bed size			<0.001
Small	7.1	6.1	
Medium	24.2	24.2	
Large	68.7	69.7	
Location			0.052
Rural	0.2	0.2	
Urban	99.8	99.8	
Teaching status			<0.001
Nonteaching	40.2	41.2	
Teaching	59.8	58.8	
In-hospital procedures and procedural details			
Multivessel disease	15.9	16.1	0.25
Bifurcation	3.1	2.9	0.011
Circulatory support	3.0	4.3	<0.001
Vasopressor use	0.6	0.7	0.001
Intra-aortic balloon pump	2.6	3.7	<0.001
Fractional flow reserve	2.8	3.2	<0.001
Intravascular ultrasound	6.5	6.5	0.92
Drug-eluting stent	77.7	71.6	<0.001
In-hospital outcomes			
Complete heart block	1.1	1.4	<0.001
TIA/stroke	3.1	3.7	<0.001
Cardiogenic shock	3.1	4.3	<0.001
Cardiac arrest	2.2	2.4	0.016
Acute kidney injury	0.6	1.0	<0.001
Major bleeding	0.7	1.1	<0.001
Blood transfusion	0.05	0.11	<0.001
Vascular complication	0.7	1.0	<0.001
Emergency CABG	1.4	1.5	0.079
LOS, days	3.9 ± 5.6	4.7 ± 4.0	<0.001
Index PCI cost, $	23,211 ± 19,605	24,888 ± 15,486	<0.001
Total cost, $	23,211 ± 19,605	37,524 ± 25,679	<0.001
Discharge destination			<0.001
Home (self-care)	87.2	75.3	
Short-term hospital	0.5	0.9	
Transfer to other institution	4.7	8.9	
Care home	7.2	14.1	
Left against medical advice or discontinued care	0.5	0.8	
Destination unknown	0.02	0.02	

Values are mean ± SD or %.

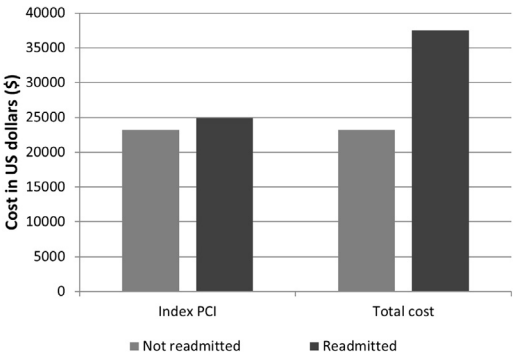
CABG = coronary artery bypass grafting; CAD = coronary artery disease; LOS = length of stay; MI = myocardial infarction; PCI = percutaneous coronary intervention; TIA = transient ischemic attack.

Continued in the next column

CABG. Additional data were collected on length of stay in hospital, hospital bed size, hospital location and hospital teaching status, and discharge destination. The causes of readmission were determined by the first diagnosis based on Clinical Classification Software codes, which are presented in detail in Online Table 1.

STATISTICAL ANALYSIS. Statistical analysis was performed on Stata version 14.0 (StataCorp, College Station, Texas). The survey estimation commands

FIGURE 1 Cost of Index PCI and Total Cost



PCI = percutaneous coronary intervention.

were used to estimate the sample size as recommended by the Agency of Healthcare Research and Quality. Descriptive statistics are presented according to readmission status for all included variables. The statistical differences between readmitted and nonreadmitted patients for continuous and categorical variables were compared using the *t* test and chi-square test, respectively. Multiple logistic regressions were used to identify independent predictors of 30-day readmissions after PCI. Further regressions were used to determine predictors of noncardiac and cardiac readmissions. The logistic regression models were adjusted for age, sex, year, elective admission, weekend admission, diagnosis of acute myocardial infarction, primary expected payer, median household income, smoking, alcohol misuse, dyslipidemia, hypertension, diabetes mellitus, obesity, heart failure, coronary artery disease, previous myocardial infarction, previous PCI, previous CABG, previous valve disease, atrial fibrillation, previous TIA or stroke, peripheral vascular disease, pulmonary circulatory disorder, peptic ulcer disease, chronic lung disease, chronic kidney disease, liver disease, hypothyroidism, fluid and electrolyte disorders, anemia, cancer, depression, dementia, hospital bed size, hospital location, hospital teaching status, multivessel disease, bifurcation lesion, circulatory support, vasopressor use, intra-aortic balloon pump use, fractional flow reserve, intravascular ultrasound use, drug-eluting stent, in-hospital complete heart block, TIA or stroke, cardiogenic shock, cardiac arrest, acute kidney injury, major bleeding, blood transfusion, vascular complications, emergency CABG, length of stay, and discharge destination. Two separate regression univariable regressions were performed to evaluate the predictive value of Charlson Comorbidity Index and number of comorbidities on readmission status. The mean cost of index admission for PCI and the costs associated with readmissions were computed and are shown graphically. The causes of readmission within 30 days are presented in figure format as noncardiac and cardiac. A flow diagram was used to describe patient outcomes (in-hospital death) for both admissions and readmissions.

