BMJ Open

Estimating the economic impacts of percutaneous coronary intervention in Australia: a registry-based cost burden study

Peter Lee ,[1] Angela L Brennan,[1] Dion Stub,[1,2] Diem T Dinh,[1] Jeffrey Lefkovits,[1,3] Christopher M Reid,[1,4] Ella Zomer,[1] Danny Liew[1]

To cite: Lee P, Brennan AL, Stub D, *et al*. Estimating the economic impacts of percutaneous coronary intervention in Australia: a registry-based cost burden study. *BMJ Open* 2021;**11**:e053305. doi:10.1136/bmjopen-2021-053305

► Prepublication history and additional supplemental material for this paper are available online. To view these files, please visit the journal online (http://dx.doi.org/10.1136/bmjopen-2021-053305).

Received 12 May 2021
Accepted 11 November 2021

[1]School of Public Health and Preventive Medicine, Monash University, Melbourne, Victoria, Australia
[2]Department of Cardiology, Alfred Hospital, Melbourne, Victoria, Australia
[3]Department of Cardiology, Royal Melbourne Hospital, Melbourne, Victoria, Australia
[4]Curtin University, Perth, Western Australia, Australia

Correspondence to
Peter Lee;
peter.lee1@monash.edu

ABSTRACT

Objectives In this study, we sought to evaluate the costs of percutaneous coronary intervention (PCI) across a variety of indications in Victoria, Australia, using a direct per-person approach, as well as to identify key cost drivers.

Design A cost-burden study of PCI in Victoria was conducted from the Australian healthcare system perspective.

Setting A linked dataset of patients admitted to public hospitals for PCI in Victoria was drawn from the Victorian Cardiac Outcomes Registry (VCOR) and the Victorian Admitted Episodes Dataset. Generalised linear regression modelling was used to evaluate key cost drivers. From 2014 to 2017, 20 345 consecutive PCIs undertaken in Victorian public hospitals were captured in VCOR.

Primary outcome measures Direct healthcare costs attributed to PCI, estimated using a casemix funding method.

Results Key cost drivers identified in the cost model included procedural complexity, patient length of stay and vascular access site. Although the total procedural cost increased from $A55 569 740 in 2014 to $A72 179 656 in 2017, mean procedural costs remained stable over time ($A12 521 in 2014 to $A12 185 in 2017) after adjustment for confounding factors. Mean procedural costs were also stable across patient indications for PCI ($A9872 for unstable angina to $A15 930 for ST-elevation myocardial infarction) after adjustment for confounding factors.

Conclusions The overall cost burden attributed to PCIs in Victoria is rising over time. However, despite increasing procedural complexity, mean procedural costs remained stable over time which may be, in part, attributed to changes in clinical practice.

Strengths and limitations of this study

- Multivariable generalised regression models were developed, allowing for the adjustment of cost models for key procedural and clinical characteristics and the identification of temporal trends in costs.
- Real-world registry data from the Victorian Cardiac Outcomes Registry were linked to the Victorian Admitted Episodes Dataset, allowing for key hospitalisations and patient data across Victoria to be captured for direct, 'bottom-up' costing.
- Analyses were limited to publicly admitted patients; the cost burden estimated in this study and findings may only be applicable to the public health sector across Australia and New Zealand.
- Analyses did not consider the cost impacts attributed to major adverse cardiac and cerebrovascular events and, readmissions, medications use or mortality following discharge; however, these remained stable over the 4-year period of evaluation.
- There was uncertainty around the extent to which changes in clinical practice had contributed to the stability observed in mean procedural costs over time.

INTRODUCTION

Cardiovascular disease (CVD), including coronary heart disease (CHD) and cerebrovascular disease, represents a significant cause of morbidity and mortality in Australia. In 2017–2018, the prevalence of CHD in Australia was estimated to be 3% of the adult population.[1] Although cardiovascular mortality has declined significantly since the 1960s, it remains the second leading cause of death (approximately 26%) in Australia.[1] The burden of CVD in terms of premature mortality and morbidity is also significant, with CHD and stroke comprising 11% and 5%, respectively, of the total disease burden in Australia in 2015.[2]

Of the estimated 580 300 Australians aged 18 years and over with CHD in 2017–2018, 40% had experienced angina and 74% had suffered acute coronary syndrome (ACS).[1] Percutaneous coronary intervention (PCI) is the preferred means of revascularisation therapy for many patients presenting with ACS based on Australian and international guidelines.[3 4] In non-ACS settings, elective PCI may also be indicated for the symptom management of stable angina.[3 4] In

2017–2018, 44 886 PCIs were performed in Australia.[1] In Victoria, 12 447 patients underwent PCI in 2018, 49% of which was for ACS.[5]

The costs attributed to the management of CVD are expectedly high. Based on estimates from the Australian Institute of Health and Welfare, in 2018–2019, expenditure for CVD amounted to $A11.8 billion, comprising 9% of the total health expenditure.[6] Of this, 68% was attributed to hospital admissions for CVD.[6]

Government estimates of health expenditure are generally generated via combination of 'top-down' and 'bottom-up' approaches.[7] In a 'top-down' approach, total expenditure is apportioned to various disease states according to epidemiological data.[8 9] However, this approach is designed for aggregate analysis of government expenditure and does not allow for the estimation of cost burden and identification of key cost drivers at the microlevel.[10] In contrast, a 'bottom-up' costing approach, in which individual healthcare resources are determined and then aggregated, allows for a greater understanding of patient factors which drive health systems costs.[10]

There are currently limited data on the direct costs of PCI in Australia based on a 'bottom-up' approach. In this study, we aimed to estimate the economic burden of PCI in Victoria for the public healthcare system, and explore key drivers of procedural costs across ACS and non-ACS indications for PCI using data from the Victorian Cardiac Outcomes Registry (VCOR).

