ABSTRACT

Objectives Patients with ST-elevation myocardial infarction (STEMI) that occur while already in hospital (‘in-hospital STEMI’) face high mortality. However, data about this patient population are scarce. We sought to investigate differences in reperfusion and outcomes of in-hospital versus out-of-hospital STEMI.

Design, Setting and Participants Consecutive patients with STEMI all treated with percutaneous coronary intervention (PCI) across 30 centres were prospectively recruited into the Victorian Cardiac Outcomes Registry (2013–2018).

Primary and secondary outcomes Patients with in-hospital STEMI were compared with patients with out-of-hospital STEMI with a primary endpoint of 30-day major adverse cardiovascular events (MACE). Secondary endpoints included ischaemic times, all-cause mortality and major bleeding.

Results Of 7493 patients with PCI-treated STEMI, 494 (6.6%) occurred in-hospital. Patients with in-hospital STEMI were older (67.1 vs 62.4 years, p<0.001), more often women (32% vs 19.9%, p<0.001), with more comorbidities. Patients with in-hospital STEMI had higher 30-day MACE (20.4% vs 9.8%, p<0.001), mortality (12.1% vs 6.9%, p<0.001) and major bleeding (4.9% vs 2.3%, p<0.001), than patients with out-of-hospital STEMI. According to guideline criteria, patients with in-hospital STEMI achieved symptom-to-device times of ≤70 min and ≤90 min in 29% and 47%, respectively. Patients with out-of-hospital STEMI achieved door-to-device times of ≤90 min in 71%. Occurrence of STEMI while in hospital independently predicted higher MACE (adjusted OR 1.77, 95% CI 1.33 to 2.36, p<0.001) and 12-month mortality (adjusted OR 1.49, 95% CI 1.08 to 2.07, p<0.001).

Conclusions Patients with in-hospital STEMI experience high mortality, despite advancements in treatment. Timely revascularisation with percutaneous coronary intervention (PCI) is a critical component of improving STEMI outcomes, with ischaemic time directly linked to mortality. STEMI that occur in patients already hospitalised for an alternate condition, termed ‘in-hospital STEMs’, have different characteristics and outcomes to classical out-of-hospital STEMI. Patients with in-hospital STEMI are older, more often women with higher coagulopathy and lower occurrence of typical symptoms.

INTRODUCTION

Coronary artery disease is the leading cause of death worldwide. In particular, patients with ST-elevation myocardial infarction (STEMI) experience high mortality, despite advancements in treatment. Timely revascularisation with percutaneous coronary intervention (PCI) is a critical component of improving STEMI outcomes, with ischaemic time directly linked to mortality. STEMI that occur in patients already hospitalised for an alternate condition, termed ‘in-hospital STEMs’, have different characteristics and outcomes to classical out-of-hospital STEMI. Patients with in-hospital STEMI are older, more often women with higher coagulopathy and lower occurrence of typical symptoms.
While outcomes of out-of-hospital STEMIIs have significantly improved over the last decade, mortality has remained constantly high for in-hospital STEMIIs. This issue has never been more important than during the era of a COVID-19 pandemic. While out-of-hospital STEMI numbers have declined in COVID-19 affected areas, in-hospital STEMIIs have been increasingly reported, with COVID-19 associated with STEMI mimickers, acute thrombosis and plaque rupture.11 12

Despite the high mortality observed for in-hospital STEMIIs, less than a handful of studies have specifically assessed this STEMI population. The studies that have been performed are limited by their single-centre nature, and/or inclusion of a heterogenous in-hospital STEMI population of which a large proportion did not undergo invasive angiography.7 8 Hence, the reasons for higher mortality of patients with in-hospital STEMI have not been fully elucidated. The contribution of system-wide delays in reperfusion and gaps in guideline-directed medical management may play a role. We need more research into STEMIIs that occur while in-hospital, if we are to improve outcomes in this understudied population. This first-of-its-kind Australian study used a large, multicentre, prospective PCI registry with the aim of investigating differences in ischaemic times, management and outcomes of in-hospital versus patients with out-of-hospital STEMI.