RESULTS

A total of 862,649 patients underwent PCI between 2013 to 2014. After exclusion of 21,116 patients who died during the index admission (2.4%) and another 8,105 patients who had planned PCI readmission within 30 days, 833,344 patients with PCI procedures were included in the analysis. At 30 days, 77,982 (9.3%) participants had an unplanned readmission.

The baseline characteristics of the participants during their initial hospital episode are shown in **Table 1**. Participants who were readmitted were more likely to be older (67.3 years of age vs. 64.5 years of age), women (39.4% vs. 31.3%), and admitted on the weekend (22.8% vs. 22.3%). Significant differences were also observed depending on the primary expected payer and median household income where private health care (30.2% vs. 18.2%) and higher median household income (highest quartile: 21.3% vs. 19.6%) was associated with reduced rates of readmissions.

Multimorbidity was also more prevalent among patients who were readmitted within 30 days. Specifically, the mean number of comorbidities was 5.7 in the readmitted group compared with 4.9 in the no-readmission group, with a higher Charlson Comorbidity Index score in the readmitted group (1.9 vs. 1.3; $p < 0.001$). Significant differences were observed in treating hospital characteristics, with differences observed based on bed size of the hospital and teaching status but not based on location. Significant differences were recorded for in-hospital complete heart block (1.4% vs. 1.1%), TIA or stroke (3.7% vs. 3.1%), acute kidney injury (1.0% vs. 0.6%), major bleeding (1.1% vs. 0.7%), blood transfusion (0.11% vs. 0.05%), and vascular complications (1.0% vs. 0.7%), which were all more frequent in the readmission group.

For the first admission for PCI, length of stay was greater in patients who were readmitted (4.7 days vs. 3.9 days), and they were more likely to be transferred to another institution (8.9% vs. 4.7%) or go to a care home on discharge (14.1% vs. 7.2%). The mean cost for the index PCI and total cost for index and first

TABLE 2 Independent Predictors of 30-Day Readmission After PCI

	Multivariable	
	OR (95% CI)	p Value
Female	1.19 (1.16–1.23)	<0.001
Elective	0.70 (0.66–0.74)	<0.001
Primary expected payer compared with Medicare		
Medicaid	1.11 (1.05–1.17)	<0.001
Private	0.67 (0.64–0.70)	<0.001
Uninsured	0.69 (0.64–0.74)	<0.001
No charge	0.89 (0.79–1.02)	0.087
Other	0.80 (0.74–0.88)	<0.001
Median household income		
26–50th vs. 0–25th	0.95 (0.91–0.98)	0.002
51–75th vs. 0–25th	0.92 (0.88–0.95)	<0.001
76–100th vs. 0–25th	0.94 (0.90–0.99)	0.011
Smoking	0.94 (0.92–0.97)	<0.001
Dyslipidemia	0.87 (0.84–0.89)	<0.001
Hypertension	1.06 (1.03–1.09)	<0.001
Diabetes mellitus	1.23 (1.19–1.26)	<0.001
Obesity	0.92 (0.89–0.95)	<0.001
Previous myocardial infarction	1.06 (1.02–1.10)	0.001
Previous CABG	1.09 (1.04–1.14)	<0.001
Atrial fibrillation	1.41 (1.36–1.46)	<0.001
Previous CVA/TIA	1.16 (1.11–1.21)	<0.001
Peripheral vascular disease	1.17 (1.13–1.22)	<0.001
Chronic lung disease	1.36 (1.31–1.40)	<0.001
Chronic kidney disease	1.50 (1.44–1.55)	<0.001
Liver disease	1.42 (1.30–1.55)	<0.001
Fluid and electrolyte disorder	1.20 (1.16–1.25)	<0.001
Anemia	1.34 (1.29–1.39)	<0.001
Cancer	1.33 (1.22–1.45)	<0.001
Depression	1.24 (1.19–1.30)	<0.001
Dementia	1.19 (1.10–1.28)	<0.001
Urban location	1.44 (1.02–2.04)	0.036
Fractional flow reserve	1.16 (1.07–1.25)	0.001
Drug-eluting stent	0.82 (0.80–0.85)	<0.001
In-hospital TIA/stroke	0.92 (0.86–0.98)	0.013
In-hospital emergency CABG	0.85 (0.75–0.96)	0.009
Length of stay (per 1-day increment)	0.98 (0.98–0.98)	<0.001
Discharge destination		
Short-term hospital vs. home	1.62 (1.38–1.90)	<0.001
Transfer to other institution vs. home	1.41 (1.32–1.50)	<0.001
Care home vs. home	1.57 (1.51–1.64)	<0.001
Left against medical advice or discontinue care vs. home	1.91 (1.65–2.22)	<0.001
Charlson score	1.28 (1.27–1.29)	<0.001
Number of comorbidities	1.18 (1.17–1.18)	<0.001

CI = confidence interval; CVA = cerebrovascular accident; OR = odds ratio; other abbreviations as in Table 1.

readmission were $23,211 ± $19,605 and $37,524 ± $25,679, respectively (Figure 1).

