Comparative Effectiveness of Population Interventions to Improve Access to Reperfusion for ST-Segment–Elevation Myocardial Infarction in Australia

Isuru Ranasinghe, MBChB, MMed (Clin Epi), FRACP; Fiona Turnbull, MBChB, MPH, PhD, FAFPHM; Andrew Tonkin, MBBS, MD, FRACP; Robyn A. Clark, PhD, FRCNA; Neil Coffee, BA(Hon), MA; David Brieger, MBBS, PhD, FRACP, FACC

Background—Improving timely access to reperfusion is a major goal of ST-segment–elevation myocardial infarction care. We sought to compare the population impact of interventions proposed to improve timely access to reperfusion therapy in Australia.

Methods and Results—Australian hospitals, population, and road network data were integrated using Geographical Information Systems. Hospitals were classified into those that provided primary percutaneous coronary intervention (PPCI) or fibrinolysis. Population impact of interventions proposed to improve timely access to reperfusion (PPCI, fibrinolysis, or both) were modeled and compared. Timely access to reperfusion was defined as the proportion of the population capable of reaching a fibrinolysis facility ≤60 minutes or a PPCI facility ≤120 minutes from emergency medical services activation. The majority (93.2%) of the Australian population has timely access to reperfusion, mainly (53%) through fibrinolysis. Only 40.2% of the population had timely access to PPCI, and access to PPCI services is particularly limited in regional and nonexistent in remote areas. Optimizing the emergency medical services’ response or increasing PPCI services resulted in marginal improvement in timely access (1.8% and 3.7%, respectively). Direct transport to PPCI facilities and interhospital transfer for PPCI improves timely access to PPCI for 19.4% and 23.5% of the population, respectively. Prehospital fibrinolysis markedly improved access to timely reperfusion in regional and remote Australia.

Conclusions—Significant gaps in timely provision of reperfusion remain in Australia. Systematic implementation of changes in service delivery has potential to improve timely access to PPCI for a majority of the population and improve access to fibrinolysis to those living in regional and remote areas. (Circ Cardiovasc Qual Outcomes. 2012;5:429-436.)

Key Words: acute coronary syndromes ▪ geo-spatial data analysis ▪ epidemiology ▪ health policy ▪ outcomes

Primary percutaneous coronary intervention (PPCI) and fibrinolysis are well-established as lifesaving therapies in ST-segment–elevation myocardial infarction (STEMI). Trial evidence supports PPCI as the reperfusion strategy of choice, given established mortality benefit. Recent data have highlighted the importance of timeliness of reperfusion, (either PPCI or fibrinolysis), with delays beyond guideline-recommended times associated with adverse 30-day and 1-year outcomes. Improving access to timely reperfusion and, preferably, to PPCI is a major goal in improving STEMI care.

Several interventions have been advocated to maximalize access to timely reperfusion. These include improving emergency medical services (EMS) response, increasing the number of PPCI facilities, transferring patients from noninterventional to PPCI-capable facilities, EMS diversion to PPCI facilities (bypassing noninterventional facilities), and prehospital fibrinolysis. These interventions have been identified through clinical trial evidence demonstrating improved outcomes for individual patients or from perceived benefit based on clinical consensus. From a health policy perspective, however, evidence of clinical efficacy alone is insufficient. It is critically important to define the situations where these interventions are of benefit and the magnitude of benefit likely to be achieved by implementing these interventions at a population level. Access to reperfusion is time-critical and is dependent on the...
population distribution, EMS response, and travel times and the distribution of PPCI and fibrinolysis facilities. Determining how to maximize timely access to PPCI (and to fibrinolysis if PPCI is not available) in the context of these population-specific factors is critical. We sought to model and compare the relative benefits of different interventions advocated to improve timely access to reperfusion. Specifically, hospital strategies involving investment in PCI programs and EMS strategies involving EMS optimization, diversion to PPCI facilities, interhospital transfer, and prehospital fibrinolysis were compared.