METHODS
Study design and patient population
From 2013 to 2018, consecutive patients with STEMI treated with PCI were prospectively recruited into the Victorian Cardiac Outcomes Registry. The Victorian Cardiac Outcomes Registry is an Australian, state-based clinical quality registry designed to monitor the performance and outcome of PCI in Victoria. It was established in 2012 and is engaged at all Victorian hospitals (13 public (ie, government funded) and 17 private) with all patients undergoing PCI or attempted PCI entered into the registry.13 It collects baseline demographic, procedural characteristics, in-hospital and 30-day outcomes through a secure web-based data collection system.14 Data integrity is ensured with regular audit activities conducted by the central registry. The Victorian Cardiac Outcomes Registry is funded by the Victorian Department of Health and Human Services. It obtains 12-month mortality for all patients through linkage with the Australian National Death Index. The deidentified data analysed for the purpose of this study are available on request to the Victorian Cardiac Outcomes Registry Committee (email: vcor@monash.edu).

Inclusion and exclusion criteria
Consecutive patients with STEMI who received successful or attempted PCI were included. At the time of entering the patient into the Victorian Cardiac Outcomes Registry database, STEMI was defined as elevated cardiac biomarkers and new ST-segment elevation in two or more contiguous leads. The clinical definition was based on a maximal concentration of troponin T or I above the MI diagnostic limit on at least one occasion within 24 hours from the index clinical event and ST-segment elevation in the ECG, equal to the Fourth Universal Definition of Myocardial Infarction.15 In-hospital STEMI was defined and captured as per Victorian Cardiac Outcomes Registry definition, based on the timing of symptom onset occurring during a hospital admission. The time recorded for symptom onset was when the patients advised the hospital staff of their symptoms. Out-of-hospital STEMI included all other STEMI cases where symptom onset occurred in the community setting. The in-hospital STEMI cohort was compared with the out-of-hospital STEMI cohort. For the analysis of symptom-to-device (STD) and door-to-device (DTD) time, the following patients were excluded from the analysis: (1) patients without a recorded time of symptom onset, (2) patients>12 hours from symptom onset, (3) patients who had symptom onset while admitted to a non-PCI capable hospital (for the in-hospital STEMIIs), and (4) patients who presented to a non-PCI capable hospital (for the out-of-hospital STEMIIs, outlined in figure 1).

Figure 1 Inclusion of patients with in-hospital and out-of-hospital ST-elevation myocardial infarction (STEMI) into the time-analysis. Flow chart showing patients which patients were excluded from and included into the analysis of symptom-to-device and door-to-device time. PCI, percutaneous coronary intervention.
Primary and secondary outcomes

The primary endpoint was 30-day major adverse cardiovascular events (MACE, consisting of all-cause death, new or recurrent MI, stent thrombosis or target vessel revascularisation). Secondary endpoints included STD and DTD times, 30-day and 12-month all-cause mortality, major adverse cardiovascular and cerebrovascular events (MACCE, consisting of MACE and stroke), major bleeding (consisting of type 3 and 5 according to the Bleeding Academic Research Consortium definition), recurrent MI, new heart failure (defined according to clinical signs), new renal impairment, length of hospital stay and referral to cardiac rehabilitation. STD time was calculated for patients with in-hospital STEMI. DTD time was calculated for patients with out-of-hospital STEMI.

The European Society of Cardiology guidelines recommend a time of ≤60 min from STEMI diagnosis to wire crossing in patients presenting to a PCI-capable hospital. Additionally, first medical contact (FMC)-to-ECG acquisition time is recommended at ≤10 min. As there are no guidelines specific to in-hospital STEMI, the time of symptom onset (as patients were already admitted under medical care) was used to take the place of FMC. An FMC-to-ECG acquisition time of ≤10 min and a STEMI diagnosis to wire crossing time of ≤60 min would result in an ideal STD time of ≤70 min for in-hospital STEMI. Accordingly, to assess for reperfusion delays, the percentage of patients with in-hospital STEMI achieving an STD time ≤70 min was analysed. The American Heart Association/American College of Cardiology guidelines recommend an FMC-to-device time of ≤90 min in patients presenting to a PCI-capable hospital. Accordingly, to assess for reperfusion delays the percentage of patients with in-hospital STEMI achieving a STD time ≤90 min and the percentage and patients with out-of-hospital STEMI achieving a DTD time ≤90 min was assessed. The terms ‘device time’ and ‘wire crossing time’ were used interchangeably for reperfusion time.

