Title
Association of Cardiac Care Regionalization With Access, Treatment, and Mortality Among Patients With ST-Segment Elevation Myocardial Infarction

Journal
Circulation Cardiovascular Quality and Outcomes, 14(3)

ISSN
1941-7713

Authors
Shen, Yu-Chu
Krumholz, Harlan
Hsia, Renee Y

Publication Date
2021-03-01

DOI
10.1161/circoutcomes.120.007195

Peer reviewed

Published in final edited form as:
Circ Cardiovasc Qual Outcomes. 2021 March ; 14(3): e007195. doi:10.1161/CIRCOUTCOMES.120.007195.

Association of cardiac care regionalization with access, treatment, and mortality among patients with ST-elevation myocardial infarction

Yu-Chu Shen, PhD[1,2], **Harlan Krumholz, MD, SM**[3,4,5], **Renee Y. Hsia, MD, MSc**[6,7]

[1]Graduate School of Defense Management, Naval Postgraduate School

[2]National Bureau of Economic Research

[3]Section of Cardiovascular Medicine, Department of Internal Medicine, Yale School of Medicine

[4]Department of Health Policy and Management, Yale School of Public Health

[5]Center for Outcomes Research and Evalution, Yale-New Haven Hospital

[6]Department of Emergency Medicine, University of California at San Francisco

[7]Philip R. Lee Institute for Health Policy Studies, University of California at San Francisco

Abstract

Background: Regionalization of ST-elevation myocardial infarction (STEMI) systems of care has been championed over the past decade. While timely access to PCI has been shown to improve outcomes, no studies have determined how regionalization has affected the care and outcomes of patients. We sought to determine if STEMI regionalization is associated with changes in access, treatment, and outcomes.

Methods: Using a difference-in-differences approach, we analyzed a statewide, administrative database of 139,494 patients with STEMI in California from 2006-2015 using regionalization data based on a survey of all local Emergency Medical Services agencies in the state.

Results: For patients with STEMI, the base rate of admission to a hospital with PCI capability was 72.7%, and regionalization was associated with an increase of 5.34 percentage points (95% CI 1.58 to 9.10), representing a 7.1% increase. Regionalization was also associated with a statistically significant increase of 3.54 (95% CI 0.61 to 6.48) percentage points in the probability of same-day PCI, representing an increase of 7.1% from the 49.7% base rate, and a 4.6% relative increase (2.97 percentage points; 95% CI 0.1, 5.85) in the probability of receiving PCI at any time during the hospitalization. There was a 1.84 percentage point decrease (95% CI −3.31, −0.37) in the probability of receiving fibrinolytics. For 7-day mortality, regionalization was associated with a 0.53 (95% CI −1 to −0.06) percentage point greater reduction (representing 5.8% off the base rate of 9.1%) and a 1.75 percentage point decrease in the likelihood of all-cause 30-day readmission

Correspondence to: Renee Y. Hsia, 1001 Potrero, Bldg 5, 6A, San Francisco, CA 94110, renee.hsia@ucsf.edu, (628) 206-4612.

DISCLOSURES
None.

(95% CI −3.39 to −0.11; representing 6.4% off the base rate of 27.4%). No differences were found in longer-term mortality.

Conclusions: Among patients with STEMI in California from 2006 to 2015, STEMI regionalization was associated with increased access to a PCI-capable hospital, greater use of PCI, lower 7-day mortality, and lower 30-day readmissions.

Keywords

ST-elevation myocardial infarction; percutaneous coronary intervention; fibrinolysis; door-to-balloon; regionalization; mortality; readmissions; systems of care

Subject terms:

Health Services; Myocardial Infarction; Quality and Outcomes

INTRODUCTION

Since 2004, organizations such as the American Heart Association (AHA) and the American College of Cardiology (ACC) have endorsed the regionalization of cardiac care, particularly for ST-elevation myocardial infarction (STEMI).[1] Studies have consistently shown that patients treated with timely percutaneous coronary intervention (PCI) in a high-volume STEMI center experience lower morbidity and mortality than those treated with fibrinolytic therapy or no intervention.[2,3] Due to resource limitations, only 37.1% of all acute care, adult hospitals in the United States offer PCI lab capability as of 2016.[4] Therefore, the goal of these regionalization initiatives has been to quickly route or transfer patients with suspected STEMI to the nearest hospital capable of PCI, bypassing potentially closer hospitals without these capabilities.[5]

STEMI regionalization has been implemented across the United States and now covers 67% of the population.[6,7] While studies have shown that there has been improvement for individuals using process measures, regionalization efforts have not been shown to improve mortality at the population level.[8-10] What is less definitive is what regionalization has accomplished. The existing literature on regionalization is limited by single-hospital or single-region studies, the lack of an appropriate control group, or minimal accounting for secular trends.