**WHAT IS KNOWN**

- Many strategies are advocated to improve access to reperfusion therapy for STEMI. The population impacts of these interventions are unknown

**WHAT THE STUDY ADDS**

- We evaluated time access to reperfusion therapy for the Australian population and found that, overall, 93.2% had timely access predominately through fibrinolysis (53.0%) rather than PPCI (42.0%).
- We found that the population interventions varied widely in their ability to improve timely access to reperfusion. Interhospital transfer and EMS diversion to PPCI facilities increased timely access to reperfusion the most.
- Our analysis suggests significant potential to improve timely access to reperfusion by systematic deployment of interventions. Geographical Information Systems provides a robust tool to model the population effects of health service interventions.

### Methods

**Data Sources**

Geographically distributed Australian population, acute hospitals, and road network data were integrated using Geographical Information Systems (GIS) software (ArcGIS version 9.3). Population data were derived from the Australian 2006 Census and assessed at the level of a collection district (CD), defined as an area including 225 dwellings and forming the smallest available population unit for analysis. Analysis was restricted to adults aged ≥20 years. A total of 38,704 collection districts were located in Australia. Acute care hospitals were identified from the Australian Institute of Health and Welfare hospital statistics dataset. Nonacute and specialized women’s, children’s, psychiatric, rehabilitation, and correctional health services were excluded. Hospitals that provided PPCI services were identified by accessing published official reports and consulting key experts involved in the provision of regional cardiac services and verified by contacting hospitals directly. All other acute care hospitals were considered capable of providing fibrinolysis. All hospitals and PPCI facilities were geocoded for the GIS analysis. Incorporation of national road network data (GEODATA Topo Series 3, Geoscience Australia) allowed precise calculation of distance and estimation of driving times between population units (CDs) and hospitals along existing roads. In keeping with previous methods, driving times were calculated as the product of estimated distances and projected travel speeds across different road types. (See online-only Data Supplement.) The closest hospital was determined with a heuristic algorithm and based on shortest driving time. Air transport was not considered for this analysis owing to the limited availability of air transport and the lack of availability of reliable estimates for flying times required for analysis in Australia.

**Baseline Analysis**

For the baseline analysis, 49% of the population was estimated to use EMS when experiencing chest pain, based on data from the Heart Foundation of Australia Early Warning Signs Program (personal communication, Christopher Poulter, National Heart Foundation). We assumed that the EMS transported the patient to the nearest available hospital and that patients who self-presented also drove to their nearest hospital. Times to reperfusion were established by estimating the median EMS dispatch, assessment, and transport time (hereafter referred to as driving time) to the nearest hospital. In estimation of prehospital driving times, we included an EMS dispatch time of 1 minute for major cities and 2 minutes for regional and remote areas, as well as an EMS response time of 9 minutes for major cities, 11 minutes for regional areas, and 15 minutes for remote areas. Additionally, time at the scene was estimated to be 15 minutes for major cities and 17 minutes for regional and remote areas. These estimates are derived from published Australian data. We assumed that patients who self-refer have the same driving time as those using EMS. The hospitals were then stratified into PPCI and fibrinolysis facilities, allowing estimation of the proportion of adult Australians for whom a PPCI or fibrinolysis facility was the nearest hospital.

**Outcome Measures**

The primary outcome was the proportion of the adult population who had timely access to reperfusion defined as the proportion of the population capable of traveling to a fibrinolysis facility ≤60 minutes or a PPCI facility ≤120 minutes from EMS activation from their place of residence (CD) for each scenario. The 60-minute time window for fibrinolysis was selected as guidelines recommend reperfusion within a total ischemic time of ≤90 to 120 minutes as target of therapy for optimal outcomes, and this can be achieved when prehospital assessment and transport time is ≤60 minutes. Additionally, the 60-minute time frame is consistent with other published studies that have evaluated timely access to reperfusion. We assumed that equipoise in outcomes between PPCI and in-hospital fibrinolysis occurs when the differential delay to the former reaches 60 minutes.

**Interventions to Improve Timely Access to Reperfusion**

The population implications of several interventions that have been proposed to improve timely access to PPCI, fibrinolysis, or both were modeled.

1. Optimizing EMS response was assessed by substituting guideline-recommended times for existing estimates of EMS response times (1 minute for EMS dispatch, 8 minutes for EMS response, and 8 minutes for time at scene). A 20% increase in EMS use from a baseline of 49% was also projected, based on the maximum potential improvement in EMS use observed in the randomized trial setting.