Preprocedural creatinine was collected up to 60 days before the PCI and the Cockcroft-Gault formula used to determine estimated glomerular filtration rate. New renal impairment was defined as an absolute rise of serum creatinine ≥44.2 µmol/L or ≥25% up to 5 days after the index PCI, when compared with baseline creatinine. Left ventricular ejection fraction was collected during the index PCI, when compared with baseline creatinine. Neither patients nor the public were involved in this retrospective analysis.

RESULTS

Baseline characteristics

A total of 7493 patients underwent PCI for the treatment of STEMI of which 494 (6.6%) were in-hospital STEMI. Baseline demographic and clinical characteristics are shown in table 1. Patients with in-hospital versus out-of-hospital STEMI were significantly older, more often women, with more comorbidities and higher proportions with cardiogenic shock or cardiac arrest requiring intubation.

Procedural and discharge characteristics

Stent thrombosis was more frequently seen for in-hospital versus out-of-hospital STEMI. Of stent thromboses resulting in an in-hospital STEMI, 5% (4/82) occurred during the same admission as an initial PCI. Patients with in-hospital STEMI needed more mechanical support, with radial access used less frequently than for out-of-hospital STEMIs. Patients with in-hospital STEMI were significantly less likely to receive guideline-directed medical therapy (adjusted OR 0.70, 95% CI 0.56 to 0.87, p<0.001, table 2).

Ischaemic times

Patients with in-hospital STEMI achieved an STD time of ≤70 min in 29% of cases and a STD time ≤90 min in 47% of cases (figure 2). Correspondingly, patients with out-of-hospital STEMI achieved a DTD time of ≤90 min in 71% of cases.

In the in-hospital STEMI group, unadjusted and adjusted geometric mean STD times were 110 min and...
80 min, respectively. Within the in-hospital STEMI group, patients with stent thrombosis (n=82) had a significantly shorter geometric mean STD time than patients without stent thrombosis (unadjusted: 83 vs 116 min, p=0.003; adjusted: 68 vs 96 min, p=0.008, not shown in table).

Clinical outcomes
30-day and 12-months clinical outcomes are shown in table 3.

Thirty-day MACE was significantly higher for in-hospital versus out-of-hospital STEMI (20.4% vs 9.8%, p<0.001) with an adjusted OR of 1.77 (95% CI 1.33 to 2.36, p<0.001). Twelve-month mortality was significantly higher for patients with in-hospital versus out-of-hospital STEMI (22.5% vs 11.2%, p<0.001), adjusted OR 1.49 (95% CI 1.08 to 2.07, p<0.001). Figure 3 shows unadjusted and adjusted Kaplan-Meier survival analysis. In-hospital symptom onset was an independent predictor for both 30-day MACE (adjusted OR 1.91, 95%CI 1.38 to 2.64, p<0.001) and 12-month mortality (adjusted OR 1.49, 95%CI 1.08 to 2.07, p<0.001). Independent multivariable associations with 30-day MACE and 12-month mortality are shown in the online supplemental table 1.

DISCUSSION
In this large, Australian PCI registry study, we investigated differences in presentation, treatment and outcomes of STEMI occurring in a patient already admitted to hospital, as compared with out-of-hospital STEMI. The principal findings of our study were that patients with in-hospital STEMI were (1) older, more likely to be women and have more comorbidities, (2) more likely to experience delays in reperfusion, (3) less likely to receive guideline-directed medical therapy, and (4) significantly more likely to experience MACE with higher all-cause mortality, compared with patients with out-of-hospital STEMI. After adjustment for confounders, patients who experienced a STEMI while already admitted to hospital had 91% higher odds of 30-day MACE and 88% higher odds of 12-month mortality, compared with standard STEMIs.