METHODS

Data sources

VCOR is a cardiac clinical quality registry established in 2012 for the purposes of monitoring and benchmarking hospital performance and outcomes in terms of PCIs undertaken in Victoria, Australia, and has previously been described in detail.[11] Since 2017, all public and private PCI-capable centres in Victoria have contributed data to VCOR. However; for the purposes of this study, our analyses were limited to publicly admitted patients.[5] Patient in-hospital baseline, demographic and clinical characteristics, as well as procedural outcomes, are collected from participating hospital sites through hospital-appointed data managers. Furthermore, patient follow-up is performed at 30 days to collect data on patient outcomes, including mortality and major adverse cardiac and cerebrovascular events (MACCE).[5 11]

To obtain relevant cost data, VCOR was linked to the Victorian Admitted Episodes Dataset (VAED), which contains data on all admissions into all Victorian hospitals, as well as diagnostic and procedural data.[12] VAED variables reflect hospital activity for funding purposes.[13 14] Of 32 852 patients enrolled in VCOR between 1 January 2013 and 31 December 2017 who were alive at 30 days following PCI, 194 were excluded from linkage due to insufficient case information, and successful matching was achieved for 28 488 (87%) patients.[15] For the purposes of this study, we analysed data for all PCIs undertaken in Victorian public hospitals from 1 January 2014 to 31 December 2017. Data from 2013, the year of commencement of data collection, were excluded as it was an incomplete dataset, with several sites only contributing data for 1 month.[16 17] Cost estimates were limited to the public hospital setting, as there are differences in cost reporting between public and private hospitals and discrepancies in the relative financial efficiency between public and private hospitals.[18] Further, cost data were not available from private hospitals contributing data to VCOR.

Costs

In Victoria, public hospitals are funded through casemix funding.[19 20] The basic casemix funding method allocates cost weights according to diagnosis-related groups (DRGs), which classify patients who have similar conditions and similar resource use.[19 20] The DRG cost weight is calculated as the ratio of the average cost of all episodes in a DRG to the average cost of all episodes across all DRGs.[19 20] As such, every episode for a DRG is funded at a flat rate determined by the DRG cost weight and the price paid per cost weight. This basic casemix funding method has been refined to account for differences in hospital length of stay as patients in a given DRG need various levels of care. This improved casemix funding is known as the 'weighted inlier-equivalent separation (WIES).[19 20]

The cost attributed to PCIs undertaken in Victorian public hospitals was estimated using the WIES casemix funding method, in which a WIES weight[18 21] was multiplied by the WIES price set for a given financial year to estimate the cost for an episode of care.[19] Additional details pertaining to the WIES weights used to inform procedural costs are presented in the online supplemental appendices. All costs were adjusted for inflation to 2020 Australian dollars (A$) based on the Health Price Index.[7]

Henceforth, the per-person cost of PCI will be referred to as the procedural cost, which is comprised of all costs by the hospital during a patient's stay, including the PCI procedure itself, hospital length of stay, critical care and medications. However, as the DRG and WIES weights represent a relative measure of resources use for each episode of care, the cost components cannot be assessed separately.

Statistical analysis

Continuous variables were expressed as mean±SD or median (IQR) where relevant, while categorical variables were expressed as frequencies (percentages). Differences in patient and procedural characteristics between years were compared using univariable linear regression, or univariable generalised linear regression models (GLM) with gamma distributions and log link where appropriate, for continuous variables. Generalised linear regression modelling with gamma distribution and log-link was used to account for the positive skew associated with length-of-stay and door-to-balloon/device time parameters.[22]

Pearson's χ^2 tests were used to assess trends over time for categorical variables.

Multivariable GLM with gamma distribution and log link was performed to establish key drivers in patient costs.[22] Multivariable GLM was also performed to identify trends in patient procedural costs over time across the ACS groups, and for patients with non-ACS indications for PCI. To identify potential confounders of procedural costs, univariable GLMs with gamma distribution and log links were performed across the following variables: age (<75 years and ≥75 years); sex; indigenous status; body mass index (BMI); in-hours hospital arrival (between 08:00 and 18:00 hours on a workday); ACS status (non-ACS, unstable angina (UA), non-ST elevation myocardial infarction (NSTEMI), STEMI); cardiogenic shock or intubated out-of-hospital cardiac arrest (OHCA); left ventricular ejection fraction (LVEF); medicated diabetes mellitus; peripheral vascular disease; cerebrovascular disease; chronic oral anticoagulation therapy; prior coronary artery bypass grafting (CABG); previous PCI; use of glycoprotein IIb/IIIa inhibitors; use of thienopyridine or ticagrelor; estimated glomerular filtration rate (eGFR); percutaneous access site selection; required mechanical ventricular support; lesion complexity (American College of Cardiology/American Heart Association type A/B1 vs type B2/C lesions); unprotected left main PCI; chronic total occlusion PCI and in-stent restenosis PCI.[23 24] Additionally, univariable GLM was performed using the variable for the year of procedure to evaluate the impact of temporal changes in patient and procedural characteristics. Variables found to have a significant impact on patient costs (p<0.05) were included in the final multivariable model to explore key drivers of patient costs.