2. Increasing PPCI services was assessed by evaluating the effect of establishing 10 new PPCI facilities (representing a substantial ~25% increase in the total number of PPCI facilities) in the most densely populated areas without existing proximate (≤120 minutes driving time) PPCI facilities.

3. Routine interhospital transfer was assessed by evaluating the proportion of the population capable of being transferred from a fibrinolysis-enabled to a PPCI-enabled facility, provided that the total time (EMS activation to first hospital plus transfer to PPCI facility) was ≤120 minutes consistent with the American Heart Association (AHA) recommendations. There are no published Australian data on the estimated time delay at the noninterventional facility. Therefore, the estimate of transfer time included an estimated door-in, door-out (DIDO) time of 68 minutes at the noninterventional hospital, reflecting median DIDO time reported in contemporary
international literature. We also modeled the impact of routine inter-hospital transfer time if the DIDO time was 30 minutes. This allowed us to represent the potential gain from improving DIDO time from the current practice to guideline-recommended time.

(4) EMS diversion to PPCI facilities was assessed by evaluating the proportion of the population for whom EMS triage and diversion to a PPCI facility (bypassing fibrinolysis hospitals) resulted in an additional delay ≤60 minutes and a total time to PPCI facility ≤120 minutes. An extra 4-minute EMS delay was included in calculating driving times to allow for a prehospital ECG. This strategy was assumed to be applicable only for the 49% of the population using EMS.

(5) Prehospital fibrinolysis was assessed by evaluating the proportion of the population using EMS and capable of receiving prehospital fibrinolysis for whom the additional delay to PPCI or in-hospital fibrinolysis services exceeded 60 minutes. This assumed: (1) PPCI is superior to fibrinolysis, provided the additional delay is ≤60 minutes; and (2) the benefit of prehospital fibrinolysis is only present where the additional delay to in-hospital fibrinolysis exceeds 60 minutes, based on existing literature.

**Data Analysis**

Data were stratified by geographical region using the 2006 Australian Standard Geographical Classification (ASGC) Remoteness classification. This classified regions as Major Cities, Inner and Outer Regional centers, Remote, and Very Remote, based on physical distance of a location from the nearest urban center based on population size. To assess the implications of projected driving speeds on our baseline analysis, a sensitivity analysis was performed by varying the projected driving speeds by ±25%. Driving times and distances were not normally distributed and are therefore presented as medians and interquartile range. All statistical analyses were performed using SAS version 9.0 (SAS Institute).

**Results**

Of the 351 acute care hospitals in Australia, 42 (12.0%) had PPCI facilities. The 2006 Australian Census identified 14.5 million adults, constituting 69% of the total population. Most (69.2%) resided in major cities, which represent 0.2% of the total land area of Australia. Most PPCI facilities (81.0%) were also located in major cities, with 8 PPCI facilities (19.0%) located in regional Australia. There were no PPCI facilities in remote Australia (Figure 1 and Table 1). When the proportion of the population residing close to PPCI and fibrinolysis facilities was evaluated, an estimated 82.1% of the adult population resided close to a PPCI facility and 87.1% resided close to a fibrinolysis-capable hospital (Table 2).

**Table 1. Hospitals and Population Distribution, Land Area, and Density by Region**

<table>
<thead>
<tr>
<th>Region</th>
<th>PPCI Hospitals*</th>
<th>Fibrinolysis Hospitals*</th>
<th>Population No.</th>
<th>% Total Population</th>
<th>Land Area (km²)</th>
<th>% Total Land Area</th>
<th>Density per km²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Major cities</td>
<td>34</td>
<td>54</td>
<td>100 48 494</td>
<td>69.2%</td>
<td>17 426</td>
<td>0.2%</td>
<td>576.63</td>
</tr>
<tr>
<td>Inner regional</td>
<td>5</td>
<td>122</td>
<td>2 819 174</td>
<td>19.4%</td>
<td>243 654</td>
<td>3.2%</td>
<td>11.57</td>
</tr>
<tr>
<td>Outer regional</td>
<td>3</td>
<td>91</td>
<td>1 346 972</td>
<td>9.3%</td>
<td>834 270</td>
<td>10.8%</td>
<td>1.61</td>
</tr>
<tr>
<td>Remote</td>
<td>0</td>
<td>22</td>
<td>208 000</td>
<td>1.4%</td>
<td>1 019 728</td>
<td>13.2%</td>
<td>0.20</td>
</tr>
<tr>
<td>Very remote</td>
<td>0</td>
<td>20</td>
<td>100 859</td>
<td>0.7%</td>
<td>5 586 988</td>
<td>72.5%</td>
<td>0.02</td>
</tr>
<tr>
<td>Australia overall</td>
<td>42</td>
<td>309</td>
<td>14 523 499</td>
<td>100%</td>
<td>7 702 066</td>
<td>100.0%</td>
<td>1.89</td>
</tr>
</tbody>
</table>

PPCI indicates primary percutaneous coronary intervention.