Patients with in-hospital STEMI were found to comprise 6.6% of overall STEMIs, similar to previously described.8 17 18  While this percentage may not appear large, the chance of a STEMI occurring while inpatient is 40–50-fold that seen in the general community.19 20 This is the first Australian study to assess in-hospital STEMIs

### Table 1 Baseline and clinical characteristics according to patients with in-hospital versus out-of-hospital ST-elevation myocardial infarction (STEMI)

|                        | Total patients with STEMI | In-hospital STEMI | Out-of-hospital STEMI | P value |
|------------------------|---------------------------|-------------------|-----------------------|---------|
|                        | n=7493                    | n=494             | n=6999                |         |
| Age (years)            | 62.7±12.7                 | 67.1±12.7         | 62.4±12.6             | <0.001  |
| Females, n (%)         | 1552 (20.7%)              | 158 (32.0%)       | 1394 (19.9%)          | <0.001  |
| BMI (kg/m²)            | 27.5 [24.6–30.7]          | 27.7 [24.7–31.2]  | 27.5 [24.6–30.6]      | 0.3     |
| Diabetes, n (%)        | 1201 (16.0%)              | 111 (22.5%)       | 1090 (15.6%)          | <0.001  |
| eGFR (ml/min)<45mL/min, n (%) | 578 (9.4%)          | 78 (16.4%)        | 500 (8.8%)            | <0.001  |
| Moderate-severe LVEF impairment, n (%) | 2029 (27.0%)          | 128 (29.0%)       | 1901 (28.9%)          | 0.965   |
| Previous CABG, and/or PCI, n (%) | 1196 (15.9%)          | 231 (46.7%)       | 965 (13.7%)           | <0.001  |
| Cerebrovascular disease, n (%) | 256 (3.4%)              | 35 (7.1%)         | 221 (3.2%)            | <0.001  |
| Peripheral vascular disease, n (%) | 165 (2.2%)              | 36 (7.3%)         | 129 (1.8%)            | <0.001  |
| Oral anticoagulant therapy, n (%) | 211 (2.8%)              | 31 (6.3%)         | 180 (2.6%)            | <0.001  |
| Onset of symptoms 07:00–20:00, n (%) | 4832 (64.7%)          | 298 (62.7%)       | 4534 (64.8%)          | 0.37    |
| Cardiogenic shock or cardiac arrest requiring intubation, n (%) | 872 (11.6%)              | 77 (15.6%)         | 795 (11.4%)           | 0.005   |
| Prehospital ECG notification, n (%) | 3993 (57.0%)          | –                 | 3993 (57.0%)          |         |

Values are number (%) or median (IQR) or mean±SDs.
BMI, body mass index; CABG, coronary artery bypass grafting; eGFR, estimated glomerular filtration rate; LVEF, left ventricular ejection fraction; PCI, percutaneous coronary intervention.
and similar to the few previous studies, patients with in-hospital STEMI had significantly higher mortality, MACE, MACCE, major bleeding, recurrent MI and new renal impairment; all were approximately double that of out-of-hospital STEMIs, with recurrent MI threefold higher. These striking differences persisted after adjustment for confounders. It is important to note that previous studies investigating in-hospital STEMIs, including the largest one by Kaul et al., assessed a heterogenous population with a large proportion who did not undergo PCI. From these studies, we know that patients with in-hospital STEMI receive less invasive angiography, potentially negatively influencing the outcomes. This is the first study to demonstrate significantly poorer outcomes for in-hospital STEMIs who were all deemed suitable for primary PCI.

Of course, in-hospital STEMIs are a distinct group of patients: being older, more often women, with higher comorbidities and complex coronary lesions. In addition, the underlying reason for hospitalisation may bias against the early recognition of STEMI and possibly affect clinical care decisions. Previous registry studies have shown that 34%–41% of in-hospital STEMIs occur in patients hospitalised for non-cardiac reasons, with the remainder occurring in cardiac inpatients. However, only a single study has adjusted for admission reason, and still found a significantly higher mortality for in-hospital compared with patients with out-of-hospital STEMI.

Poorer outcomes of in-hospital STEMIs may in part be due to reperfusion delays. According to the European Society of Cardiology guidelines, a symptom-onset-to-ECG acquisition and STEMI-diagnosis-to-reperfusion of ≤10 and ≤60 min, respectively, are recommended. Yet despite symptom onset within a PCI-capable hospital, less than a third of our in-hospital STEMIs achieved this. The American Heart Association/American College of Cardiology recommend an STD time of ≤90 min; yet this was achieved in less than half of our patients with in-hospital STEMI. We know from previous in-hospital STEMI studies that the majority of ischaemic delays occur from symptom onset to catheterisation laboratory activation, presumably