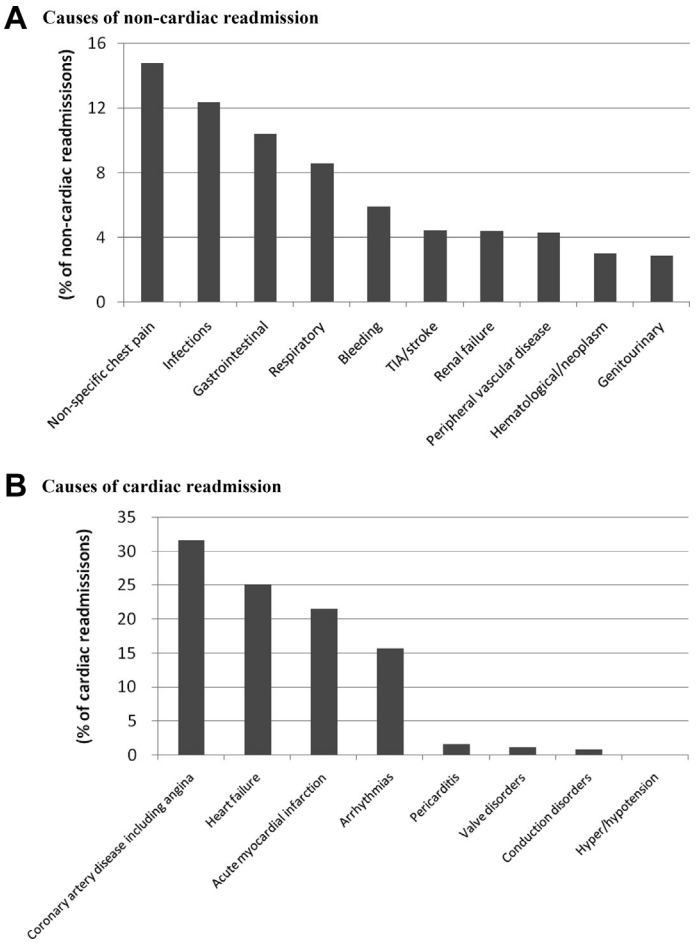
The independent predictors of 30-day readmission are shown in Table 2. Factors around discharge and discharge destination were most associated with unplanned readmission. Patients self-discharging against medical advice (odds ratio [OR]: 1.91; 95% confidence interval [CI]: 1.65 to 2.22; $p < 0.001$), short-term hospital (OR: 1.62; 95% CI: 1.38 to 1.90; $p < 0.001$), care home (OR: 1.57; 95% CI: 1.51 to 1.64; $p < 0.001$), and transfer to other institution (OR: 1.41; 95% CI: 1.32 to 1.50; $p < 0.001$) were independently associated with unplanned readmission within 30 days. Comorbidities were also associated with readmission, with the largest ORs observed in chronic kidney disease (OR: 1.50; 95% CI: 1.44 to 1.55; $p < 0.001$), liver disease (OR: 1.42; 95% CI: 1.30 to 1.55), atrial fibrillation (OR: 1.41; 95% CI: 1.36 to 1.46; $p < 0.001$), and chronic lung disease (OR: 1.36; 95% CI: 1.31 to 1.40; $p < 0.001$). Participants who had private insurance (OR: 0.67; 95% CI: 0.64 to 0.70; $p < 0.001$), no insurance (OR: 0.69, 0.64 to 0.74; $p < 0.001$), elective index admission (OR: 0.70; 95% CI: 0.66 to 0.74; $p < 0.001$), and drug-eluting stent (OR: 0.82; 95% CI: 0.80 to 0.85; $p < 0.001$) were independently associated with a decreased risk of unplanned 30-day readmission. Comorbidity burden as defined by Charlson Comorbidity Index (OR: 1.28; 95% CI: 1.27 to 1.29; $p < 0.001$) or number of comorbidities (OR: 1.18; 95% CI: 1.17 to 1.18; $p < 0.001$) was independently associated with readmission.

The causes of readmission are shown in Figure 2. The readmissions due to noncardiac causes were slightly more common (56.1%). Among the noncardiac causes for readmission the most common causes were nonspecific chest pain (14.8%), infection (12.3%), gastrointestinal disease (10.4%), respiratory disease (8.6%), and major bleeding complications (5.9%). Among cardiac causes for readmission the most common causes were coronary artery disease including angina (31.6%), heart failure (25.1%), acute myocardial infarction (21.6%), arrhythmias (15.8%), and pericarditis (1.5%).

Table 3 shows the predictors of noncardiac and cardiac readmissions after PCI. Factors with significant associations only for noncardiac readmissions were hypertension, dementia, and vascular complications. Factors with significant associations only for cardiac readmission were smoking, urban location, and an index hospitalization occurrence of complete heart block and stroke or TIA.

Figure 3 shows a flow diagram in-hospital mortality for index procedure, cardiac, and noncardiac causes of unplanned readmission. The in-hospital mortality rate for patients undergoing index PCI was 2.4%, whereas the in-hospital death among those who had an unplanned readmission was 3.1% for noncardiac readmissions and 2.8% for cardiac readmissions.

FIGURE 2 Causes of Readmission



TIA = transient ischemic attack.