*No. of hospitals.
Table 2. Current Access to PPCI and Fibrinolysis Facilities by Region

<table>
<thead>
<tr>
<th>Region</th>
<th>PPCI Closest Hospital, No. (% Population)</th>
<th>Timely Access* ≤120min</th>
<th>Median Time Minutes (IQR)</th>
<th>Median Distance Kilometers (IQR)</th>
<th>Population Resident in Proximity†</th>
</tr>
</thead>
<tbody>
<tr>
<td>Major cities</td>
<td>5 159 974 (51.4%)</td>
<td>5 159 974 (51.4%)</td>
<td>34.0 (30.1–40.9)</td>
<td>9.6 (5.3–17.4)</td>
<td>10 048 494 (100.0%)</td>
</tr>
<tr>
<td>Inner regional</td>
<td>3 59 717 (12.8%)</td>
<td>359 717 (12.8%)</td>
<td>109.9 (74.0–167.0)</td>
<td>102.4 (50.7–162.2)</td>
<td>1 468 790 (52.1%)</td>
</tr>
<tr>
<td>Outer regional</td>
<td>326 350 (24.2%)</td>
<td>320 579 (23.8%)</td>
<td>211.9 (117.8–293.6)</td>
<td>202.5 (91.1–302.8)</td>
<td>414 867 (30.8%)</td>
</tr>
<tr>
<td>Remote</td>
<td>4482 (2.2%)</td>
<td>0 (0.0%)</td>
<td>506.9 (328.4–700.6)</td>
<td>522.1 (316.9 to –733.3)</td>
<td>0 (0.0%)</td>
</tr>
<tr>
<td>Very remote</td>
<td>2341 (2.3%)</td>
<td>0 (0.0%)</td>
<td>912.6 (710.1–1308.7)</td>
<td>909.5 (676.8–1246.0)</td>
<td>0 (0.0%)</td>
</tr>
<tr>
<td>Australia overall</td>
<td>5 852 864 (40.3%)</td>
<td>5 838 447 (40.2%)</td>
<td>41.5 (32.2–107.1)</td>
<td>17.2 (7.3–95.8)</td>
<td>11 923 793 (82.1%)</td>
</tr>
</tbody>
</table>

Timely Access* ≤60 Minutes

<table>
<thead>
<tr>
<th>Region</th>
<th>Fibrinolysis Closest Hospital, No. (% Population)</th>
<th>Timely Access* ≤60 Minutes</th>
<th>Median Time Minutes (IQR)</th>
<th>Median Distance Kilometers (IQR)</th>
<th>Population Resident in Proximity†</th>
</tr>
</thead>
<tbody>
<tr>
<td>Major cities</td>
<td>4 885 330 (48.6%)</td>
<td>4 885 330 (48.6%)</td>
<td>31.1 (28.7–34.4)</td>
<td>6.2 (3.7–9.5)</td>
<td>9 830 972 (97.8%)</td>
</tr>
<tr>
<td>Inner regional</td>
<td>2 455 187 (87.2%)</td>
<td>2 074 912 (73.6%)</td>
<td>41.8 (34.5–55.0)</td>
<td>10.4 (4.0 to –23.6)</td>
<td>2 074 912 (73.6%)</td>
</tr>
<tr>
<td>Outer regional</td>
<td>1 015 858 (75.8%)</td>
<td>611 525 (45.4%)</td>
<td>58.3 (38.3–85.3)</td>
<td>24.8 (6.8–50.1)</td>
<td>611 525 (45.4%)</td>
</tr>
<tr>
<td>Remote</td>
<td>193 317 (97.8%)</td>
<td>102 336 (49.2%)</td>
<td>117.1 (40.8–185.8)</td>
<td>69.5 (5.1–138.6)</td>
<td>103 376 (49.7%)</td>
</tr>
<tr>
<td>Very remote</td>
<td>81 038 (97.7%)</td>
<td>24 811 (24.6%)</td>
<td>275.2 (151.8–419.8)</td>
<td>203.8 (65.5–321.6)</td>
<td>270 303 (26.8%)</td>
</tr>
<tr>
<td>Australia overall</td>
<td>8 630 730 (59.7%)</td>
<td>7 697 454 (53.0%)</td>
<td>33.6 (30.1–42.3)</td>
<td>7.3 (3.9–14.6)</td>
<td>12 649 968 (87.1%)</td>
</tr>
</tbody>
</table>