This paper addresses this gap in the literature by determining the extent to which regionalization has been associated with changes in overall access to care, treatment, and health outcomes for patients with STEMI in regionalized vs. non-regionalized communities at the population-level, rather than simply at the hospital-level. Using a difference-in-differences approach across counties in California that have regionalized at different time points, we hypothesized that cardiac regionalization is associated with significant benefits for patients with STEMI through increased access to PCI-capable hospitals, greater likelihood of receiving angiography and PCI, and decreased mortality and readmissions.

METHODS

Data Transparency

Because of the sensitive nature of the data, requests to access the dataset may be sent to the California Office of Statewide Health Planning and Development (OSHPD).

Data sources

Several databases were linked to address this population-based research question. First, non-public patient discharge and emergency department data from January 1, 2006- September 30, 2015 were obtained from OSHPD. This dataset contains every hospitalization and ED encounter to non-federal hospitals in California, and include patient demographics, geographical identifier of the patient, insurance sources, process and health outcomes, and a rich set of comorbidity data identified through ICD-9 diagnostic codes. In addition, a unique patient ID was used to track whether a patient was readmitted for hospitalization within 30 days of initial hospital discharge and was linked to vital statistics data. We also obtained Vital Statistics data from the state of California that were matched to the patient identifiers to track out-of-hospital mortality.

Second, detailed regionalized care arrangement from all 33 local EMS in California was collected through a survey done in 2015.[10,11] This dataset identifies key policy variables in the analysis and contains dates of implementation of STEMI regionalization and details of these protocols. The governmental structure of EMS in California with designated local EMS agencies creates organized oversight of large urban counties or a collection of multiple rural counties and allows for the development of such EMS-driven systems.

Third, additional hospital organizational characteristics (e.g., hospital ownership, teaching hospital status, system membership, financial characteristics) were captured from the American Hospital Association annual hospital surveys, as well as annual hospital utilization data from the California OSHPD, which contains annual procedure volumes of several cardiac procedures, including PCI. This study was approved by the UCSF Committee for Human Research.

Patient selection

Following previous literature, patients with STEMI were identified by the ICD-9-CM principal discharge diagnosis from the emergency department or inpatient admission was 410.x0 or 410.x1, excluding 410.7x,[7,12] from both the inpatient discharge database as well as the emergency department discharge database, to capture all patients whether they were admitted to the hospital inpatient ward or only to the ED. The patient universe began with 408,101 cases of AMI between 2006 and 2015 (excluding 20,518 patients who were not California residents). Based on previous work,[13] 71 patients with admissions with length of stay less than 1 day (including those who died) were excluded to minimize selection bias, as they may have been potential misclassifications of AMI. Among the remaining 408,303 AMI patients, 139,494 were identified as STEMI patients. Transfers (both from another hospital and from another ED) were also tracked so that a patient who was transferred between two hospitals only appears once in the dataset.

Patient and Public Involvement

This research was done without patient involvement.

Outcomes

The pre-specified primary outcomes relevant to the success of regionalization included: 1) access to a PCI-capable hospital; 2) receipt of treatment, defined as separately as receipt of same-day PCI or PCI during the hospitalization; and 3) receipt of fibrinolytics.

The secondary outcomes included risk-adjusted mortality at different time periods (7, 30, 90, and 365-day) and 30-day all-cause readmission rates.