DISCUSSION

Our analysis of 833,344 PCI procedures demonstrates that unplanned readmissions within 30 days of the index PCI are common (9.3%). The majority of readmissions within 30 days are noncardiac (56%), with female sex, chronic kidney disease, liver failure, atrial fibrillation, increasing comorbidity burden, and discharge location among the strongest predictors of unplanned 30-day readmission. Patients who experienced an unplanned readmission for noncardiac reasons tended to be younger, with more comorbidities, including alcohol misuse, cancer, and dementia, whereas patients who are readmitted for cardiac reasons are more likely to have in-hospital complications at their index PCI event. Finally, unplanned readmissions were associated with increased mortality rates and health care costs.

Our study overcomes several limitations in the existing literature on unplanned readmissions following PCI. The largest study of readmissions after PCI currently published described a cohort of Medicare patients between 2000 to 2012 and reported a 30-day readmission rate of 15.8% (14). One of the most important limitations of this study was that it did not distinguish between unplanned and planned readmissions, which may explain why their reported readmission rate was higher compared with the current study in which planned readmissions were excluded. Furthermore, a planned admission for a staged procedure or investigation has neither the health care cost implications, nor the impact on hospital services that an unplanned readmission will have. Second, the study was undertaken in a Medicare cohort, which limits generalizability to all admissions, in contrast to our study, which included Medicaid, private and uninsured patients, as well as Medicare patients. We observed in the current study that the Medicare cohort had the highest proportion of patients with readmission 65.0% versus 51.8%. This suggests that a study including only Medicare patients would be a higher risk cohort for unplanned readmission that may not be representative of the wider PCI practice within the United States. Third, the study focused on PCI outcomes from procedures undertaken over 15 years ago and therefore may not represent contemporary practice and its associated outcomes. Other studies have also evaluated readmissions after PCI but are limited because they are small studies derived from either single, or a small number of centers (15-18), or are derived from procedures undertaken more than 10 years ago, which may not be relevant to modern PCI practices (19,20).

Although our previous work has shown that comorbidity burden has important prognostic impact in PCI (21,22), we find for the first time the comorbidity as defined by the Charlson Comorbidity Index score and number of comorbidities are an important predictive tool for unplanned readmissions. It is not clear whether measures such as greater emphasis on management of comorbid conditions during the index procedure may reduce readmissions or whether comorbidity burden is a surrogate for a higher risk cohort. An area for future research may be determining if better management of comorbid illness and closer follow-up once discharged may reduce unplanned readmissions.

We found that noncardiac causes are more common, which may reflect the worsening comorbid burden in patients who undergo PCI overtime. Furthermore, PCI practices have evolved, with improved drug-eluting stent designs with thinner

struts, which reduce stent thrombosis (23,24) and powerful antiplatelet agents, which reduce major adverse cardiovascular events (25,26) and stent thrombosis (26,27). Newer tools, such as fractional flow reserve, help to characterize lesions that require treatment and use of intravascular imaging modalities, such as intravascular ultrasound and optical coherence tomography, optimize stent deployment, which has also been shown to improve patient outcomes (28,29). These changes in PCI practices may serve to reduce cardiac causes of readmission.

Another potential reason for the dominance of noncardiac readmissions may relate to the decline in length of stay, which may influence the management or optimization of non-cardiac-related comorbidities because improvements in PCI practices facilitate early discharge to reduce associated hospital expenditure. Although our analysis suggests that the majority of 30-day unplanned readmissions are noncardiac in origin, it is important to note that they may still relate or occur as a consequence of the index PCI procedure. For example, patients post-PCI are advised to seek medical attention if they experience chest pain, which may explain the increased rates of noncardiac chest pain reported in our analyses. Other causes of readmission such as bleeding complications may directly relate to the PCI procedure as potent antiplatelet agents prescribed increased the propensity toward such bleeding complications, even if such bleeding events are classified as noncardiac causes of readmission.

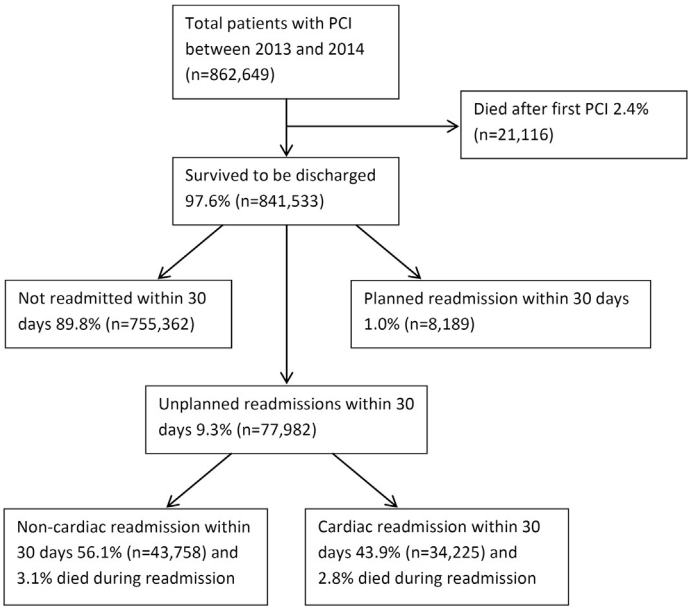
Our results support our previous systematic review that identified that female sex, pre- or periprocedural myocardial infarction, peripheral vascular disease, diabetes, renal failure, and nonelective PCI were associated with more readmissions, although data were mostly derived from single centers with small sample sizes and often in less contemporary cohorts (3). Other studies have also identified other predictors that were not evaluated in the current study. For example, Hannan et al. (20) reported reduced ejection fraction, ≥3 diseased vessels, and malignant ventricular arrhythmias as a predictor of readmission. Harjai et al. (18) also found PCI to left anterior descending artery, lesion length >28 mm, aspirin dose, and proton pump inhibitor use were predictive of readmission. Factors that predispose to readmission after PCI will most probably depend on the risk profile of the cohort and the case mix, such as proportion of cases that were elective or emergency. Although additional studies (16,17,30) have looked at predictors, this is the largest study to date and the first to study characteristics, predictors, and outcomes in a national cohort.