Access to PPCI Facilities

**PPCI** indicates primary percutaneous coronary intervention; IQR, interquartile range.

*Defined as the proportion of the population capable of reaching a fibrinolysis facility ≤60 minutes or a PPCI facility ≤120 minutes of EMS activation, assuming that the patient is transferred by EMS or self-presents to the nearest hospital.

†Denoted the proportion of the adult population normally resident close to a facility (≤120 minutes driving time from a PPCI hospital or ≤60 minutes driving time from a fibrinolysis hospital) respectively.

Current Access to Reperfusion in STEMI

A PPCI facility was the nearest acute hospital for 40.3% (5.85 million) of the adult population for whom timely access (≤120 minutes) was possible for 40.2% (Table 2, Figure 2A). For the remaining 59.7% (8.63 million) of the adult population, a fibrinolysis-capable hospital was the nearest hospital, with 53.0% capable of accessing this facility within 60 minutes (Table 2, Figure 2A). Overall, 93.2% of the population had timely access to some form of reperfusion therapy. All those residing within major cities were capable of timely access to reperfusion (PPCI or fibrinolysis); however, a reduction in timely access occurred with increasing remoteness (Figure 2A). Timely access to PPCI was poor (12.8% to 23.8%) in regional areas and absent in remote areas. Timely access to fibrinolysis also declined, with increasing remoteness with <50% of the population in remote regions capable of accessing a fibrinolysis facility ≤60 minutes. Variation in projected driving speeds of ±25% resulted in minimal (<1%) change from baseline estimates of timely access. (See online-only Data Supplement Appendix I.)

Interventions to Improve Access to Reperfusion: Optimizing Emergency Medical Services Response

Optimized EMS response resulted in improvement in timely access for an additional 1.8% of the adult population, with all of the improvement resulting from improved timely access to fibrinolysis (Table 3). Benefit from optimized EMS response occurred primarily in inner and outer regional areas, with an estimated 6.2% to 6.4% increase in population access to timely reperfusion in these areas (Figure 2B).

Establishing New PPCI Facilities

Modeling the establishment of 10 new PPCI facilities resulted in a modest 3.7% improvement in timely access to PPCI (Figure 2C), with benefit primarily occurring in inner regional areas, but resulted in a corresponding decline in access to fibrinolysis, with no improvement in overall timely access to reperfusion (Table 3).

Interhospital Transfer From Noninterventional to Interventional Facilities

Modeling interhospital transfer for PPCI resulted in additional timely access to PPCI services for an estimated 23.5% (3.42 million) of the adult population who would have otherwise received fibrinolysis in hospital (Figure 2D, Table 3). For those who were transferred, the median additional distance and time delay resulting from interhospital transfer was 12.4 (interquartile range [IQR], 10.0 to 16.4) km and 78.3 (IQR, 75.1 to 83.0) minutes, with a median total time to reach PPCI facilities from EMS activation (driving time to initial hospital plus interhospital transfer time) of 109.9 (IQR, 105.6 to 115.0) minutes and a total distance of 19.2 (IQR, 14.6 to 24.5) km. The benefits of interhospital transfer primarily occurred in major cities, where PPCI and fibrinolysis facilities were located in proximity, making interhospital transfer feasible. Although the above results were obtained estimating a DIDO time of 68 minutes, adopting a DIDO time of 30 minutes (as recommended by current guidelines) resulted in an increase in timely access to PPCI services for an estimated 34.4% (4.91 million), representing an additional 10.9% improvement in access to PPCI.
Prehospital EMS Triage and EMS Diversion to PPCI Facilities