All statistical analyses were performed using Stata V.14 (StataCorp).

Patient and public involvement

No patients or the public were involved in this study.

RESULTS

From 1 January 2014 to 31 December 2017, 20,345 PCIs for non-ACS or ACS indications undertaken in Victorian public hospitals were captured in VCOR. Baseline clinical and preprocedural characteristics are presented in table 1. For comparison, patient clinical characteristics for PCIs undertaken across Victorian private hospitals are presented in the online supplemental appendix.

Compared with patients in 2014, patients in 2017 had higher baseline risk. They were more likely to be aged ≥75 years (p<0.001), had greater average BMI (p=0.015) and lower mean eGFR (p=0.011) and LVEF (p=0.002). Over time, a greater proportion of patients were treated with PCI for NSTEMI or STEMI indications (p<0.001) and experienced cardiogenic shock (p=0.049) and preprocedural cardiac arrest (p=0.022). The proportion of patients with a prior history of cerebrovascular disease, patients being treated with chronic oral anticoagulant therapy, and patients presenting with a prior PCI also increased over the 4-year period (all p<0.05).

Patient procedural characteristics, door-to-balloon time metrics for patients with STEMI (excluding in-hospital transfers and inpatients) and 30-day outcomes are presented in table 2.

Over time, patients were more likely to be managed with radial access PCI (p<0.001). Additionally, patients were likely to present with greater case complexity over time. There were increases in the proportion of patients being treated with multivessel coronary artery disease (5.15% in 2014 to 7.68% in 2017), presenting with American College of Cardiology/American Heart Association B2/C lesion complexity (53.57% in 2014 to 57.66% in 2017) or with unprotected left main artery disease (0.81% in 2014 to 1.31% in 2017), and a greater occurrence of postprocedural renal impairment (2.49% in 2014 to 3.99% in 2017) observed across public hospitals over time in Victoria (all p<0.05). Drug-eluting stent (DES) use increased over the 4-year period (68% in 2014 to 88% in 2017), and STEMI patients were more likely to be treated within parameters for timely reperfusion (all p<0.05). Procedural success rates did not change (p=0.148), and patients were more likely to be referred to cardiac rehabilitation services over the 4-year period (p<0.001). There was no trend in patient mortality, MACCE and cardiac readmissions at 30 days throughout the study period (all p>0.05).

Table 3 summarises the total costs of PCI over the 4 years of evaluation, and the change in mean costs over time stratified by non-ACS, UA, NSTEMI and STEMI indications.

The total costs of PCI increased considerably over the 4-year period, from $A55 569 740 in 2014 to $A72 179 656 in 2017. However, based on multivariable GLM, adjusted mean procedural costs remained stable over time, from $A12 521 (95% CI $A12 323 to $A12,720) in 2014 to $A12 185 (95% CI $A11 986 to $A12 384) in 2017. Procedural costs also remained stable across the ACS subgroups and for patients undergoing PCI for non-ACS indications over time (table 3). The results of the univariable and multivariable regression analyses are presented in table 4.

Factors associated with lower costs were PCI for UA and in-hours arrival (all p<0.001). Costs were higher for femoral access (vs radial access) PCI (3% increase, p<0.001) and increasing case complexity, as evidenced by the considerable percentage increase in mean costs with increasing patient length-of-stay (p<0.001). Other indicators of case complexity, including NSTEMI/STEMI indications for PCI, OHCA, multivessel disease and required mechanical ventricular support were also associated with increases in costs (all p<0.05). Adjusted mean procedural costs were highest for patients with STEMI (4-year adjusted mean: $A15 930, 95% CI: $A15606 to $A16254). Patients with NSTEMI (4-year adjusted mean: $A12 677, 95% CI $A12 495 to $A12 860) or UA (4-year adjusted mean: $A9872, 95% CI $A9653 to $A10091) and patients undergoing PCI for non-ACS indications (4-year adjusted mean: $A10142, 95% CI: $A10019 to $A10264) incurred lower costs.