TABLE 3 Independent Predictors of 30-Day Noncardiac and Cardiac Readmissions After PCI

	Noncardiac		Cardiac	
	OR (95% CI)	p Value	OR (95% CI)	p Value
Age (per 1-yr increment)	0.99 (0.99–1.00)	0.002	1.00 (0.99–1.00)	0.17
Female	1.23 (1.19–1.27)	<0.001	1.15 (1.10–1.20)	<0.001
Elective	0.79 (0.74–0.83)	<0.001	0.59 (0.55–0.64)	<0.001
Primary expected payer compared with Medicare				
Medicaid	1.06 (0.99–1.14)	0.097	1.17 (1.09–1.27)	<0.001
Private	0.61 (0.58–0.65)	<0.001	0.74 (0.70–0.79)	<0.001
Uninsured	0.63 (0.57–0.69)	<0.001	0.77 (0.69–0.85)	<0.001
No charge	0.79 (0.66–0.93)	0.006	1.03 (0.85–1.26)	0.73
Other	0.73 (0.65–0.82)	<0.001	0.90 (0.81–1.00)	0.060
Median household income				
26th–50th vs. 0–25th	0.94 (0.90–0.99)	0.016	0.95 (0.90–0.99)	0.030
51th–75th vs. 0–25th	0.94 (0.90–0.99)	0.011	0.89 (0.84–0.94)	<0.001
76th–100th vs. 0–25th	0.96 (0.91–1.01)	0.13	0.93 (0.88–0.99)	0.019
Smoking	0.97 (0.93–1.00)	0.069	0.91 (0.88–0.95)	<0.001
Alcohol misuse	1.12 (1.02–1.24)	0.023	0.92 (0.82–1.03)	0.13
Dyslipidemia	0.84 (0.81–0.87)	<0.001	0.91 (0.87–0.94)	<0.001
Hypertension	1.06 (1.02–1.11)	0.002	1.04 (1.00–1.09)	0.079
Diabetes	1.20 (1.15–1.24)	<0.001	1.26 (1.21–1.31)	<0.001
Obese	0.93 (0.88–0.97)	0.001	0.91 (0.87–0.96)	<0.001
Heart failure	1.20 (1.08–1.35)	0.001	0.83 (0.71–0.96)	0.013
Previous MI	1.04 (0.99–1.09)	0.13	1.10 (1.04–1.16)	0.001
Previous PCI	0.99 (0.95–1.04)	0.75	1.05 (1.00–1.10)	0.055
Previous CABG	1.09 (1.03–1.16)	0.005	1.09 (1.02–1.16)	0.013
Atrial fibrillation	1.30 (1.24–1.36)	<0.001	1.56 (1.49–1.64)	<0.001
Previous stroke/TIA	1.17 (1.11–1.24)	<0.001	1.14 (1.07–1.21)	<0.001
Peripheral vascular disease	1.20 (1.14–1.25)	<0.001	1.13 (1.07–1.20)	<0.001
Chronic lung disease	1.45 (1.39–1.51)	<0.001	1.23 (1.17–1.29)	<0.001
Chronic renal failure	1.44 (1.38–1.50)	<0.001	1.58 (1.49–1.66)	<0.001
Liver disease	1.58 (1.42–1.75)	<0.001	1.20 (1.04–1.39)	0.013
Fluid and electrolyte disorder	1.24 (1.19–1.29)	<0.001	1.16 (1.10–1.22)	<0.001
Anemia	1.43 (1.36–1.49)	<0.001	1.22 (1.15–1.28)	<0.001
Cancer	1.53 (1.38–1.68)	<0.001	1.05 (0.92–1.20)	0.47
Depression	1.24 (1.17–1.31)	<0.001	1.24 (1.16–1.33)	<0.001
Dementia	1.24 (1.13–1.36)	<0.001	1.12 (1.00–1.25)	0.052
Urban location	1.27 (0.88–1.84)	0.20	1.72 (1.15–2.57)	0.008
Fractional flow reserve	1.16 (1.05–1.28)	0.003	1.15 (1.03–1.27)	0.010
Drug-eluting stent	0.81 (0.78–0.84)	<0.001	0.83 (0.80–0.87)	<0.001
Complete heart block	0.93 (0.80–1.09)	0.36	1.16 (1.00–1.35)	0.047
Stroke/TIA	0.95 (0.87–1.05)	0.33	0.86 (0.78–0.96)	0.005
Cardiogenic shock	0.91 (0.83–1.01)	0.082	1.13 (1.01–1.27)	0.033
Vascular complication	1.23 (1.05–1.44)	0.011	0.96 (0.78–1.19)	0.71
Emergency CABG	0.90 (0.77–1.05)	0.20	0.79 (0.67–0.93)	0.006
Length of stay (per 1-day increment)	0.98 (0.97–0.98)	<0.001	0.98 (0.97–0.98)	<0.001
Discharge location				
Short-term hospital vs. home	1.34 (1.09–1.66)	0.006	1.92 (1.56–2.35)	<0.001
Transfer to other institution vs. home	1.67 (1.56–1.79)	<0.001	1.08 (0.98–1.18)	0.14
Care home vs. home	1.66 (1.57–1.75)	<0.001	1.46 (1.37–1.55)	<0.001
Left against medical advice or discontinue care vs. home	1.71 (1.40–2.09)	<0.001	2.17 (1.79–2.63)	<0.001

