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Driving Times and Distances to Hospitals With Percutaneous Coronary Intervention in the United States

Implications for Prehospital Triage of Patients With ST-Elevation Myocardial Infarction

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Background—The success of prehospital triage protocols for patients with ST-elevation myocardial infarction (STEMI) will depend, in part, on how patients are geographically distributed around hospitals that perform percutaneous coronary intervention (PCI). Accordingly, we determined the proportion of the adult population in the United States with timely access to PCI hospitals using driving times and distances.

Methods and Results—We performed a cross-sectional study using hospital-level data from the American Hospital Association Annual Survey and Census tract-level data on adults 18 years of age or older from the 2000 United States Census. Our aims were to determine the proportion of the adult population who (1) lived within 60 minutes of a PCI hospital and (2) had additional transport times within 30 minutes if directly referred to a PCI hospital as opposed to a closer, non-PCI hospital. Median times and distances to the closest PCI hospital were 11.3 (interquartile range [IQR] 5.7 to 28.5) minutes and 7.9 (IQR 3.5 to 22.4) miles, respectively. A total of 79.0% of the adult population lived within 60 minutes of a PCI hospital. Among those with a non-PCI hospital as their closest facility, 74.0% required additional transport times of <30 minutes if directly referred to a PCI hospital as opposed to the non-PCI hospital. These estimates varied substantially across regions and urban, suburban, and rural Census tracts.

Conclusions—Nearly 80% of the adult population in the United States lived within 60 minutes of a PCI hospital in 2000. Even among those living closer to non-PCI hospitals, almost three fourths would experience <30 minutes of additional delay with direct referral to a PCI hospital, which suggests that such a strategy might be feasible for these individuals. **(*Circulation*. 2006;113:1189-1195.)**

Key Words: ST-elevation myocardial infarction ■ percutaneous coronary intervention ■ regionalization

Primary percutaneous coronary intervention (PCI) is more effective than fibrinolytic therapy as reperfusion therapy for patients with an ST-elevation myocardial infarction (STEMI) when it is performed rapidly and by experienced operators.[1,2] As a result, several cardiovascular experts and the National Heart Attack Alert Program have called for prehospital ambulance triage of patients with STEMI to PCI hospitals in the United States.[3–6] However, the time required to initiate primary PCI is closely related to clinical outcomes.[7,8] Delays that are incurred from directly transporting patients to a PCI hospital may eliminate the advantage of primary PCI or even place the patient at greater risk if a closer, non-PCI hospital is available but bypassed.[9,10]

Editorial p 1159
Clinical Perspective p 1195

The success of prehospital triage protocols aimed at preferentially triaging STEMI patients to PCI hospitals depends, in large part, on how patients are geographically distributed around PCI and non-PCI hospitals and whether timely access can be achieved even under optimal circumstances. Such proximity is necessary, although not sufficient, to the development of a regionalization policy. Accordingly, the aims of this study were to estimate (1) driving times and distances to the closest PCI hospital for the US adult population and (2) the additional driving times and distances required to reach

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the closest PCI hospital when a closer, non-PCI hospital was available (ie, prehospital bypass delay). Although the first aim provides an overview of access to PCI hospitals in the general population, the second aim has direct policy implications for prehospital triage protocols that are being considered by emergency medical systems across the United States.

Methods

We assessed timely access to PCI hospitals using 3 approaches. First, we estimated driving times and distances to the closest PCI hospital for the adult population in the United States who were 18 years of age or older. Second, we used driving times to determine the proportion of the population who could reach a PCI hospital within 60 minutes. This prehospital time period included the time required for emergency medical system activation, ambulance arrival, early treatment and stabilization, and driving times for transporting the patient. We specifically chose a 60-minute window for this time period because hospital arrival within this time period maximizes the likelihood of favorable outcomes after reperfusion therapy.[11]

We also estimated driving times and distances to the closest non-PCI hospital and used these values to calculate differences in driving times and distances between the closest PCI and non-PCI hospitals. This difference in driving time, which represents the additional time or "prehospital bypass delay" required for preferentially triaging patients to a PCI hospital, was 0 when the closest hospital was a PCI hospital. Among those with a non-PCI hospital as their closest facility, we then determined the proportion who had prehospital bypass delays within a 30-minute time period. We specifically chose a 30-minute window for this time period because the advantages of primary PCI may be lost for many patients with longer delays.[10] We also evaluated a 60-minute prehospital triage delay because high-risk subgroups of patients (fibrinolytic-ineligible) may still benefit from primary PCI despite longer delays.