Table 1 Characteristics of patients undergoing PCI in Victorian public hospitals

Variable	2014 (N=4424)	2015 (N=4838)	2016 (N=5225)	2017 (N=5858)	Total (N=20 345)	P value*
Age (years)						<0.001
Mean (SD)	62.95 (11.82)	63.25 (11.74)	63.56 (12.00)	64.32 (12.05)	63.57 (11.93)	
Median (IQR)	63 (18)	63 (17)	64 (17)	65 (17)	64 (18)	
Age group (n, N%)						
<75	3601 (81.40)	3891 (80.43)	4190 (80.19)	4559 (77.83)	16 241 (79.83)	
≥75	823 (18.60)	947 (19.57)	1035 (19.81)	1299 (22.17)	4104 (20.17)	
Aboriginal/Torres strait Islander (n, N%)	31 (0.70)	26 (0.54)	27 (0.52)	47 (0.80)	131 (0.64)	0.195
Sex (n, N%)						0.286
Male	3433 (77.60)	3749 (77.49)	4057 (77.65)	4471 (76.32)	15 710 (77.22)	
Female	991 (22.40)	1089 (22.51)	1168 (22.35)	1387 (23.68)	4635 (22.78)	
BMI (n, N%)						0.015
Underweight (<18.5 kg/m^2)	30 (0.68)	28 (0.58)	57 (1.09)	37 (0.63)	152 (0.75)	
Normal (18.5–24.9 kg/m^2)	944 (21.34)	1060 (21.91)	1091 (20.88)	1331 (22.72)	4426 (21.75)	
Overweight (25–29.9 kg/m^2)	1783 (40.30)	1886 (38.98)	2068 (39.58)	2245 (38.32)	7982 (39.23)	
Obese (≥30 kg/m^2)	1601 (36.19)	1786 (36.92)	1957 (37.45)	2180 (37.21)	7524 (36.98)	
Missing	66 (1.49)	78 (1.61)	52 (1.00)	65 (1.11)	261 (1.28)	
ACS type (n, N%)						<0.001
Non-ACS	1574 (35.58)	1787 (36.94)	1913 (36.61)	2320 (39.60)	7594 (37.33)	
UA	325 (7.35)	305 (6.30)	351 (6.72)	301 (5.14)	1282 (6.30)	
NSTEMI	1247 (28.19)	1381 (28.54)	1518 (29.05)	1610 (27.48)	5756 (28.29)	
STEMI	1278 (28.89)	1365 (28.21)	1443 (27.62)	1627 (27.77)	5713 (28.08)	
Cardiogenic shock (n, N%)	131 (2.96)	169 (3.49)	198 (3.79)	175 (2.99)	673 (3.31)	0.049
Intubated OHCA (n, N%)	70 (1.58)	78 (1.61)	96 (1.84)	109 (1.86)	353 (1.74)	0.594
Pre-procedure cardiac arrest (n, N%)	108 (2.44)	104 (2.15)	117 (2.24)	95 (1.62)	424 (2.08)	0.022
LVEF grade (n, N%)						0.002
Normal (≥50%)	1931 (43.65)	2081 (43.01)	2310 (44.21)	2496 (42.61)	8818 (43.34)	
Mild (45%–49%)	744 (16.82)	938 (19.39)	841 (16.10)	997 (17.02)	3520 (17.30)	
Moderate (35%–44%)	355 (8.02)	364 (7.52)	467 (8.94)	502 (8.57)	1688 (8.30)	
Severe (<35%)	178 (4.02)	166 (3.43)	211 (4.04)	224 (3.82)	779 (3.83)	
Missing	1216 (27.49)	1289 (26.64)	1396 (26.72)	1639 (27.98)	5540 (27.23)	
Medicated diabetes (n, N%)	966 (21.84)	1134 (23.44)	1153 (22.07)	1265 (21.59)	4518 (22.21)	0.115
Peripheral vascular disease (n, N%)	168 (3.80)	166 (3.43)	189 (3.62)	202 (3.45)	725 (3.56)	0.744
Cerebrovascular disease (n, N%)	137 (3.10)	225 (4.65)	175 (3.35)	266 (4.54)	803 (3.95)	<0.001
Chronic oral anticoagulant therapy (n, N%)	146 (3.30)	186 (3.84)	261 (5.00)	318 (5.43)	911 (4.48)	<0.001
Previous CABG (n, N%)	300 (6.78)	321 (6.63)	335 (6.41)	378 (6.45)	1334 (6.56)	0.873
Previous PCI (n, N%)	1201 (27.15)	1438 (29.72)	1513 (28.96)	1767 (30.16)	5919 (29.09)	0.006
Dialysis (n, N%)	51 (1.15)	69 (1.43)	80 (1.53)	67 (1.14)	267 (1.31)	0.206
Renal transplant (n, N%)	13 (0.29)	15 (0.31)	21 (0.40)	25 (0.43)	74 (0.36)	0.608
Renal replacement therapy (n, N%)						0.207
No	4371 (98.80)	4762 (98.43)	5139 (98.35)	5788 (98.81)	20 060 (98.60)	
Yes	1 (0.02)	5 (0.10)	6 (0.12)	3 (0.05)	15 (0.07)	
Missing	52 (1.18)	71 (1.47)	80 (1.53)	67 (1.14)	270 (1.33)	
Fibrinolytic therapy (n, N%)	167 (3.77)	219 (4.53)	233 (4.46)	240 (4.10)	859 (4.22)	0.236
eGFR						0.011

Continued

Table 1 Continued

Variable	2014 (N=4424)	2015 (N=4838)	2016 (N=5225)	2017 (N=5858)	Total (N=20 345)	P value*
Mean (SD)	95.00 (38.28)	95.31 (38.92)	95.90 (40.57)	93.16 (39.68)	94.78 (39.44)	
Median (IQR)	91.37 (48.84)	91.34 (49.98)	91.74 (50.35)	89.09 (49.64)	90.77 (49.62)	
eGFR group (n, N%)						0.010
Normal (≥90 mL/min/1.73 m^2)	3385 (76.51)	3705 (76.58)	3974 (76.06)	4339 (74.07)	15 403 (75.71)	
Moderate (30–89 mL/min/1.73 m^2)	632 (14.29)	726 (15.01)	741 (14.18)	908 (15.50)	3007 (14.78)	
Severe (<30 mL/min/1.73 m^2)	93 (2.10)	109 (2.25)	117 (2.24)	141 (2.41)	460 (2.26)	
Missing	314 (7.10)	298 (6.16)	393 (7.52)	470 (8.02)	1475 (7.25)	