| Table 2 Procedural and discharge characteristics according to patients with in-hospital versus out-of-hospital ST-elevation myocardial infarction (STEMI) |
|---------------------------------------------|---------------------------------------------|-----------------|
| In-hospital STEMI | Out-of-hospital STEMI | P value |
| Radial access, n (%) | 185 (37.4%) | 3850 (55.0%) | <0.001 |
| Glycoprotein IIb/IIIa inhibitor, n (%) | 166 (33.6%) | 2655 (37.9%) | 0.055 |
| Mechanical ventricular support, n (%) | 44 (8.9%) | 220 (3.1%) | <0.001 |
| Culprit vessel, n (%) | | | |
| RCA | 202 (40.9%) | 2851 (40.7%) | <0.001 |
| LAD | 206 (41.7%) | 2914 (41.6%) | |
| LCx | 61 (12.3%) | 1108 (15.8%) | |
| Left main | 9 (1.8%) | 89 (1.3%) | |
| Graft | 16 (3.2%) | 37 (0.5%) | |
| Stent thrombosis, n (%) | 82 (16.6%) | 217 (3.1%) | <0.001 |
| Complex lesion, n (%) | 366 (74.1%) | 4628 (66.1%) | <0.001 |
| Number of stents implanted | 1.09±0.65 | 1.17±0.52 | 0.002 |
| Drug-eluting stent, n (%) | 344 (69.6%) | 5336 (76.2%) | <0.001 |
| Procedural success, n (%) | 461 (93.3%) | 6610 (94.4%) | 0.30 |
| Length of stay | 9.7±19.1 | 4.9±4.7 | <0.001 |
| Referral to cardiac rehabilitation, n (%) | 327 (74.7%) | 5538 (84.4%) | <0.001 |
| Discharge medications, n (%) | | | |
| Aspirin | 415 (95.2%) | 6409 (98.1%) | <0.001 |
| Thienopyridine | 153 (35.1%) | 1802 (27.6%) | <0.001 |
| Ticagrelor | 267 (61.4%) | 4606 (70.5%) | <0.001 |
| Beta blockers | 338 (78.1%) | 5735 (87.9%) | <0.001 |
| ACE/ARB | 307 (70.7%) | 5526 (84.7%) | <0.001 |
| Statin | 401 (92.4%) | 6338 (97.1%) | <0.001 |
| Oral anticoagulants | 49 (11.3%) | 561 (8.6%) | 0.054 |

Values are number (%) or mean±SD.
ARB, angiotensin receptor blockers; LAD, left anterior descending artery; LCx, circumflex artery; RCA, right coronary artery.
due to delays in ECG acquisition and interpretation. In order to reduce ischaemic times, education programmes of non-cardiac wards and medical staff should focus on reducing delays to ECG. Such education programmes should also highlight that in-hospital STEMs may present with atypical symptoms, such as unexplained haemodynamic instability in the instance of postsurgical or intubated patients.

We found that patients with in-hospital STEMI had a higher rate of bleeding, likely exacerbated by older age, higher use of oral anticoagulants, together with lower rates of radial access and perhaps due to surgical admissions. We know that postprocedural bleeding is a strong predictor of mortality in STEMI. The higher rates of bleeding and concomitant anticoagulant use in the in-hospital STEMI cohort may have led to the lower

Table 3  Outcomes according to patients with in-hospital versus out-of-hospital ST-elevation myocardial infarction (STEMI)