Abbreviations as in Tables 1 and 2.

FIGURE 3 Flow Diagram of Readmissions and Outcomes



PCI = percutaneous coronary intervention.

Although readmissions are important from a financial perspective, it may not be the ideal quality of care indicator. The Quality of Care and Outcomes Research in Cardiovascular Disease and Stroke Working Group described principles of selection of performance measures (31), but readmissions meet some but not all criteria with concerns raised by a previous editorial on readmissions after transcatheter aortic valve replacement (32). First, unplanned readmissions are meaningful, as they are a health care expenditure and burden to patients. Second, measurements of unplanned readmissions are easily documented, reliable in hospital databases, and can be used to compare different health care providers. However, it is unclear that adjustment for patient variability will enable performance of the health care system to have direct impact on unplanned readmission rates. Furthermore, it is uncertain if unplanned readmissions can be modified by improvements in processes of care. There are many studies that have tested interventions aimed to reduce readmissions (33), but there are currently no measures with good evidence base that have been shown to reduced readmission after PCI.

The prevention of 30-day hospital readmissions has been previously reviewed by Leppin et al. (33). Although none of the studies in the review were in PCI settings, their reviewed classified different discharge interventions such as a comprehensive discharge planning and home follow-up protocol for elderly, which has been shown to reduce readmissions and health expenditures (34). Other interventions have been tested such as telephone follow-up (35), telemonitoring (36), and self-management-focused education programs (37). The only study of PCI patients tested an intervention, which involved initial patient readmission risk assessment and used a discharge checklist to ensure access to appropriate medications and close follow-up of high-risk patients, which resulted in a reduction of 30-day readmissions after PCI from 9.6% to 5.3% (38). Targeting specific causes of readmission may be an important area for future research. For example, specific care paths for recognized causes of readmission after PCI in the emergency room could preclude admission or direct patients for observation rather than inpatient status. Education for appropriate assessment and management of cardiac or procedure-related complication may also have a role in reducing readmissions.

Our study has several strengths. First, this is a large contemporary nationwide cohort that provides results that are generalizable to current PCI practices. The data are nearly complete with no missing data and previous studies using the NRD only having published data derived from 1 year (39). In addition, we could explore difference in predictors of all unplanned readmissions as well as noncardiac and cardiac readmissions and further explore mortality and length-of-stay outcomes for patients for both the index and readmission according to causes.

STUDY LIMITATIONS. Our study is also subject to the common limitations of retrospective analyses of administrative data. Our data were collected from administrative claims sampled from 21 states, which account for 49% of the U.S. population and hospitalizations, but the results of the current study may not be generalizable to all regions, as geographic heterogeneity in outcomes could not be explored (40). Second, although we were able to review data over a 2-year period, the overall data comprise 2 unique datasets corresponding to each in the period 2013 and 2014, and no linkage is possible between years. Third, even though we were able to adjust for a variety of variables and comorbidities, there is still the risk of residual confounding, as the study is observational in nature, and the NRD dataset does not capture measures of frailty that are known to affect PCI outcomes (41). Finally, causes of readmission were identified using the primary discharge diagnosis codes, which may be subject to reporting biases, although previous studies have used a similar approach for TAVR readmissions (42,43).

CONCLUSIONS

Our results suggest that 30-day readmissions in the United States is common and comorbid illnesses and places of discharge are important factors that influence readmissions. Clinicians should focus on the optimization of the management of any comorbid condition during a patient's index admission for PCI and consider developing outreach programs to patients discharged to short-term hospitals, other institutions, and care homes. There are important financial consequences of such readmissions, and further strategies to reduce the prevalence should be explored.

ADDRESS FOR CORRESPONDENCE: Dr. Chun Shing Kwok, Keele Cardiovascular Research Group, Centre for Prognosis Research, Institute for Primary Care and Health Sciences, Stoke-on-Trent ST4 7QB, United Kingdom. E-mail: shingkwok@doctors.org.uk.