Data Sources

Our primary data sources were the 2000 US Census and the American Hospital Association (AHA) Annual Survey for fiscal year 2001.[12,13] Data sources were available through the US Census Bureau Web site[14] and the Digital Spatial Data Catalog at the University of Michigan Map Library (Ann Arbor, Mich).

Data from the 2000 US Census included information on the number of individuals and their geographic location (longitude and latitude) at the Census tract level. Census tracts are small statistical subdivisions of a county with between 2500 and 8000 people. They are designed to be homogeneous with respect to population characteristics, economic status, and living conditions. For each Census tract, we used population centers provided by the US Census Bureau to represent specific geographic locations.[15] Population centers correspond to the approximate location, or "point in space," within a Census tract that is closest to most of its residents.

Data on the general attributes and local addresses of US healthcare facilities were obtained from the AHA Annual Survey.[13] Specific geographic locations (longitude and latitude) for the approximately 6000 facilities in the AHA Annual Survey were available as mapped addresses through a shapefile released by the Environmental Systems Research Institute, Inc (ESRI, Redlands, Calif). Because certain facilities provide limited emergency services to the general population, we excluded Veterans Administration (VA) or military hospitals, children's or women's hospitals, long-term care or rehabilitation facilities, and hospitals associated with an infirmary or prison.

Although the AHA Annual Survey represents one of the largest and most comprehensive registries of US hospitals, it includes voluntary, self-reported data on select attributes and has no information on PCI availability. We therefore identified hospitals capable of performing PCI using 2 strategies. First, we used data from the AHA Annual Survey to identify facilities that reported providing open-heart surgery and cardiac catheterization services. Second, we used hospital-level data from 2001 in Medicare beneficiaries to identify any facility that reported performing PCI in patients with acute myocardial infarction. Hospitals identified by either approach were considered PCI hospitals.

Driving Times and Distances and Calculation of Timely Access

We performed our analyses separately across the 9 regions represented by US Census Divisions: New England (Connecticut, Massachusetts, Maine, New Hampshire, Rhode Island, and Vermont), Middle Atlantic (New Jersey, New York, and Pennsylvania), South Atlantic (Washington, DC, Delaware, Florida, Georgia, Maryland, North Carolina, South Carolina, Virginia, and West Virginia), East North Central (Illinois, Indiana, Michigan, Ohio, and Wisconsin), West North Central (Iowa, Kansas, Minnesota, Missouri, North Dakota, Nebraska, and South Dakota), East South Central (Alabama, Kentucky, Mississippi, and Tennessee), West South Central (Arkansas, Louisiana, Oklahoma, and Texas), Mountain (Arizona, Colorado, Idaho, Montana, New Mexico, Nevada, Utah, and Wyoming), and Pacific (California, Oregon, and Washington). Within each region, access to PCI and non-PCI hospitals in neighboring states was allowed if those were the closest facilities. Due to the unique geographies of Hawaii and Alaska, we limited our analyses to the 48 continental states and the District of Columbia. We also excluded Census tracts (0.1%) that were unpopulated or in which ground transport to PCI hospitals was unable to be determined (eg, remote or landlocked).

Driving distances from the population centers of each Census tract to the closest PCI and non-PCI hospital were estimated with a nationwide Topologically Integrated Geographic Encoding and Referencing (TIGER) 2000-based road network (Streetmap USA, ESRI), which included data from interstate, state, and local roads. Consistent with strategies used by earlier investigators, driving times were calculated as the product of estimated distances and projected travel speeds across different road types with Census Feature Classification Codes (CFCC) Appendix A (found in the online-only Data Supplement).[16,17] Importantly, the "closest" hospital was determined with a heuristic algorithm[18,19] and based on shortest driving time, not shortest distance.