The PCI capability of a patient's admitted hospital was identified by linking patient discharge data to the facility data via the admitting hospitals' ID. Therefore, hospitals that began to perform PCI during the study period were also incorporated in the analysis. Given that setting up a PCI lab involves a high sunk cost and procedure volume might vary widely or missing in some years, a previously documented smoothing algorithm was used by identifying the opening year of a PCI lab in a hospital as the first year of the first consecutive 2 years in which a hospital reached the PCI volume threshold. Closure year was defined as the year after the last year in which the hospital met the volume threshold.

The second set of primary outcomes captured procedures received by each patient with STEMI. In particular, we used the following ICD-9 procedure codes: PCI (00.66, 36.00-36.09), both same-day and during the hospitalization separately; and fibrinolytic therapy (99.10) during the hospitalization.[14-16] Receipt of fibrinolytics was used as an outcome not because this is a goal of regionalization but because any increase in early PCI should be accompanied by a downward trend of fibrinolytics. Our model included coronary angiography (using ICD-9 procedure codes 37.21-37.23, 88.50-88.57) for patients with STEMI in the definition of PCI, to capture attempts at intervention. While PCI is generally the definitive treatment for STEMI, inclusion of coronary angiography accounts for clinical realities of false positive diagnoses of STEMI, failed PCI attempts, and referral to CABG in circumstances where PCI would be less effective.

As secondary outcomes, mortality of different time periods were used since studies have found that some system-level factors (such as access to EDs) have differential effects on short-term and long-term mortality rates.[17] Examining multiple health outcomes provides a more complete picture in assessing the benefit of such a network (e.g., if a regionalized scheme only defers death by 1 month by precluding immediate death but results in extremely poor heart function that leads to later demise, for instance, then the cost of operating such a system might outweigh the limited benefits). Finally, all-cause 30-day risk-standardized readmission rates for patients with STEMI, as defined by CMS,[18] were also examined.

Definition of regionalization

STEMI regionalization networks require complex organization, and include use of 12 lead EKG and interpretation by Emergency Medical Services (EMS), designation of STEMI centers with 24/7 PCI availability, commitment to quality improvement, and transfer agreements between STEMI referral hospitals and STEMI centers. STEMI regionalization does not only entail coordination across EMS agencies and hospitals, but also health systems and physician groups, as well as continuous feedback and evaluation across these providers, while ensuring protocol implementation from dedicated coordinators. As described in other work,[19] an objective categorization of STEMI regionalization are rooted in two Class I recommendations specified by the ACC and AHA, where regionalized areas are those that: 1) have emergency medical systems (EMS) that direct pre-hospital transport to bypass the nearest hospitals that do not offer emergent percutaneous coronary intervention (PCI) to facilities that offer emergent PCI for patients with STEMI; and 2) have inter-hospital transfer protocols specifically for patients with STEMI. Using this survey[10,11] to quantify the degree of regionalization, we received a 100% response rate from all local EMS agencies covering all 58 counties in California. In the main analysis, a county is considered regionalized on and after the year that at least 50% of its EMS jurisdiction met either of the two criteria. Sensitivity analyses further categorized regionalization status into partial (if 50%-94% of the EMS jurisdiction met one of the criteria but not both), substantial (if 50-94% of the EMS jurisdiction met both criteria), and complete (if at least 95% of the EMS jurisdiction met both criteria).

Statistical Analysis

A major deficiency in the existing literature is the lack of longitudinal comparison between regionalized and non-regionalized communities. As a result, any benefits in process or outcome measures cannot exclude the possibility that these are due to secular improvements in care or regional variation rather than regionalization network itself.[12]

To enhance causal identification of the regionalization effect, the state of California was used, where counties have regionalized in different years. For any adjacent years, some counties changed their regionalization status (the treatment group) and some did not (i.e., the control group). The time differences in the implementation across counties allow us to implement a difference-in-differences approach that compare *changes in outcome* between control and treatment groups using county fixed effects. By including county fixed effects and year indicators, any unobserved baseline differences across counties and secular trend in outcomes were removed.