A strategy of EMS triage and diversion to a PPCI facility resulted in a 19.4% (2.82 million) increase in the proportion of the population who had timely access to PPCI services (Figure 2E, Table 3). For those who underwent diversion, the median driving time and distance to the PPCI facility was estimated to be 46.4 (39.4 to 59.3) minutes and 20.1 (11.8 to

Table 3. Population Effects of Strategies to Improve Timely Access to Reperfusion

<table>
<thead>
<tr>
<th>Strategy</th>
<th>PPCI ≤120min</th>
<th>Δ Baseline*</th>
<th>Fibrinolysis ≤60min</th>
<th>Δ Baseline*</th>
<th>Overall Timely Access</th>
<th>Δ Baseline*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline</td>
<td>40.2%</td>
<td>--</td>
<td>53.0%</td>
<td>--</td>
<td>93.2%</td>
<td>--</td>
</tr>
<tr>
<td>Optimized EMS response</td>
<td>40.2%</td>
<td>0.0%</td>
<td>54.8%</td>
<td>1.8%</td>
<td>95.1%</td>
<td>1.8%</td>
</tr>
<tr>
<td>New PPCI facilities</td>
<td>43.9%</td>
<td>3.7%</td>
<td>49.3%</td>
<td>−3.7%</td>
<td>93.2%</td>
<td>0.0%</td>
</tr>
<tr>
<td>Interhospital transfer for PPCI</td>
<td>63.8%</td>
<td>23.5%</td>
<td>29.4%</td>
<td>−23.5%</td>
<td>93.2%</td>
<td>0.0%</td>
</tr>
<tr>
<td>Direct transfer for PPCI</td>
<td>59.6%</td>
<td>19.4%</td>
<td>33.5%</td>
<td>−19.4%</td>
<td>93.2%</td>
<td>0.0%</td>
</tr>
<tr>
<td>Prehospital fibrinolysis†</td>
<td>40.2%</td>
<td>0.0%</td>
<td>56.7%</td>
<td>3.7%</td>
<td>96.9%</td>
<td>3.7%</td>
</tr>
</tbody>
</table>

PPCI indicates primary percutaneous coronary intervention; EMS, emergency medical services.

*Refers to population change from baseline levels of access.

†Values for fibrinolysis ≤60 min includes in-hospital fibrinolysis and prehospital fibrinolysis.
Prehospital Fibrinolysis

A strategy of prehospital fibrinolysis led to an estimated 3.7% increase in the adult population who received timely reperfusion. The benefit was exclusively seen in regional and remote areas. The estimated 7.4% to 36.9% incremental benefits of prehospital fibrinolysis noted in regional and remote areas was markedly higher than any other strategy evaluated in these regions (Figure 2F, Table 3).

Discussion

These analyses, based on GIS, a robust means of assessing access to healthcare services, show that timely access to reperfusion is currently provided to the majority of the Australian population; however, current systems of care in which the default strategy is to transport patients to the nearest acute care hospital means that only 40.2% of population has timely access to PPCI. In-hospital fibrinolysis remains the main mode of timely reperfusion throughout Australia, and in regional and remote areas, many individuals do not have timely access to any form of reperfusion therapy.

The population impact of interventions advocated to improve reperfusion, modeled in this analysis, varied markedly in both scope and magnitude. Optimizing EMS response alone (without preferential diversion to PPCI facilities or providing prehospital fibrinolysis) resulted in a modest increase in access to timely reperfusion; however, most (66% to 75%) deaths from STEMI occur before hospitalization.23,24 Rapid EMS response and treatment (especially defibrillation) may improve survival.25 A near 25% increase in PPCI facilities resulted in a modest 3.7% improvement in timely access to PPCI facilities. This limited impact most likely reflects the population densities of regional and remote areas, which are 50-fold lower than in major cities. Any increase in the number of PPCI facilities in these areas results in only modest overall population gain. The limited benefit of increasing PPCI facilities in improving access has also been noted in other recent studies.26 Conversely, 82.1% of the adult population in Australia resides within 120 minutes of driving time of PPCI facilities. This indicates that existing PPCI facilities are substantially underused in the absence of systems to preferentially divert patients to these facilities.