In estimating prehospital times, we added 1.4 minutes for ambulance dispatch in urban and suburban areas and 2.9 minutes in rural areas. These estimates were obtained from a recent meta-analysis of the literature on prehospital times for trauma care.[20,21] On the basis of recent guideline recommendations for STEMI, we added 8 minutes for time spent at the patient scene in urban and suburban areas but then adjusted this estimate to 9 minutes in rural areas due to the anticipation of slightly greater delays in these areas.[20–22] Although we directly estimated driving times from the patient to the closest hospital, specific locations of ambulance depots were unavailable, and driving times to the patient could not be determined directly. Instead, we multiplied the time required for driving from the patient to the closest hospital by empirically derived constants of 1.6 for urban areas, 1.5 for suburban areas, and 1.4 for rural areas to determine overall roundtrip driving times. These constants were adapted from similar analyses on timely access to trauma care.[20,21]

We report our results for the entire US adult population, as well as stratified by US region and urban, suburban, and rural Census tracts. Census tracts were categorized as urban, suburban, or rural on the basis of tertiles of population densities (residents per square mile). In our baseline analyses, nondriving times did not include potential delays in ambulance dispatch or time spent at the patient scene, and driving times did not include potential delays from traffic patterns or congestion. However, we performed sensitivity analyses to determine how (1) a 10-minute increase or decrease and (2) a 25% increase or decrease in prehospital times influenced our results. The former evaluated absolute variations in estimates of the prehospital time period, whereas the latter reflected relative changes.

We used ArcGIS version 9.1 (ESRI) for network analyses and map construction, with all maps displayed in the Albers equal-area conic projection, and Stata version 8 (Stata Corporation) for all other statistical analyses.

The agencies and foundations that funded this work were not involved in the design and conduct of the study; in the collection,

US Census tracts located within a 60-minute prehospital time period of a PCI hospital.

analysis, and interpretation of the data; or in the preparation, review, or approval of the manuscript. The authors had full access to all data in the study and take responsibility for the integrity of the data and the accuracy of the data analysis.

Results

A total of 4609 acute-care hospitals met our inclusion criteria, with 1176 (25.5%) identified as PCI hospitals. From the 2000 US Census, we identified 207 537 449 adults 18 years of age or older in Census tracts with road network access to PCI hospitals. Overall, the median driving time and distance to the closest PCI hospital for the adult population were 11.3 (interquartile range [IQR] 5.7 to 28.5) minutes and 7.9 (IQR 3.5 to 22.4) miles, respectively, and 42.0% of the adult population had PCI hospitals as their closest facility. In addition, 79.0% of the adult population lived within 60 minutes of a PCI hospital (Figure). These results varied substantially across US regions (Table 1).

For the 58.0% of the adult population with a non-PCI hospital as their closest facility, the median additional driving time (ie, prehospital bypass delay) to a PCI hospital was 10.6 (IQR 3.2 to 31.4) minutes, and the median additional driving distance was 9.7 (IQR 2.7 to 28.0) miles. A total of 73.8% of the adult population with a non-PCI hospital as their closest facility had prehospital bypass delays within 30 minutes, and 90.3% had prehospital bypass delays within 60 minutes. These results again varied substantially across US regions (Table 2).

Timely access to PCI hospitals also differed across urban, suburban, and rural Census tracts (Tables 1 and 2). Driving times to the closest PCI hospital were 5.5 (IQR 3.4 to 8.6) minutes for adults in urban Census tracts, 10.5 (IQR 6.3 to 18.2) minutes for those in suburban Census tracts, and 35.9 (IQR 20.7 to 58.1) minutes for those in rural Census tracts. In addition, 98.1% of adults in urban Census tracts lived within 60 minutes of a PCI hospital. Of those adults in urban Census

TABLE 1. Driving Times and Distances to the Closest PCI Hospital and Proportion With Prehospital Time Periods Within 60 Minutes for the US Adult Population