The unit of analysis was the patient. Though all outcomes were dichotomous, a linear probability model with county fixed effects was employed to identify the STEMI network effect on the dependent variable through an indicator that takes on the value of 1 on and after the year that a patient’s community is switched to a STEMI regionalized network. We also included year indicators to control for the macro trends of outcomes, county fixed effects controls for unobserved time-invariant heterogeneity across counties (including any inherent differences in baseline access to technology, and case-mix of the underlying population, or other unobserved characteristics across communities), patient’s insurance categories (private, Medicare, Medicaid, indigent care, self-pay, and others), patient demographic covariates (e.g., 5-year age groups, gender, race and ethnicity), as well as twenty-two Elixhauser patient comorbid indicators to control for underlying individual patient health conditions.[17] Race/ethnicity was recorded in the dataset as fixed categories and abstracted from patient charts, which could have been from self-determination or determined by hospital staff, and was measured to account for documented disparities in access and receipt of treatment, the primary outcomes in this study.

For the variables used in our models, there is a trivial number of missing data on age (237 cases out of 139,494 observations, representing 0.17% of the patient population). In 3,915 observations, the PCI capability of the admitted hospital (2.8% of the study population) cannot be ascertained. Given that PCI capability is the key variable in the model, all models that contained PCI capability as the independent variable were estimated using multiple imputation[20] method.

For treatment and health outcomes, a second model was implemented to control for the admitting hospital's PCI capacity. Additional sensitivity analyses were implemented to provide robustness check and better understanding of the mechanisms behind how regionalization might be associated with certain outcomes. The first sensitivity model replaced the binary regionalization indicator with a more granular data on regionalization; the second sensitivity model used a more conservative model where the assumption that a catheterization procedure did not equate to PCI, and instead these outcomes were analyzed separately; and the third sensitivity model stratified analyses based on whether the patient was directly admitted to the hospital or was a transfer case. All estimations were performed in Stata 16 (Stata Corp, College Station, TX), and we used the conventional 5% level of significance with 2-sided testing. In addition, we report both the unadjusted p-value, which assumes the hypothesized relationship between regionalization and each outcome is independent of each other, and the adjusted p-value for multiple comparison using Benjamini-Hochberg method.[21]

RESULTS

Figure 1 shows the number of patients in regionalized and non-regionalized counties over this period. Out of 139,494 total patients in the study, 77,357 (55.5%) were in counties that had regionalized on or before 2008. By the end of 2012, all California counties were regionalized to some degree, which we considered regionalized. All counties were tracked up to September 30, 2015 for all outcomes except for mortality (which are available to us until December 31, 2013; therefore, mortality was only calculated for patients admitted prior to December 31, 2012), which ensured a sufficient number of post-regionalization observations from all counties.

Table 1 presents patient, hospital, and community characteristics of our sample; and further categorize the sample into patients living in early adopter (counties that were regionalized on and before 2008) and late adopter counties. Statistics from Table 1 captured all patients with STEMI in California, regardless of whether they were treated before or after regionalization; the demographic distribution, therefore, reflects that of California at large. Counties that implemented regionalization on or before 2008 had a significantly larger population (median population counts is 3,169,776 vs. 1,019,640), higher median family income ($44,474 vs. $36,243), and a higher percentage of Hispanic population (21% vs. 14% Hispanic patients). Patients in early adopter counties were more likely to be admitted to larger (median hospital bed size 316 vs. 264) and public hospitals (17% vs. 11% government run hospitals). Approximately 14% of patients were transferred to another hospital in early adopter counties, with 67% of those transfers receiving PCI at the 2nd hospital; in late adopter counties, 19% of patients were transferred, with 71% of those patients receiving PCI at the 2nd hospital.

Figure 2 and 3 shows the trends of selected unadjusted outcomes. Even though our empirical model captures the exact year a given county became regionalized, for clarity of presentation, we show the trends separately for counties that were regionalized on or before 2008 and those that were regionalized after 2008. The early adopters had a statistically higher percentage of patients being admitted to PCI hospital in 2006 than the late adopters (75% vs. 66% in 2006), but by the end of the study period in 2014, the late adopters did not have a statistically different level (86%) of PCI access. The increasing probability of receiving PCI procedure during this period also did not differ significantly between patients in early and late adopter counties (from 66% in 2006 to 84% in 2015 in early adopters and from 62-86% in late adopter counties). Both early and late adopters showed a decreasing trend in patients receiving fibrinolytic therapy, with a larger decline in patients from late adopter counties. Mortality and readmission rates also improved for all counties during this period. Our empirical analysis takes into account these macro trends that are common across all counties.

