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

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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.

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. Although cardiovascular mortality has declined significantly since the 1960s, it remains the second leading cause of death (approximately 26%) in Australia. 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.

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). Percutaneous coronary intervention (PCI) is the preferred means of revascularisation therapy for many patients presenting with ACS based on Australian and international guidelines. In non-ACS settings, elective PCI may also be indicated for the symptom management of stable angina.
2017–2018, 44,886 PCIs were performed in Australia. In Victoria, 12,447 patients underwent PCI in 2018, 49% of which was for ACS. 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. Of this, 68% was attributed to hospital admissions for CVD.

Government estimates of health expenditure are generally generated via combination of ‘top-down’ and ‘bottom-up’ approaches. In a ‘top-down’ approach, total expenditure is apportioned to various disease states according to epidemiological data. 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. 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.

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. 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. 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). 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. VAED variables reflect hospital activity for funding purposes. 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. 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. 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. Further, cost data were not available from private hospitals contributing data to VCOR.

Costs
In Victoria, public hospitals are funded through casemix funding. 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. 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. 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).’ The cost attributed to PCIs undertaken in Victorian public hospitals was estimated using the WIES casemix funding method, in which a WIES weight was multiplied by the WIES price set for a given financial year to estimate the cost for an episode of care. 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.

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.
Pearson’s $\chi^2$ 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.  
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; priority 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.  
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 more 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: $A15 606 to $A16 254). 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=20345) | P value* |
|---------------------------------|---------------|---------------|---------------|---------------|----------------|----------|
| Age (years) Mean (SD)           | 62.95 (11.82) | 63.25 (11.74) | 63.56 (12.00) | 64.32 (12.05) | 63.57 (11.93)  | <0.001   |
| Age (years) Median (IQR)        | 63 (18)       | 63 (17)       | 64 (17)       | 65 (17)       | 64 (18)        |          |
| Age group (<75, N%)             | 3601 (81.40)  | 3891 (80.43)  | 4190 (80.19)  | 4559 (77.83)  | 16 241 (79.83) |          |
| Age group (≥75, N%)             | 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%) Male                 | 3433 (77.60)  | 3749 (77.49)  | 4057 (77.65)  | 4471 (76.32)  | 15 710 (77.22) |          |
| Sex (n, N%) Female               | 991 (22.40)   | 1089 (22.51)  | 1168 (22.35)  | 1387 (23.68)  | 4635 (22.78)   |          |
| BMI (n, N%) Underweight (<18.5 kg/m²) | 30 (0.68) | 28 (0.58)     | 57 (1.09)     | 37 (0.63)     | 152 (0.75)     | 0.015    |
| BMI (n, N%) Normal (18.5–24.9 kg/m²) | 944 (21.34) | 1060 (21.91)  | 1091 (20.88)  | 1331 (22.72)  | 4426 (21.75)   |          |
| BMI (n, N%) Overweight (25–29.9 kg/m²) | 1783 (40.30) | 1866 (38.98)  | 2068 (39.58)  | 2245 (38.32)  | 7982 (39.23)   |          |
| BMI (n, N%) Obese (≥30 kg/m²)    | 1601 (36.19)  | 1786 (36.92)  | 1957 (37.45)  | 2180 (37.21)  | 7524 (36.98)   |          |
| BMI (n, N%) Missing              | 66 (1.49)     | 78 (1.61)     | 52 (1.00)     | 65 (1.11)     | 261 (1.28)     |          |
| ACS type (n, N%) Non-ACS          | 1574 (35.58)  | 1787 (36.94)  | 1913 (36.61)  | 2320 (39.60)  | 7594 (37.33)   | <0.001   |
| ACS type (n, N%) UA               | 325 (7.35)    | 305 (6.30)    | 351 (6.72)    | 301 (5.14)    | 1282 (6.30)    |          |
| ACS type (n, N%) NSTEMI           | 1247 (28.19)  | 1381 (28.54)  | 1518 (29.05)  | 1610 (27.48)  | 5756 (28.29)   |          |
| ACS type (n, N%) 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%) Normal (≥50%) | 1931 (43.65)  | 2081 (43.01)  | 2310 (44.21)  | 2496 (42.61)  | 8818 (43.34)   | 0.002    |
| LVEF grade (n, N%) Mild (45%–49%) | 744 (16.82)  | 938 (19.39)   | 841 (16.10)   | 997 (17.02)   | 3520 (17.30)   |          |
| LVEF grade (n, N%) Moderate (35%–44%) | 355 (8.02) | 364 (7.52)   | 467 (8.94)    | 502 (8.57)    | 1688 (8.30)    |          |
| LVEF grade (n, N%) Severe (<35%)  | 178 (4.02)    | 166 (3.43)    | 211 (4.04)    | 224 (3.82)    | 779 (3.83)     |          |
| 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)      |          |
| Fibrinolytic therapy (n, N%)    | 167 (3.77)    | 219 (4.53)    | 233 (4.46)    | 240 (4.10)    | 859 (4.22)     | 0.236    |
| eGFR                            |               |               |               |               |               | 0.011    |