Interhospital transfer and diversion to PPCI facilities preferentially direct patients to PPCI services for those who would otherwise receive fibrinolysis. These interventions both provide the potential for pre-PCI hospital activation of catheterization laboratories, which can result in marked reduction in door–to–balloon times and improved patient outcomes after STEMI.27–29 The benefits are largely limited to major cities where fibrinolysis and PPCI facilities are located in proximity, making access to PPCI facilities within an additional 60-minute delay feasible. In addition, the benefit of diversion to PPCI facilities is limited to those who use EMS.

Our evaluation of interhospital transfer resulted in an estimated additional transfer time to PPCI facility of 78.3 (IQR, 75.1 to 83.0) min. This is consistent with findings of meta-analysis of interhospital transfer trials, which suggests benefit of PPCI over thrombolytic therapy persists for time delays of up to 70 to 130 minutes.30 The estimated DIDO time of 68 minutes used in our analysis is reflective of actual clinical practice31,32 but is substantially longer than the recommended time interval of 30 minutes; however, a small proportion of patients do achieve DIDO time ≤30 minutes, suggesting this optimistic target is plausible. Our estimates suggest additional capacity to further improve access to PPCI by interhospital transfer if a DIDO time of 30 minutes can be routinely achieved in clinical practice. Concerted measure to improve DIDO time, routine measurement of interhospital transfer delay as a quality indicator, and adoption of system-based interventions associated with reduced transfer times identified in recent analyses may overcome existing barriers to rapid interhospital transfer.32,33

Prehospital fibrinolysis and improving EMS response were the only interventions associated with improvement in overall timely access to reperfusion for the Australian population. Primary benefit of prehospital fibrinolysis occurs in outer regional and remote areas, where hospitals are sparse and existing timely access is suboptimal. Implementing this strategy alone would ensure 96.9% of our adult population would have timely access to reperfusion regardless of their residential location.

A hybrid approach of fibrinolysis (pre- or in-hospital) followed by rapid transfer to PPCI facilities may be associated with reduced mortality compared with fibrinolysis alone.34–37 Our analysis evaluated access to the initial mode of reperfusion, which, we believe, is the most time-critical; however, existing timely access to a fibrinolysis or PCI-capable facility for the majority of the population limits the applicability of prehospital lysis to a small proportion (3.7%) for whom prehospital-based facilitated PCI or a pharmaco-invasive approach may be considered. Conversely, in-hospital fibrinolysis and rapid transfer for PPCI is likely to be highly feasible, given that 33.8% of the population are already capable of transfer within 1 hour, which is substantially shorter than the 3 to 24 hours advocated for a pharmaco-invasive approach.38

Our study does have several limitations. There is currently no national database that reports services offered by individual hospitals in Australia and, although PPCI services are relatively readily identifiable, it is possible, but unlikely, that some of the acute care hospitals included in our study did not provide fibrinolysis. We used projected driving speeds based on road type, and we did not take into consideration other factors such as traffic conditions; however, our sensitivity analysis does suggest that variation in driving times does not significantly influence access to PPCI facilities, and traffic patterns have limited effect on EMS response times.39 Our baseline analysis assumed that all patients are transported to the nearest hospital and did not take into account hospitals...
with existing prehospital triage systems; however these facilities are currently very few in number and constrained by restricted EMS capacity. We did not consider air transport for STEMI owing to the relative lack of availability of this resource in Australia and the inconsistent evidence of the benefit of air transport in shortening reperfusion times in the literature.\textsuperscript{39–40} Our analysis did not consider the duration of symptoms before EMS activation, which may influence the choice of PPCI or fibrinolysis. Additionally, we did not consider the cost-effectiveness of each intervention, which may also influence their implementation.