	Median Driving Time, min (IQR)	Median Driving Distance, Miles (IQR)	<60-Minute Prehospital Time Period, %
Total United States	11.3 (5.7–28.5)	7.9 (3.5–22.4)	79.0
US Census divisions			
New England	16.3 (7.4–27.1)	12.7 (5.1–23.1)	82.9
Middle Atlantic	9.1 (4.8–19.8)	6.2 (3.0–15.1)	87.4
South Atlantic	14.5 (7.4–32.6)	10.2 (4.7–25.3)	76.2
East North Central	11.6 (5.5–29.3)	7.9 (3.3–22.3)	79.0
West North Central	16.2 (6.3–54.4)	12.2 (3.9–44.4)	62.9
East South Central	21.4 (8.4–43.0)	15.9 (5.5–34.3)	64.9
West South Central	11.5 (5.8–30.2)	7.9 (3.6–23.6)	77.7
Mountain	10.3 (5.4–45.2)	7.0 (3.2–35.2)	72.5
Pacific	7.6 (4.6–14.4)	5.1 (2.7–11.2)	89.9
Population density			
Urban	5.5 (3.4–8.6)	3.5 (2.0–6.0)	98.1
Suburban	10.5 (6.3–18.2)	7.2 (3.9–14.2)	89.6
Rural	35.9 (20.7–58.1)	27.8 (14.9–46.3)	47.8

TABLE 2. Additional Driving Times and Distances to the Closest PCI Hospital and Prehospital Bypass Delays for the US Adult Population With a Non-PCI Hospital as the Closest Facility

	Median Additional Driving Time, min	Median Additional Driving Distance, Miles (IQR)	<30-Minute Prehospital Bypass Delay,*%
Total	10.6 (3.2–31.4)	9.7 (2.7–28.0)	73.8
US Census divisions			
New England	12.8 (4.1–22.5)	12.4 (3.4–21.5)	82.9
Middle Atlantic	5.4 (2.3–14.0)	4.5 (1.7–12.7)	88.9
South Atlantic	13.1 (4.5–32.2)	12.4 (3.8–27.6)	72.7
East North Central	13.0 (3.4–32.1)	11.3 (2.8–28.4)	72.3
West North Central	35.9 (10.3–69.7)	30.9 (9.9–59.4)	45.2
East South Central	25.9 (8.6–41.5)	23.4 (7.7–36.0)	59.3
West South Central	13.9 (4.3–41.7)	12.9 (3.9–35.5)	66.6
Mountain	29.5 (4.0–104.8)	26.4 (4.0–95.1)	50.0
Pacific	4.7 (2.1–14.4)	4.2 (1.6–13.8)	87.0
Population density			
Urban	3.2 (1.4–6.4)	2.6 (1.1–5.4)	96.6
Suburban	8.7 (3.1–21.2)	7.9 (2.8–19.5)	81.8
Rural	27.8 (12.8–50.1)	25.0 (11.6–43.5)	53.0

*Prehospital bypass delay refers to the additional time and distance required to reach a PCI hospital for the proportion of the population with a non-PCI hospital as the closest facility.

tracts with non-PCI hospitals as their closest facility, 96.6% had prehospital bypass delays within 30 minutes. Among adults in suburban Census tracts, 89.6% lived within 60 minutes of a PCI hospital, whereas 81.8% with a non-PCI hospital as their closest facility had prehospital bypass delays within 30 minutes. In comparison, 47.8% of adults in rural Census tracts lived within 60 minutes of a PCI hospital, and 53.0% of those with non-PCI hospitals as their closest facility had prehospital bypass delays within 30 minutes.

Sensitivity analyses found that a 10-minute increase or decrease and a 25% increase or decrease in prehospital times did not substantially influence our results overall. In most cases, the proportion of the adult population living within 60 minutes of a PCI hospital and the proportion with 30-minute prehospital bypass delays changed less than 10% (Table 3); however, more substantial changes were noted when prehospital times were varied in rural Census tracts.