There were 1 missing case for medicated diabetes status, 4 for OHCA, 1 for in-hospital preprocedure cardiac arrest, 3 for peripheral vascular disease, 2 for cerebrovascular disease or chronic oral anticoagulant therapy and 1 for renal transplant.
*P value for year-to-year trend.
ACS, acute coronary syndrome; BMI, body mass index; CABG, coronary artery bypass graft; eGFR, estimated glomerular filtration rate; LVEF, left ventricular ejection fraction; NSTEMI, non-STEMI; OHCA, out-of-hospital cardiac arrest; PCI, percutaneous coronary intervention; STEMI, ST-elevation myocardial infarction; UA, unstable angina.;

DISCUSSION

To the best of our knowledge, our study is the first to evaluate the costs of PCI in Victorian public hospitals. The cost burden of PCI increased from 2013 to 2017, but mean procedural costs remained stable over this period. Expectedly, patient factors which significantly increased costs included moderate and severe reductions in LVEF, declining eGFR, the need for mechanical ventricular support and cardiogenic shock or intubated OHCA. Higher acuity ACS presentations were also associated with greater costs. The observed increase in total costs of PCI over time may be attributed to the increased proportion of patients presenting with multiple comorbidities or NSTEMI/STEMI, and an overall increase in the number of procedures performed in Victoria.[5] Similar trends in the evolution of patient risk in contemporary practice have been observed across other registries in Australia, the UK and the USA.[25–27]

Adjusted mean procedural costs remained stable over time across non-ACS/ACS indications (see online supplemental appendix). This is despite the greater number of patients presenting with multiple comorbidities for PCI, and may be attributed to changes in patient management over time and across institutions. Previous Australian studies have explored the cost and clinical impacts of routine PCI in multivessel coronary artery disease compared with CABG, the appropriate use of DESs, and intravascular ultrasound guidance for PCI.[28–30] These studies explore the cost consequences of evidence-based changes in clinical practice, and highlight the value of economic analyses for improving efficiency in cardiac care.[28–30]

In our study, a key cost driver identified was hospital length of stay. Across our cohort, patients were more likely to be treated with radial access (43% in 2014, increasing to 68% in 2017, p<0.001) PCI (see online supplemental appendix), which is associated with improved patient outcomes as well as shorter length of stay. Our results demonstrate that radial access is also associated with lower procedural costs. Our group recently published a cost-effectiveness analysis of radial access PCI using trial-based data.[31] We found that radial access was cost-saving compared with femoral access PCI, via a reduction in major bleeding and mortality.[31]

Our study highlights the importance of ongoing performance benchmarking and feedback in reducing the cost burden attributed to PCI. Recent data from VCOR have highlighted that despite evidence for the safety of same-day discharge of patients undergoing elective PCI, same-day discharge remains uncommon in Victoria, being implemented in only 3% of elective PCIs from 2014 to 2017.[32] As length of stay was a significant driver of patient costs in our multivariable model, increasing the rate of same-day discharge for elective PCI is likely to result in further cost savings.[32–35] An economic evaluation using registry-based data is warranted to explore the impacts of increasing the uptake of same-day discharge for elective PCI on costs.[32] Timely reperfusion (as indicated by door-to-balloon/device times ≤90 min) was associated with improved outcomes for STEMI patients.[36] In our dataset, the proportion of STEMI patients undergoing timely reperfusion increased significantly over the 4-year period (68% in 2014 increasing to 78% in 2017, p<0.001) (see online supplemental appendix). A future study exploring the clinical and cost impacts attributed to improvements in this metric is warranted.

A key strength of our study lies in the use of linked data from VCOR and the VAED. VCOR collects granular data on all PCIs undertaken in Victoria and the VAED is complete for all hospitalisations occurring in the state, with relevant variables to allow for 'bottom-up' costing. A key limitation to our study was that we limited our analyses to explore the costs of PCI attributed to publicly admitted patients only. Hence, the results are confined to the public hospital setting and likely underestimates the true costs of PCI in Victoria. While the majority of patients presenting