PERSPECTIVES

WHAT IS KNOWN? Unplanned rehospitalizations following PCI carry significant burden to both patients and the local health care economy and are increasingly considered as an indicator of quality of care.

WHAT IS NEW? Our analysis of 833,344 PCI procedures demonstrates that unplanned readmissions within 30 days of the index PCI are common. Most readmissions were due to noncardiac causes (56.1%), and comorbidities and discharge location are strong predictors of unplanned 30-day readmission.

WHAT IS NEXT? Future work should explore if optimization of the management of any comorbid condition during a patient's index admission for PCI and outreach programs to patients discharged to short-term hospitals, other institutions, and care homes may reduce early readmissions.

REFERENCES

1. Weiss AJ, Elixhauser A, Andrews RM. Characteristics of Operating Room Procedures in U.S. Hospitals, 2011. Health Cost and Utilization Project Statistical Brief #170. Rockville, MD: Agency for Healthcare Research and Quality, 2011. Available at: https://www.hcup-us.ahrq.gov/reports/statbriefs/sb170-Operating-Room-Procedures-United-States-2011.jsp. Accessed February 8, 2018.

2. Chhatriwalla AK, Amin AP, Kennedy KF, et al. Association between bleeding events and in-hospital mortality after percutaneous coronary intervention. JAMA 2013;309:1022–9.

3. Kwok CS, Hulme W, Olier I, Holroyd E, Mamas MA. Review of early hospitalisation after percutaneous coronary intervention. Int J Cardiol 2017;227:370–7.

4. Fischer C, Lingsma HF, Marang-van de Mheen PJ, Kringos DS, Klazinga NS, Steyerberg EW. Is the readmission rate a valid quality indicator? A review of the evidence. PLoS One 2014;9:e112282.

5. Goldfield NI, McCullough E, Hughes JS, et al. Identifying potentially preventable readmissions. Health Care Financ Rev 2008;30:75–91.

6. Halfon P, Eggli Y, Pretre-Rohrbach I, Meylan D, Marazzi A, Burnand B. Validation of the potentially avoidable hospital readmission rate as a routine indicator of the quality of hospital care. Med Care 2006;44:972–81.

7. Kripalani S, LeFevre F, Phillips CO, Williams MV, Basaviah P, Baker DW. Deficits in communication and information transfer between hospital-based and primary care physicians. JAMA 2007;297:831–41.

8. Kwok CS, Wong CW, Shufflebotham H, et al. Early readmissions after acute myocardial infarction. Am J Cardiol 2017;120:723–8.

9. Pub. L. 111–148; Patient Protection and Affordable Care Act, 2010.

10. Robinson P. Hospital Readmissions and the 30 Day Threshold, 2010. A CHKS Market Intelligence Report, 2010. Available at: http://www.chks.co.uk/userfiles/files/CHKS%20Report%20Hospital%20readmissions.pdf. Accessed February 8, 2018.

11. HCUP Central Distributor. Introduction to the Nationwide Readmission Database (NRD) 2013. Healthcare Cost and Utilization Project (HCUP). Rockville, MD: Agency for Healthcare Research and Quality, 2015.

12. 2013 Introduction to the NRD. Healthcare Cost and Utilization Project (HCUP). Rockville, MD: Agency for Healthcare Research and Quality, 2015.

13. Elixhauser Comorbidity Software, Version 3.7. Available at: https://www.hcup-us.ahrq.gov/toolssoftware/comorbidity/comorbidity.jsp. Accessed February 8, 2018.

14. McNeely C, Markwell S, Vassileva CM. Readmissions after inpatient percutaneous coronary intervention in the Medicare population from 2000 to 2012. Am Heart J 2016;179:195–203.

15. Wasfy JH, Strom JB, O'Brien C, et al. Causes of short-term readmission after percutaneous coronary intervention. Circ Cardiovasc Interv 2014;7:97–103.

16. Yost GW, Puher SL, Graham J, et al. Readmission in the 30 days after percutaneous coronary intervention. J Am Coll Cardiol Intv 2013;6:237–44.

17. Khawaja FJ, Shah ND, Lennon RJ, et al. Factors associated with 30-day readmission rates after percutaneous coronary intervention. Arch Intern Med 2012;117:112–7.

18. Harjai KJ, Singh M, Boura J. Early readmissions after percutaneous coronary interventions in a rural tertiary center (from the Guthrie Health Off-label Stent [GHOST] registry). Am J Cardiol 2012;110:491–7.

19. Curtis JP, Schreiner G, Wang Y, et al. All-cause readmission and repeat revascularization after percutaneous coronary intervention in a cohort of Medicare patients. J Am Coll Cardiol 2009;54:903–7.

20. Hannan EL, Zhong Y, Krumholz H, et al. 30-Day readmission for patients undergoing percutaneous coronary interventions in New York State. J Am Coll Cardiol Intv 2011;4:1335–42.