TABLE 3. Sensitivity Analysis of Changes in Driving Times on Timely Access

	% Within 60-Minute Prehospital Time Period				% Within 30-Minute Prehospital Bypass Delay*			
	10-Minute Decrease	25% Decrease	10-Minute Increase	25% Increase	10-Minute Decrease	25% Decrease	10-Minute Increase	25% Increase
Total	83.2	86.7	73.9	72.7	73.8	81.0	73.8	68.3
US Census divisions								
New England	87.3	90.8	74.3	71.9	82.9	90.1	82.9	77.2
Middle Atlantic	90.8	93.7	83.1	82.0	88.9	93.4	88.9	85.5
South Atlantic	81.5	86.0	70.0	68.5	72.7	81.4	72.7	67.0
East North Central	83.9	88.0	73.0	71.7	72.3	81.8	72.3	65.0
West North Central	67.5	71.7	58.6	57.6	45.2	54.3	45.2	38.0
East South Central	73.3	80.0	56.5	55.1	59.3	73.4	59.3	47.3
West South Central	81.1	84.4	72.5	71.5	66.6	73.7	66.6	60.8
Mountain	74.1	75.7	70.7	70.0	50.0	52.9	50.0	48.6
Pacific	92.4	93.9	86.8	86.1	87.0	90.8	87.0	83.4
Population density								
Urban	98.6	99.0	97.3	97.1	96.6	97.8	96.6	95.4
Suburban	92.0	93.9	85.8	84.7	81.8	87.2	81.8	77.4
Rural	57.8	66.2	36.7	34.3	53.0	65.5	53.0	43.8

*Prehospital bypass delay refers to the additional time and distance required to reach a PCI hospital for the proportion of the population with a non-PCI hospital as the closest facility.

Discussion

We found that a large proportion of the adult population in the United States lived within reasonable proximity to PCI hospitals in 2000. Almost 80% lived within 60 minutes of a PCI hospital, and >40% lived in areas where a PCI hospital was their closest facility. Among those with non-PCI hospitals as their closest facility, nearly three fourths lived in areas where the additional time required to reach a PCI hospital (or prehospital bypass delay) was <30 minutes. However, we did find that substantial differences in these measures of timely access to PCI hospitals existed across US regions and urban, suburban, and rural Census tracts.

Our findings have policy implications for strategies aimed at improving timely access to primary PCI. First, the overall number and geographic distribution of PCI hospitals across the United States appears sufficient in many areas. Second, our findings suggest that with well-organized, prehospital triage protocols for ambulances, a large proportion of the population could have timely access to PCI hospitals on the basis of the presence of relatively short prehospital bypass delays. Some cities and states have already begun such protocols for triaging STEMI patients,[23,24] and advancements in global positioning systems may improve these further by quickening emergency medical system responses.[25]

However, 43.6 million adults live outside a 60-minute prehospital time period for a PCI hospital, and timely access varied substantially across different US regions. These findings suggest that for individual communities, local resources and geographies will be vital in designing population-based strategies for optimizing reperfusion therapy. For example, remote areas may need to focus on the use of fibrinolytic therapy or seek innovative transport strategies such as the use of emergency air medical services (like those used in trauma networks) to ensure timely access to primary PCI.[26]

Our findings only describe the feasibility of prehospital triage protocols for STEMI patients. Although proximity to a PCI hospital is necessary for such protocols to work, it is in and of itself not sufficient to ensure timely access to primary PCI.[27] Of course, ultimate success will depend on the coordination of professionals in emergency medicine and cardiovascular diseases and healthcare systems across prehospital and in-hospital settings. Even so, it may be that additional strategies such as prehospital fibrinolytic therapy, which may have clinical outcomes that are equivalent to primary PCI,[28] or immediate fibrinolytic therapy at a nearby non-PCI hospital could be preferable under certain circumstances, such as for low-risk STEMI patients who present early after symptom onset.[29]

In addition, even though many patients may have timely access to primary PCI, this should not eliminate the importance of non-PCI hospitals being prepared to care for STEMI patients. Only 50% of STEMI patients use the emergency medical system in the prehospital setting, with many transporting themselves.[30] Improving the appropriate use of emergency medical systems also has been challenging.[31] Therefore, non-PCI hospitals will still need to be prepared to manage to manage STEMI patients, especially because interhospital transport systems in the United States are limited and often result in substantial delays to reperfusion therapy.[32]

Another widely discussed option is to expand primary PCI to more hospitals, including those without on-site cardiac surgery. This strategy may improve clinical outcomes compared with on-site fibrinolytic therapy and reduce delays to reperfusion therapy compared with interhospital transport for primary PCI.[33,34] Nonetheless, it may have some important limitations. The resource costs associated with duplicating these specialized services and the lack of technical staff (including interventional cardiologists) for 24-hour coverage will limit its use. There is also concern that it would prevent primary PCI from being concentrated at high-volume centers where clinical outcomes may be better.[35] Because our findings suggest that the number and distribution of PCI hospitals is sufficient in most areas, we believe that expansion may play less of a role overall in improving timely access to PCI hospitals than enhancements in the emergency medical system and prehospital triage.