Table 2 shows that 72.7% of patients were admitted to a PCI-capable hospital at baseline in 2006. Regionalization was associated with a 5.34 percentage point increase (95% CI 1.58, 9.10) in the likelihood of being admitted to a hospital with PCI capability for patients whose counties became regionalized compared to patients in counties that did not have a change in regionalization status, reflecting a 7.1% increase in access associated with regionalization (full regression results in Supplemental Table I).

The top panel of Table 2 also shows the “net” effect of regionalization on treatment outcomes, in that we did not control for PCI capacity at site of care. At baseline, 49.7% of patients with STEMI received a PCI procedure on the same day of hospitalization. Regionalization was associated with a statistically significant increase of 3.54 percentage points in the probability of receiving same-day PCI (95% CI 0.61, 6.48), representing a 7.1% increase in PCI treatment. In addition, we found regionalization was associated with a growth of 2.97 percentage points in the probability of receiving PCI during the hospitalization (95% CI 0.1, 5.85; equivalent to a 4.6% increase given that 64.2% of patients with STEMI received PCI during the hospitalization). Regionalization was also associated with a 1.84 percentage point decrease (95% CI −3.31, −0.37) in the probability of receiving fibrinolytics for patients with STEMI, reflecting a 24.9% relative decrease off the baseline of 7.4%.

The top panel of Table 3 shows the net association of regionalization on health outcomes (full regression results in Supplemental Table I). We did not find any statistically significant association with 30-day, 90-day, or 1 year mortality, although we did find a small 0.53 percentage point reduction (CI −1, −0.06) in 7-day mortality (equivalent to 5.8% reduction off the baseline of 9.1%) and a 1.75 percentage point decrease in the likelihood of all-cause

30-day readmission (95% CI −3.39, −0.11), equivalent to 6.4% reduction off the baseline 27.4% readmission rate).

The bottom panels of Tables 2 & 3 show that, conditional on being admitted to a PCI-capable hospital, aside from a statistically significant decrease in the likelihood of receiving fibrinolytic therapy, there were no statistically significant differences in treatment and health outcomes between patients in regionalized and non-regionalized counties. These results suggest that the benefit of regionalization observed in Table 2 was largely through the improved access to PCI-capable hospitals, but that regionalization also did – separately from access to PCI centers – change the practice of administering fibrinolytic therapy to patients with STEMI.

For our sensitivity analyses, the association of regionalization on these outcomes did not differ when analyzing outcomes by more granular categories of regionalization (Supplemental Table II) —there were no statistically significant differences in the estimated change in all outcomes across counties that were classified as partially, substantially, and completely regionalized categories. The second sensitivity analysis (Supplemental Table III) shows the results of using a narrower definition of PCI as an outcome that excludes catheterization, with similar results. Finally, Supplemental Table IV provides stratified results by direct admit patients with STEMI and those patients with STEMI who were transferred, showing a larger benefit in all primary outcomes and several secondary outcomes for direct admit patients. However, this table should be interpreted with caution, as regionalization itself could change the composition and the underlying mortality risk of transfer patients, since inter-hospital transfer protocols may facilitate transport of sicker patients who would have stayed at the non-PCI hospital previously.

DISCUSSION

Regionalization in California was associated with an improvement in access to PCI-capable hospitals and subsequent receipt of PCI. Regionalization was also associated was a statistically significant reduction in 30-day readmissions and 7-day mortality, with admittedly larger confidence intervals. This 7-day mortality benefit did not translate into longer-term mortality reductions.

These findings importantly contribute to our understanding of the effects of regionalization. While regionalization has been shown to improve door-to-balloon times (DTB) and first medical contact to device,[8] and these process measures have been associated with decreased mortality,[22] the relationship between regionalization and improved mortality in the U.S has been less definitive.[23] Few studies of multiple regions so far that have used a control group. One study with Medicare patients in North Carolina showed that improvements in mortality were the same as seen in non-intervention groups and were likely due to secular improvements in STEMI mortality.[7] Another important study evaluating the addition of regional coordinators to existing STEMI regionalization efforts used a control group of hospitals already participating in a registry and showed a mortality benefit; however, because only selected hospitals participated, the population-based effects of regionalization (to account for patients who did not present to participating hospitals) could not be ascertained.