Table 2 Procedural characteristics of PCI in Victorian public hospitals

Variable	Year 2014 (N=4424)	2015 (N=4838)	2016 (N=5225)	2017 (N=5858)	Total (N=20 345)	P value*
Access site (n, N%)						<0.001
Radial	1888 (42.68)	2491 (51.49)	3287 (62.91)	4010 (68.45)	11 676 (57.39)	
Femoral	2536 (57.32)	2347 (48.51)	1938 (37.09)	1848 (31.55)	8669 (42.61)	
Peri-procedural medications (n, N%)						<0.001
Glycoprotein IIb/IIIa inhibitor	754 (17.04)	709 (14.65)	628 (12.02)	633 (10.81)	2724 (13.39)	
Thienopyridine or ticagrelor	3531 (79.81)	3644 (75.32)	3794 (72.61)	4064 (69.38)	15 033 (73.89)	
Aspirin	73.89 (76.85)	4154 (85.86)	4755 (91.00)	5655 (96.53)	17 964 (88.30)	
Antithrombin	4070 (92.00)	4567 (94.40)	4814 (92.13)	5349 (91.31)	18 800 (92.41)	
Lesion characteristics (n, %N)						
Treated vessel						
Left main coronary artery	62 (1.40)	64 (1.32)	88 (1.68)	114 (1.95)	328 (1.61)	0.044
Multi-lesion disease	637 (14.40)	811 (16.76)	908 (17.38)	1121 (19.14)	3477 (17.09)	<0.001
Multivessel disease	228 (5.15)	297 (6.14)	360 (6.89)	450 (7.68)	1335 (6.56)	<0.001
Lesion complexity						<0.001
Type A or B1	2054 (46.43)	2415 (49.92)	2436 (46.62)	2480 (42.34)	9385 (46.13)	
Type B2 or C	2370 (53.57)	2423 (50.08)	2789 (53.38)	3378 (57.66)	10 960 (53.87)	
Unprotected left main PCI (n, %N)	36 (0.81)	35 (0.72)	63 (1.21)	77 (1.31)	211 (1.04)	0.006
Chronic total occlusion (n, %N)	151 (3.41)	203 (4.20)	223 (4.27)	221 (3.77)	798 (3.92)	0.111
In-stent restenosis (n, %N)	221 (5.00)	257 (5.31)	251 (4.80)	289 (4.93)	1018 (5.00)	0.690
Device used (n, %N)						
BMS only	1143 (25.84)	951 (19.66)	604 (11.56)	300 (5.12)	2998 (14.74)	<0.001
DES	2991 (67.61)	3477 (71.87)	4296 (82.22)	5170 (88.26)	15 934 (78.32)	<0.001
POBA only	270 (6.10)	332 (6.86)	291 (5.57)	380 (6.49)	1273 (6.26)	0.047
Postprocedural characteristics						
Procedure success (n, %N)	4019 (90.85)	4338 (89.67)	4739 (90.70)	5271 (89.98)	18 367 (90.28)	0.148
New renal impairment (n, %N)	110 (2.49)	148 (3.06)	148 (2.83)	234 (3.99)	640 (3.15)	<0.001
Discharge characteristics						
Length-of-stay						0.715
Median (IQR)	3 (3)	3 (3)	3 (3)	3 (3)	3 (3)	
Referred to cardiac rehabilitation (n, %N)	3274 (74.01)	3923 (81.09)	4326 (82.79)	4438 (75.76)	15 961 (78.45)	<0.001

Door to balloon time (STEMI only)†	Year 2014 (n=775)	2015 (n=819)	2016 (n=846)	2017 (n=1042)	Total (n=3482)	
Door-to-balloon/device time (minutes, median (IQR))	70 (50)	72 (52)	68 (49)	63 (43)	68 (48)	0.008
Door-to-balloon/device time (n, %N)						<0.001

Continued

Table 2 Continued

Door to balloon time (STEMI only)†	Year 2014 (n=775)	2015 (n=819)	2016 (n=846)	2017 (n=1042)	Total (n=3482)	
≤90 min	529 (68.26)	563 (68.74)	611 (72.22)	814 (78.12)	2517 (72.29)	
>90 min	244 (31.48)	252 (30.77)	235 (27.78)	227 (21.79)	958 (27.51)	
Missing	2 (0.26)	4 (0.49)	0 (0.00)	1 (0.10)	7 (0.20)	
Outcomes (0–30 days)						
Mortality	133 (3.01)	123 (2.54)	147 (2.81)	164 (2.80)	567 (2.79)	0.600
MACCE	252 (5.70)	242 (5.00)	252 (4.82)	286 (4.88)	1032 (5.07)	0.192
Cardiac readmissions	249 (5.63)	300 (6.20)	329 (6.30)	400 (6.83)	1278 (6.28)	0.101

*P value for year-to-year trend.
†Excluding all inter-hospital transfer arrivals and patients with STEMI onset while a current in-patient.
BMS, bare metal stent; DES, drug-eluting stent; MACCE, major adverse cardiac or cerebrovascular event; PCI, percutaneous coronary intervention; POBA, plain old balloon angioplasty; STEMI, ST-elevation myocardial infarction.

with ACS are treated in public hospitals in Australia (64% of ACS cases in public hospitals vs 30% in the private sector,[37] indications for PCI performed at private hospitals are more likely to be for non-ACS or elective cases for older patients (see online supplemental appendix).[5 38] As demonstrated in our analyses, case complexity and ACS-indications are key cost drivers. Hence, although our estimates are only applicable to the public health sector, our analysis likely captures the majority of the cost burden attributed to PCI in Victoria. Our findings may be generalised across PCI-capable centres in Australia and New Zealand, as the Australian and New Zealand healthcare systems are both heavily subsidised by government.[5 39] Furthermore, both countries have commonality in physician training and guidelines for the management of ACS and PCI.[3 38 40 41] Importantly, other registry-based studies conducted in the UK, Sweden and the USA on the evolution of PCI over time have found considerable improvements in both hospital adherence to guideline-recommended practices and patient outcomes.[25 42–45]

Table 3 Total annual cost burden and mean cost per procedure over time and indication