The present study has important limitations. First, because no national database of PCI hospitals exists, we had to determine a hospital's capability for primary PCI indirectly using hospital-level characteristics that are associated with nonemergent PCI. These hospital-level characteristics were primarily obtained from responses in the AHA Annual Survey and Medicare data. Second, it is likely that there has been an increase in the number of hospitals with PCI capability since 2001, including facilities without open-heart surgery that are now performing primary PCI. This has clearly expanded the availability of PCI in the general population. We believe both these concerns conservatively bias our estimates of driving times and distances to the closest PCI hospitals. Third, our estimates of timely access were based on residential locations. Although acute illnesses may obviously occur when patients are at work or in other settings, the average distance for daily trips from US households is ≈10 miles, which suggests close proximity to routine destinations for many people.[36]

Additional concerns are the potential for geographic areas without emergency medical systems to be included in our analysis and for traffic congestion to substantially influence estimates of driving times. However, >90% of the US population reportedly has access to 9-1-1 services,[22] and traffic patterns may minimally affect ambulance driving times.[20] Sensitivity analyses also demonstrated that modest changes in driving times did not substantially alter our overall results, with the exception of rural areas. This suggests that factors such as local traffic patterns will need to be considered when one evaluates prehospital triage protocols, particularly if potential mismatches between estimated and actual driving times are suspected. Of note, we used empirically derived constants to calculate roundtrip driving times because specific locations of ambulance depots were unavailable. Our analysis is only meant to describe overall national patterns of timely access and should be interpreted carefully with these issues in mind.

Despite these limitations, the present study has several unique strengths. We estimated travel times and distances using road networks, avoiding straight-line or "as the crow flies" distances.[37,38] We used specific geographic locations for hospitals as opposed to locations approximated from

postal ZIP codes. We also evaluated timely access on the basis of population size and not land coverage. This is an important point, because the US population is heavily concentrated in urban and suburban areas. Thus, although the Figure suggests that land coverage may be far from complete, this is misleading, because most densely populated areas like metropolitan cities generally do have timely access. Most important, we estimated the additional driving times and distances between the closest non-PCI and PCI hospitals. This measure of prehospital bypass delay is relevant because non-PCI hospitals are able to provide fibrinolytic therapy safely and effectively in many patients.

In conclusion, nearly 80% of the US adult population in 2000 lived within 60 minutes of a PCI hospital, and >40% lived in areas where a PCI hospital was the closest healthcare facility. Among those with non-PCI hospitals as their closest facility, nearly three fourths lived in areas where the additional time required to reach a PCI hospital was <30 minutes. Although substantial variation existed across regions in the United States, protocols aimed at preferentially triaging STEMI patients to PCI hospitals in the prehospital setting may be feasible for a large number of patients.

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Disclosures

None.

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CLINICAL PERSPECTIVE

Several cardiovascular experts have called for prehospital ambulance triage of patients with ST-elevation myocardial infarction (STEMI) to hospitals that perform percutaneous coronary intervention (PCI) in the United States; however, delays that are incurred from directly transporting patients to a PCI hospital may eliminate the advantage of primary PCI if a closer, non-PCI hospital with fibrinolytic therapy is bypassed. The success of prehospital triage protocols aimed at preferentially triaging STEMI patients to hospitals capable of performing primary PCI will therefore depend, in large part, on how patients are geographically distributed around PCI and non-PCI hospitals. The aims of this study were to estimate (1) driving times and distances to the closest PCI hospital for the US adult population and (2) the additional driving times and distances required to reach the closest PCI hospital when a closer, non-PCI hospital was available (ie, prehospital bypass delay). The first aim provides an overview of access to PCI hospitals in the general population, whereas the second aim has direct policy implications for prehospital triage protocols that are being considered by emergency medical systems across the United States. We found that nearly 80% of the adult population in the United States lived within 60 minutes of a PCI hospital. In addition, among those living closer to non-PCI hospitals, almost three fourths would experience <30 minutes of additional delay with direct referral to a PCI hospital by prehospital triage, which suggests that such a strategy might be feasible for these individuals. However, these estimates varied substantially across US regions and urban, suburban, and rural Census tracts.