[24] Other studies examining mortality before and after regionalization have been unable to show any effect.[8-10]

Like other studies,[24,25] the improved short-term mortality associated with regionalization in California in this study did not persist over the longer-term. If regionalization has been shown to decrease DTB times,[8,26] and decreased DTB times are associated with improvements in mortality, why have studies of regionalization been unable to be directly show improvements in longer-term mortality? There are several possibilities. First, patients may actually take a longer time to reach the “door” (the PCI-equipped hospital). Using DTB or similar process measures therefore ignore the consideration of longer field or transit times. The conflicting evidence[22,27] and apparent dissociation between DTB times and mortality has been recognized by others[23] who have noted that DTB times are only one component of many different factors associated with STEMI mortality and, therefore, may not provide an accurate measure of regionalization outcomes. This is now recognized as the field has moved towards measuring first medical contact to device times. In addition, regionalization efforts to push inter-hospital transfer could potentially have an unintended consequence of increasing symptom to reperfusion times if fibrinolytics could have been administered significantly earlier.

Second, while treatment with PCI has been shown to lower mortality rates,[2] and regionalization may improve access to PCI, effects from regionalization may be difficult to find because even without formal or governmental regionalization schemes, there can be *de facto* regionalization where hospitals may create transfer relationships with PCI centers for patients with STEMI even when not under a regionalization scheme. In addition, it is possible that the growth of PCI centers in hospitals across the United States may have reached a point that there is not sufficient volume to sustain operator expertise.[28] Already in 2010, less than 12% (574 of 4,931) of all hospitals offered PCI for a high volume of patients with STEMI (>40 primary PCI annually), with even fewer of these supporting round-the-clock availability.[29] Another study showed that despite a decreasing prevalence of myocardial infarction, PCI centers have increased at a rate 1.5x that of the population,[30] potentially exacerbating a situation of oversupply of PCI hospitals. The “volume-outcomes” relationship is well-documented across numerous conditions, including cardiac care, such that mortality rates can differ by 28% when comparing the highest-volume angioplasty hospitals with the lowest-volume angioplasty hospitals.[3,31]

Third, it is possible that regionalization has had an unintended consequence of creating a “one-way valve,” where any cardiac patient may be more likely re-directed to PCI hospitals, and large percentages of inappropriately diverted patients could overwhelm existing resources.[32] Similarly, bypassed hospitals that do not offer PCI experience may see fewer patients with myocardial infarction, which may decrease their experience and impede their ability to provide high-quality care. There could also be financial consequences of lower volumes of cardiac patients for these hospitals, with the downstream threat of overall decreased access to the healthcare system if these facilities become financially unsustainable. Finally, most studies are not sufficiently powered enough to detect a small change in an outcome such as longer-term mortality, which can be overwhelmed by noise from variation in other causes of death.

Given that regionalization is typically implemented in an effort to better treat the entire community, population-based studies are needed to assess the effects of regionalization on access, treatment, and outcomes for all patients with the target condition, not only those who actually receive certain treatments. The findings of this study raise questions regarding the larger context in which hospitals provide services such as PCI. While others have also modeled cost-effectiveness of regionalization strategies to include quality-adjusted life-years, and shown that emergency medical systems (EMS)-based strategies are less costly and more effective than any type of hospital expansion option,[26,33] economic incentives are such that PCI expansion may continue, despite decreasing prevalence of STEMI.[12] At best, this study shows that regionalization efforts may shift the timing of death from 7 days to only slightly later. Therefore, while regionalization has improved access, the effect on health outcomes seem to be limited.

A final important finding of this study lies in the fact that even though all counties were regionalized as of 2012, not all patients with STEMI were sent to PCI-capable hospitals (<90% even as of 2015). And while we found that regionalization networks were statistically associated with a greater likelihood of receiving PCI, the percentage of patients with STEMI receiving PCI was still well below 80% at the end of the study period. While certainly there are clinical contraindications for PCI, these findings may support other literature documenting a systematic duplication of PCI centers in communities that already have access, are wealthier, and have more private insurance, while significant gaps in access remain for other underserved communities.[4,34] Concannon et al has shown that in a short 5-year period, PCI-capable hospitals proliferated by 44%, but only improved population access to PCI by 1%.[35] These larger environmental factors may prove challenging in efforts to regionalize care in high-volume centers, with implications not only for the regionalization of cardiac care, but also other conditions, such as stroke and trauma,[36,37] where hospitals may experience differential financial effects from service-line specialization.