Despite these limitations, this study does have a number of strengths. Decisions regarding implementation of health services are often made on clinical evidence alone, which, in part, reflects the lack of robust methodology to facilitate incorporation of population-specific factors into the decision-making process. GIS methods overcome this limitation by providing an objective process to incorporate population-specific factors. Although this involves modeling based on best available estimates, GIS is, nonetheless, a powerful tool that allows for both large area (national) and precise (small area) analysis. Although the use of GIS methods for quantifying access to services is not novel,\textsuperscript{10–12} we believe there is great potential for the wider use of GIS methods in conducting population-level comparative effectiveness research (CER), leading to substantially better-informed decision-making regarding implementation. These analyses are critical for informing future health policy innovation, particularly in the current era of increasing healthcare costs and increased demand for better use of limited resources. Although we have used Australian data in the context of reperfusion for STEMI, GIS methods can be readily adapted to other health services or populations. We believe increasing knowledge of GIS methods, ease of use of GIS software, and increasing accessibility to spatially distributed population datasets will facilitate the wider use of GIS methods by clinicians and healthcare policy planners.

Conclusions

We have identified deficiencies in current service provision in Australia that reflect a failure to implement nationwide policies to maximize timely access to lifesaving treatments for STEMI. Concerted efforts to improve outcomes for patients with STEMI will require multiple system-level changes. Interventions whereby prehospital triage and diversion to a PPCI site is provided to patients who call EMS, expedited interhospital transfer is provided to those who self-present to a fibrinolysis hospital, and prehospital fibrinolysis is facilitated in remote Australia are likely to result in the greatest improvement in health outcomes.

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Disclosures

None.

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SUPPLEMENTAL MATERIAL

Projected driving speeds:

Projected driving speeds were based on the National road type classification (Geoscience Australia*). Road type, projected speeds and the ±25% variation for sensitivity analyses is given below.

**Projected driving speeds based on road type.**

<table>
<thead>
<tr>
<th>Road Type*</th>
<th>Projected Speed (Km/Hr)</th>
<th>Minus 25%</th>
<th>Plus 25%</th>
<th>Definition of Road Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dual Carrigeway</td>
<td>100</td>
<td>75</td>
<td>125</td>
<td>Divided Highway, Freeway, Tollway, or other major roads with separated carriageways in opposite directions</td>
</tr>
<tr>
<td>Principle Road</td>
<td></td>
<td></td>
<td></td>
<td>Highways, major through routes and major connecting roads</td>
</tr>
<tr>
<td>Sealed</td>
<td>70</td>
<td>52.5</td>
<td>87.5</td>
<td></td>
</tr>
<tr>
<td>Unsealed</td>
<td>40</td>
<td>30</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>Secondary Road</td>
<td></td>
<td></td>
<td></td>
<td>Connecting roads that provide a connection between major through routes and/or major connecting roads, or connections</td>
</tr>
<tr>
<td>Sealed</td>
<td>50</td>
<td>37.5</td>
<td>62.5</td>
<td></td>
</tr>
<tr>
<td>Unsealed</td>
<td>40</td>
<td>30</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>Minor road</td>
<td></td>
<td></td>
<td></td>
<td>All other roads which form part of the public roads system between Principal roads and Secondary roads.</td>
</tr>
<tr>
<td>Sealed</td>
<td>40</td>
<td>30</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>Unsealed</td>
<td>30</td>
<td>22.5</td>
<td>37.5</td>
<td></td>
</tr>
<tr>
<td>Vechical Track</td>
<td></td>
<td>20</td>
<td>15</td>
<td>Public or private roadways of minimum or no construction which are not necessarily maintained</td>
</tr>
<tr>
<td>Unsealed</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>


Appendix 1:

**Appendix 1: Effect of altering projected driving speeds**

<table>
<thead>
<tr>
<th>Region</th>
<th>Minus 25% Driving Speed</th>
<th>Plus 25% Driving Speed</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Timely Access to PPCI</td>
<td>% change‡</td>
</tr>
<tr>
<td>Major Cities</td>
<td>51.22%</td>
<td>-0.13%</td>
</tr>
<tr>
<td>Inner Regional</td>
<td>10.75%</td>
<td>-2.00%</td>
</tr>
<tr>
<td>Outer Regional</td>
<td>21.67%</td>
<td>-2.13%</td>
</tr>
<tr>
<td>Remote</td>
<td>0.00%</td>
<td>0.00%</td>
</tr>
<tr>
<td>Very Remote</td>
<td>0.00%</td>
<td>0.00%</td>
</tr>
<tr>
<td>Australia Overall</td>
<td>39.54%</td>
<td>-0.68%</td>
</tr>
</tbody>
</table>

**Appendix 1 Footnote:**

Abbreviations:  PPCI = Primary percutaneous coronary intervention