Variable	Year 2014	2015	2016	2017
Total annual cost	$55 569 740	$59 958 968	$67 189 976	$72 179 656
Mean procedural cost				
Crude	$12 629 ($12 294–$12 965)	$12 468 ($12 135–$12 801)	$12 936 ($12 563–$13 310)	$12 473 ($12 120–$12 825)
Adjusted*	$12 521 ($12 323–$12 720)	$12 407 ($12 210–$12 603)	$12 745 ($12 552–$12 938)	$12 185 ($11 986–$12 384)
Stratified mean procedural cost				
Non-ACS				
Crude	$10 212 ($9804–$10 621)	$10 325 ($10 058–$10 593)	$10 439 ($10 195–$10 683)	$10 554 ($10 184–$10 924)
Adjusted*	$10 144 ($9975–$10 313)	$9996 ($9824–$10 168)	$10 291 ($10127–$10455)	$10 127 ($9956–$10 298)
UA				
Crude	$9622 ($9093–$10 151)	$9766 ($9419–$10 114)	$9913 ($9555–$10 271)	$10 061 ($9498–$10 6245)
Adjusted*	$9607 ($9375–$9838)	$9826 ($9575–$10 078)	$10 363 ($10 103–$10 623)	$9619 ($9373–$9866)
NSTEMI				
Crude	$12 266 ($11 781–$12 751)	$12 529 ($12 208–$12 850)	$12 797 ($12 491–$13 103)	$13 071 ($12 598– $13 545)
Adjusted*	$12 598 ($12 366–$12 830)	$12 737 ($12 518–$12 957)	$12 879 ($12 665–$13 093)	$12 497 ($12 238–$12 757)
STEMI				
Crude	$16 792 ($15 991–$17 592)	$16 383 ($15 875–$16 891)	$15 983 ($15 519–$16 448)	$15 594 ($14 910–$16 278)
Adjusted*	$16 204 ($15 812–$16 597)	$15 811 ($15 439–$16 184)	$16 514 ($16 118–$16 910)	$15 301 ($14 959–$15 644)

*Based on multivariable generalised linear regression modelling, adjusted for key confounding variables. All costs are reported in 2020 Australian Dollars (A$).
Non-ACS, non-acute coronary syndrome; NSTEMI, non-STEMI; STEMI, ST-elevation myocardial infarction; UA, unstable angina.

Table 4 Results of univariable and multivariable generalised linear regression modelling

	Univariable				Multivariable			
Variable	**B-coefficient**	**% Change**	**95% CI**	**P value**	**B-coefficient**	**% Change**	**95% CI**	**P value**
Year								
2014	REF				REF			
2015	−0.013	−1.28%	−0.050 to 0.025	0.503	−0.011	−1.09%	−0.030 to 0.008	0.313
2016	0.024	2.43%	−0.015 to 0.063	0.231	0.013	1.30%	−0.005 to 0.031	0.054
2017	−0.013	−1.24%	−0.051 to 0.026	0.528	−0.016	−1.63%	−0.036 to 0.003	0.409
Socioeconomic status					–	–	–	–
Lower quartile	−0.0246	−2.43%	−0.065 to 0.016	0.237				
Sex								
Female	−0.008	−0.82%	−0.038 to 0.021	0.585	–	–	–	–
Aboriginal/Torres Strait Islander	0.165	17.89%	0.094 to 0.235	<0.001	0.233	26.18%	0.189 to 0.276	<0.001
ACS								
Non-ACS	REF							
UA	−0.056	−5.41%	−0.095 to −0.016	0.006	−0.179	−16.35%	−0.207 to −0.150	<0.001
NSTEMI	0.199	22.05%	0.167 to 0.231	<0.001	0.031	3.18%	0.006 to 0.057	0.016
STEMI	0.440	55.27%	0.404 to 0.475	<0.001	0.072	7.50%	0.042 to 0.103	<0.001
Age								
≥75 years	0.000	−0.02%	−0.029 to 0.028	0.987	–	–	–	–
In hours arrival	−0.108	−10.25%	−0.136 to −0.080	<0.001	−0.020	−2.02%	−0.034 to −0.007	0.004
Length-of-stay (quartiles)								
1	REF							
2	0.208	23.07%	0.193 to 0.221	<0.001	0.210	23.42%	0.190 to 0.230	<0.001
3	0.306	35.76%	0.295 to 0.316	<0.001	0.269	30.88%	0.247 to 0.291	<0.001
4	0.865	137.49%	0.828 to 0.902	<0.001	0.640	90.27%	0.609 to 0.677	<0.001
LVEF grade								
Normal (≥50%)	REF							
Mild (45%–49%)	0.123	13.06%	0.092 to 0.154	<0.001	−0.005	−0.47%	−0.022 to 0.013	0.602
Moderate (35%–44%)	0.311	36.49%	0.254 to 0.368	<0.001	0.037	3.79%	0.007 to 0.067	0.014
Severe (<35%)	0.712	103.76%	0.615 to 0.809	<0.001	0.146	15.71%	0.088 to 0 .203	<0.001
Medicated diabetes mellitus	0.028	2.81%	−0.006 to 0 .061	0.105	–	–	–	–
PVD	0.178	19.46%	0.109 to 0.246	<0.001	0.073	7.59%	0.031 to 0.116	0.001
CBVD	0.167	18.20%	0.071 to 0.263	0.001	0.016	1.65%	−0.029 to 0.063	0.489