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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 ventilator 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. Similar trends in the evolution of patient risk in contemporary practice have been observed across other registries in Australia, the UK and the USA.23–27

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 1 Continued

| Variable                      | 2014 (N=4424) | 2015 (N=4838) | 2016 (N=5225) | 2017 (N=5858) | Total (N=20 345) | P value* |
|-------------------------------|---------------|---------------|---------------|---------------|-----------------|---------|
| Median (IQR)                 | 91.37 (48.84) | 91.34 (49.98) | 91.74 (50.35) | 89.09 (49.64) | 90.77 (49.62)   |         |
| Mean (SD)                    | 95.00 (38.28) | 95.31 (38.92) | 95.90 (40.57) | 93.16 (39.68) | 94.78 (39.44)   | 0.010   |
| eGFR group (n, N%)           |               |               |               |               |                 |         |
| Normal (≥90 mL/min/1.73 m²)  | 3385 (76.51)  | 3705 (76.58)  | 3974 (76.06)  | 4339 (74.07)  | 15 403 (75.71)  |         |
| Moderate (30–89 mL/min/1.73 m²) | 632 (14.29)   | 726 (15.01)   | 741 (14.18)   | 908 (15.50)   | 3007 (14.78)    |         |
| Severe (<30 mL/min/1.73 m²)  | 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)     |         |

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| 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 |

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with ACS are treated in public hospitals in Australia (64% of ACS cases in public hospitals vs 30% in the private sector,\(^3\))\(^7\)\(^8\)\(^9\)\(^{10}\)\(^1\), 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).\(^5\)\(^6\)\(^7\)\(^8\)\(^9\) 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\(^6\)\(^7\)\(^8\)\(^9\)\(^1\), 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.\(^5\)\(^6\)\(^7\)\(^8\)\(^9\)\(^1\),\(^1\)\(^0\) Furthermore, both countries have commonality in physician training and guidelines for the management of ACS and PCI.\(^3\)\(^5\)\(^6\)\(^7\)\(^8\)\(^9\)\(^1\)\(^1\)\(^0\) 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.\(^2\)\(^5\)\(^6\)\(^7\)\(^8\)\(^9\)\(^1\)\(^)\(^2\)\(^3\)\(^4\)\(^5\)\(^6\)\(^7\)\(^8\)\(^9\)\(^1\)

### Table 2

| Door to balloon time (STEMI only)† | 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)    |
| MACCE                             | 252 (5.70)   | 242 (5.00)   | 252 (4.82)   | 286 (4.88)   | 1032 (5.07)   |
| Cardiac readmissions              | 249 (5.63)   | 300 (6.20)   | 329 (6.30)   | 400 (6.83)   | 1278 (6.28)   |

*P value for year-to-year trend.
†Excluding all inter-hospital transfer arrivals and patients with STEMI onset while a current in-patient.

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

| Variable               | 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 ($9,804–$10,621) | $10,325 ($10,058–$10,593) | $10,439 ($10,195–$10,683) | $10,554 ($10,184–$10,924) |
| Adjusted*              | $10,144 ($9,975–$10,313) | $9,996 ($9,824–$10,168) | $10,291 ($10,127–$10,455) | $10,127 ($9,956–$10,298) |
| UA                     |             |             |             |             |
| Crude                  | $9,622 ($9,093–$10,151) | $9,766 ($9,419–$10,114) | $9,913 ($9,555–$10,271) | $10,061 ($9,498–$10,6245) |
| Adjusted*              | $9,607 ($9,375–$9,838) | $9,826 ($9,575–$10,078) | $10,363 ($10,013–$10,623) | $9,619 ($9,373–$9,866) |
| 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 ($14,950–$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-STMI; STEMI, ST-elevation myocardial infarction; UA, unstable angina.

Lee P, et al. BMJ Open 2021;11:e053305. doi:10.1136/bmjopen-2021-053305
| Variable                        | Univariable | Multivariable |
|--------------------------------|-------------|---------------|
|                                | 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                        |             |               |             |         |             |               |             |           |
| 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 melitus     | 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
| Variable                                | Univariable |          |          |          |          |          |          |          |          |          |          |          |          |          |
|-----------------------------------------|-------------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|
| 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 m²)             | REF         |          |          |          |          |          |          |          |
| Moderate (30–89 mL/min/1.73 m²)         | 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 m²)             | 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; NSTE-MI, 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). Finally, WIES weights are adjusted annually using cost data reported from the previous financial year to the Victorian Cost Data Collection. 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.

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