| Outcome                                      | Overall STEMI | In-hospital STEMI | Out-of-hospital STEMI | Unadjusted p value | Adjusted OR | Adjusted 95% CI | Adjusted p value |
|-----------------------------------------------|---------------|-------------------|-----------------------|--------------------|-------------|-----------------|-----------------|
| 30-day outcomes                               | n=7493        | n=494             | n=6999                |                    |             |                 |                 |
| MACE, n (%)                                   | 785 (10.4%)   | 101 (20.4%)       | 684 (9.8%)            | <0.001             | 1.77        | 1.33 to 2.36    | <0.001          |
| All-cause mortality, n (%)                    | 542 (7.2%)    | 60 (12.1%)        | 482 (6.9%)            | <0.001             | 1.17        | 0.80 to 1.72    | 0.41            |
| MACCE, n (%)                                  | 824 (11.0%)   | 108 (21.9%)       | 716 (10.2%)           | <0.001             | 1.88        | 1.42 to 2.49    | <0.001          |
| Major bleeding, n (%)                         | 188 (2.5%)    | 24 (4.9%)         | 164 (2.3%)            | <0.001             | 1.81        | 1.13 to 2.89    | 0.01            |
| New heart failure, n (%)                      | 112 (1.5%)    | 12 (2.4%)         | 100 (1.4%)            | 0.083              | 1.5         | 0.80 to 2.82    | 0.21            |
| Recurrent MI, n (%)                           | 132 (1.8%)    | 28 (6.7%)         | 104 (1.7%)            | <0.001             | 3.23        | 2.01 to 5.20    | <0.001          |
| New renal impairment, n (%)                   | 461 (6.1%)    | 53 (11.7%)        | 408 (6.0%)            | <0.001             | 1.53        | 1.09 to 2.16    | 0.01            |
| 12-month all-cause mortality, n (%)           | 718 (11.9%)   | 89 (22.5%)        | 629 (11.2%)           | <0.001             | 1.49        | 1.08 to 2.07    | 0.02            |

Values are number (%). Adjustment was made for patient age, comorbidities, cardiogenic shock, intubation and out-of-hospital cardiac arrest, and time of symptom onset (day vs night).

MACCE, major cardiovascular and cerebrovascular events; MACE, major cardiovascular events; MI, myocardial infarction.
observed use of potent P2Y12 inhibitors. A total of 17% of in-hospital STEMs were due to stent thrombosis with 95% unrelated to a recent PCI. It is possible that a major driving factor for in-hospital STEMIs was antiplatelet therapy cessation due to trauma or planned surgery. This again is likely to impact on optimal medical therapy and overall mortality. Of more concern is that significantly less patients with in-hospital STEMI received guideline-directed medications at discharge, likely negatively impacting on MACE. Potential explanations include patients with in-hospital STEMI being older, potentially frailer, with more comorbidities. However, these significant discrepancies have not been described before and warrant further study.

**Limitations**

Our study provides observational data and therefore only associations can be made between ischaemic time and outcomes. Further, our study is limited by the registry not capturing the condition for which patients with in-hospital STEMI were hospitalised, which could have influenced outcomes. However, this is similar to the few previous studies on in-hospital STEMI, where exact admission diagnoses were not known. In addition, we are limited in ascertaining where the delays in ischaemic times stem from, with time of ECG acquisition (and therefore ECG-to-device time) not routinely collected. We cannot exclude selection and survivor bias since only

**Figure 3** Unadjusted and adjusted Kaplan-Meier survival analysis. Twelve-months mortality was significantly higher for patients with in-hospital versus out-of-hospital ST-elevation myocardial infarction (STEMI) in the unadjusted and adjusted Kaplan-Meier survival analysis (p<0.001).

**Figure 4** Illustration of a series of factors influencing outcomes in patients with in-hospital ST-elevation myocardial infarction (STEMI).
patients with STEMI treated with PCI were included. However, it is well known that only a minority of patients with in-hospital STEMI undergo PCI, which would only strengthen our findings, since in-hospital STEMs not taken to the catheterisation laboratory are likely to have an even poorer outcome. Further, by studying a more homogenous population of patients with in-hospital STEMI, all deemed candidates for primary PCI, we have still identified significant treatment and outcome disparities. The data were not assessed for multiple recruitment; however, only 5% of stent thrombosis-related in-hospital STEMI occurred during the same admission as an initial PCI. Lastly, a number of patients had to be excluded from the data analysis, such as those who initially presented to non-PCI capable hospitals since VCOR only collects STD time and DTD time at hospital that are. However, these patients would have had to be excluded regardless since they would have introduced a large bias, representing a totally different patient cohort than those presenting directly to a PCI capable hospital.

CONCLUSIONS

Patients with in-hospital STEMI experience reperfusion delays and face significantly worse outcomes than patients with out-of-hospital STEMI, even after adjustment for confounders. We identified key targets to address, namely strategies to improve ischaemic time and optimal medical therapy prescription. Raising awareness of the issues facing patients who suffer a STEMI while already admitted to hospital is urgently needed if we are to improve outcomes in this under-investigated and under-treated patient population (figure 4).

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