Continued

Table 4 Continued

Variable	Univariable				Multivariable			
	B-coefficient	% Change	95% CI	P value	B-coefficient	% Change	95% CI	P value
Chronic oral anticoagulant therapy	0.087	9.12%	0.016 to 0.159	0.017	0.033	3.33%	−0.003 to 0.069	0.076
Prior PCI	−0.109	−10.31%	−0.137 to −0.081	<0.001	0.031	3.14%	0.014 to 0.048	<0.001
Medications								
Glycoprotein	0.273	31.34%	0.231 to 0.314	<0.001	0.009	0.88%	−0.014 to 0.031	0.453
Thienopyridine or ticagrelor	−0.045	−4.42%	−0.079 to −0.011	0.010	−0.005	−0.57%	−0.021 to 0.010	0.465
Aspirin	−0.004	−0.41%	−0.041 to 0.032	0.827	–	–	–	–
Antithrombin	0.134	14.37%	0.091 to 0.178	<0.001	0.032	3.27%	0.009 to 0.055	0.005
eGFR group								
Normal (≥90 mL/min/1.73 m^2)	REF							
Moderate (30–89 mL/min/1.73 m^2)	0.134	14.33%	0.093 to 0.174	<0.001	0.004	0.43%	−0.015 to 0.024	0.666
Severe (<30 mL/min/1.73 m^2)	0.377	45.75%	0.281 to 0.472	<0.001	0.100	10.47%	0.032 to 0.167	0.004
Access								
Femoral	0.144	15.46%	0.115 to 0.172	<0.001	0.028	2.82%	0.014 to 0.041	<0.001
Mechanical ventricular support	1.341	282.47%	1.178 to 1.505	<0.001	0.510	66.58%	0.357 to 0.664	<0.001
Multivessel disease	0.183	20.08%	0.112 to 0.254	<0.001	0.033	3.36%	−0.005 to 0.071	0.090
Lesion complexity								
Lesion B2 or C	0.132	14.17%	0.106 to 0.159	<0.001	0.007	0.68%	−0.006 to 0.020	0.305
Unprotected left main PCI	0.492	63.63%	0.290 to 0.695	<0.001	−0.067	−6.47%	−0.158 to 0.025	0.155
Shock or OHCA	1.183	226.73%	1.102 to 1.266	<0.001	0.695	100.00%	0.621 to 0.769	<0.001
Chronic total occlusion	0.018	1.82%	−0.084 to 0.120	0.729	–	–	–	–
ISR	0.000	−0.18%	−0.077 to 0.073	0.962	–	–	–	–

ACS, acute coronary syndrome; BMI, body mass index; CABG, coronary artery bypass graft; CBVD, cerebrovascular disease; eGFR, estimated glomerular filtration rate; ISR, in-stent restenosis; LVEF, left ventricular ejection fraction; NSTEMI, non-STEMI; OHCA, out-of-hospital cardiac arrest; PCI, percutaneous coronary intervention; PVD, peripheral vascular disease; REF, Reference; STEMI, ST-elevation myocardial infarction; UA, unstable angina.

Although a limited number of studies have explored the cost impacts attributed to these trends, it is likely that findings of improved health services efficiency will be observed against a background of improved patient management, in line with our analyses.

Additionally, our analyses did not consider the cost impacts attributed to patient MACCE, readmissions, medications use and patient mortality following discharge, as these cost inputs were not captured in the dataset and our analyses were limited to exploring drivers of procedural costs. However, MACCE, readmissions and mortality remained stable and low throughout the period of evaluation, in line with findings from VCOR annual reporting and similar studies using registry datasets (table 2).[5 16 27] Finally, WIES weights are adjusted annually using cost data reported from the previous financial year to the Victorian Cost Data Collection.[19] Therefore, there was uncertainty around the extent to which changes in clinical practice, such as reduced length of stay attributed to greater uptake of radial access PCI, had contributed to the stability observed in mean procedural costs over time. Future studies which capture the direct cost and clinical impacts attributed to improved adherence to guideline-recommended practices over time are therefore warranted. Ultimately, although conservative, our study provides important insight into key cost drivers of PCI in Australia.

CONCLUSIONS

Although the cost burden of PCI in Victoria is considerable and rising over time, mean procedural costs remain stable. The latter is likely attributable to changes in the clinical management of patients managed with PCI which better reflect evidence-based guidelines, which are facilitated through the ongoing monitoring and benchmarking of patient outcomes through VCOR.

Contributors PL and DL had full access to all of the data in this study and take responsibility for the integrity of the data and accuracy of the data analysis. PL, EZ and DL were responsible for the study concept and design, the acquisition, analysis and interpretation of data and drafting of the manuscript. PL, ALB, DS, DTD, JL, CMR, EZ and DL made significant contribution to drafting the work, or revising it critically for intellectual content. PL, ALB, DS, DTD, JL, CMR, EZ and DL provided final approval of the version to be published. PL is the guarantor of this paper.

Funding The authors have not declared a specific grant for this research from any funding agency in the public, commercial or not-for-profit sectors.

Competing interests PL is supported by an Australian Government Research Training Program (RTP) scholarship (Award/Grant number is not applicable). EZ has received grants from Amgen, Astra Zeneca, Pfizer, Shire and Zoll Medical Corporation outside of the submitted work. DL has received honoraria or study grants from Abbvie, Amgen, Astellas, AstraZeneca, Bohringer Ingelheim, Bristol Myers Squibb, Novartis, Pfizer, Sanofi, Shire and Zoll Medical Corporation, outside the submitted work. DS is supported by the National Heart Foundation Fellowship and Viertel Foundation Award. CMR is supported by a National Health and Medical Research Council Principal Research Fellowship (GNT1136372). All other authors have no conflicts of interest to disclose.

Patient consent for publication Not applicable.

Ethics approval This study received ethical approval from Monash University Human Research Ethics Committee (13882).

Provenance and peer review Not commissioned; externally peer reviewed.

Data availability statement All data relevant to the study are included in the article or uploaded as online supplemental information.

Author note All authors takes responsibility for all aspects of the reliability and freedom from bias of the data presented and their discussed interpretation.

ORCID iD

Peter Lee http://orcid.org/0000-0001-7059-1959

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