21. Mamas MA, Fath-Ordoubadi F, Danzi GB, et al. Prevalence and impact of co-morbidity burden as defined by the Charlson co-morbidity index on 30-day and 1- and 5-year outcomes after coronary stent implantation (from the Nobori-2 Study). Am J Cardiol 2015;116:364–71.

22. Rashid M, Kwok CS, Gale CP, et al. Impact of co-morbid burden on mortality in patients with coronary heart disease, heart failure and cerebrovascular accident: a systematic review and meta-analysis. Eur Heart J Qual Care Cardiovasc Outcomes 2016;3:20–36.

23. Navarese EP, Tandjung K, Blaessen B, et al. Safety and efficacy of first and second generation durable polymer drug eluting stents and biodegradable polymer biolimus eluting stents in clinical practice: comprehensive network meta-analysis. BMJ 2013;347:f6530.

24. Palmerini T, Biondi-Zoccai G, Riva DD, et al. Stent thrombosis with drug-eluting stents: Is the paradigm shifting. J Am Coll Cardiol 2013;62:1915–21.

25. Wallentin L, Becker RC, Budaj A, et al. Ticagrelor versus clopidogrel in patients with acute

coronary syndromes. N Engl J Med 2009;361:1045–57.

26. Wiviott SD, Braunwald E, McCabe CH, et al. Prasugrel versus clopidogrel in patients with acute coronary syndromes. N Engl J Med 2007;357:2001–15.

27. Steg PG, Harrington RA, Emanuelsson H, et al. Stent thrombosis with ticagrelor versus clopidogrel in patients with acute coronary syndromes: an analysis from the prospective, randomized PLATO trial. Circulation 2013;128:1055–65.

28. De Bruyne B, Fearon WF, Pijls NH, et al. Fractional flow reserve-guided PCI for stable coronary artery disease. N Engl J Med 2014;371:1208–17.

29. Elgendy IY, Mahmoud AN, Elgendy AY, Bavry AA. Outcomes with intravascular ultrasound-guided stent implantation. Circ Cardiovasc Interv 2016;9:e003700.

30. Przybysz-Zdunek B, Ploch M, Pluta W, Dada M, Opolski G. All-cause readmissions and repeat revascularization after percutaneous coronary intervention. Cardiol J 2014;19:174–9.

31. Quality of Care and Outcomes Research in CVD and Stroke Working Groups. Measuring and improving quality of care. A report from the American Heart Association/American College of Cardiology First Scientific Forum on Assessment of Healthcare Quality in Cardiovascular Disease and Stroke. Circulation 2000;101:1483–93.

32. Swaminathan RV, Rao SV. Hospital readmission as a transcatheter aortic valve replacement performance measure too soon? Circ Cardiovasc Interv 2017;10:e004752.

33. Leppin AL, Gionfriddo MR, Kessler M, et al. Preventing 30-day hospital readmissions. A systematic review and meta-analysis of randomized trials. JAMA Intern Med 2014;174:1095–107.

34. Naylor MD, Brooten D, Campbell R, et al. Comprehensive discharge planning and home follow-up of hospitalized elders: a randomized clinical trial. JAMA 1999;281:613–20.

35. Altfeld SJ, Shier GE, Rooney M, et al. Effects of an enhanced discharge planning intervention for hospitalized older adults: a randomized trial. Gerontolgist 2013;53:430–40.

36. Bowles KH, Hanlon AL, Glick HA, et al. Clinical effectiveness, access to, and satisfaction with care using a telehomecare substitution intervention: a randomized controlled trial. Int J Telemed Appl 2011;2011:540138.

37. Davis KK, Mintzer M, Dennison Himmelfarb CR, et al. Targeted Intervention improves knowledge but not self-care or readmissions in heart failure patients with mild cognitive impairment. Eur J Heart Fail 2012;14:1041–9.

38. Tanguturi VK, Temin E, Yeh RW, et al. Clinical interventions to reduce preventable hospital readmission after percutaneous coronary intervention. Circ Cardiovasc Qual Outcomes 2016;9:600–4.

39. Khera R, Jain S, Pandy A, et al. Comparison of readmission rates following acute myocardial infarction in 3 patient age groups (18-44, 45-65 and ≥65 years) in the USA. Am J Cardiol 2017;120:1761–7.

40. O'Brien C, Valsdottir L, Wasfy JH, et al. Comparison of 30-day readmission rates after hospitalization for acute myocardial infarction in men versus women. Am J Cardiol 2017;120:1070–6.

41. Murali-Krishnan R, Iqbal J, Rowe R, et al. Impact of frailty on outcomes after percutaneous coronary intervention: a prospective cohort study. Open Heart 2015;2:e000294.

42. Hannan EL, Samadashivili Z, Jordan D, et al. Thirty-day readmissions after transcatheter aortic valve replacement versus surgical aortic valve replacement in patients with severe aortic stenosis in New York State. Circ Cardiovasc Interv 2015;8:e002744.

43. Kolte D, Khera S, Sardar R, et al. Thirty-day readmissions after transcatheteric aortic valve replacement in the United States. Circ Cardiovasc Interv 2017;10:e0004472.

KEY WORDS cost, percutaneous coronary intervention, predictors, readmission

APPENDIX For a supplemental table, please see the online version of this paper.