Limitations

This study has several limitations. First, we used administrative data using discharge diagnoses, and STEMI coding was changed in 2005, introducing a potential concern regarding consistent capture of STEMI admissions with ICD-9 coding. However, validity testing of these codes has been done in previous literature with other administrative data, with the finding that trends in STEMI over time have been consistent; Yeh et al., for example, found that STEMI coding from 1999-2008 has been fairly consistent and accurate over time when compared to detailed chart review of a Kaiser health system, even despite the change in ICD-9 coding in 2005.[12] We chose to be conservative and included only the post-revision time period from 2006-2012. Nevertheless, the positive predictive value found in other data sets using these ICD-9 codes could differ in our state administrative data. We did investigate the potential of using registries with more physician-based diagnoses, such as the ACC/AHA's ACTION Registry®-Get With The Guidelines™ (GWTG) and CathPCI Registry®. However, the former are unable to provide historical information due to merging of several modules after 2008, and most ACTION participants are STEMI receiving hospitals. The marked absence of STEMI referral hospitals renders it impossible to determine differences among communities, and the registry does not capture out-of-hospital mortality. The CathPCI Registry® captures only patients who received PCI, and therefore precludes evaluation of all patients with STEMI in an integrated STEMI system. Neither allows outcomes evaluation at the population level. In fact, the percentage of STEMI patients receiving PCI in our population-based study, which includes all hospitals, including the small, non-PCI capable hospitals, may be lower than the majority of published studies that rely on registry data to provide estimates of STEMI treatment for PCI patients because these registries include only hospitals who choose to participate in these cardiac quality improvement efforts. Because our data, however, do not include granular clinical data, such as number of minutes from first medical contact to intervention, we were unable to calculate improvements in such measurements.

Second, our study accounted for both inpatient patients and those who were only admitted through the emergency department, but did not account for a certain proportion of deaths that may occur in the field, during transport, or in the ED. However, given the difficulty of diagnosing cause of death and the relatively rare nature of this event, we do not expect this to significantly affect our results.

Third, it is possible we did not have enough post regionalization observations for mortality outcomes from all counties, especially those that regionalized after 2012, so that we did not detect a mortality effect. Fourth, even though our approach removes any time-invariant unobserved differences between the two groups, there may still be concerns that our results were driven by significant differences between regionalized and non-regionalized communities that could be accounted for in our study. To address the concern that there might be intrinsic time varying differences between regionalized and non-regionalized counties that cannot be removed via the difference-in-differences method, two additional analyses were implemented. First, Supplemental Figure I shows that mortality trends during the pre-regionalization period (2001-2005) were similar across counties that were early and late adopters of regionalization network, with parallel mortality trends between both types of counties in the pre-regionalization period. Second, we implemented a sensitivity analysis where we matched patients based on the pre-trend (i.e. slope) of the community's mortality trend during the pre-treatment period. This is essentially a propensity score matching based on pre-trend slope, excluding patients outside of the common support region. Supplemental Table IV shows similar results as our main table (with slightly larger magnitude).

CONCLUSIONS

Among patients with STEMI in California from 2006 to 2015, STEMI regionalization was associated with increased access to a PCI-capable hospital, greater use of PCI, and lower 7-day mortality, but no difference in longer-term mortality.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgments

FUNDING SOURCES

This work was supported by grants R01HL114822 and R01HL134182 (NHLBI) for Dr. Renee Y. Hsia and Dr. Yu-Chu Shen. The sponsors had no role in the design and conduct of the study; collection, analysis, and interpretation of data; preparation, writing, review, or approval of the manuscript; or in the decision to submit the manuscript for publication.

NON-STANDARD ABBREVIATIONS AND ACRONYMS

AHA	American Heart Association
ACC	American College of Cardiology
DTB	door-to-balloon
EMS	Emergency Medical Services
GWTG	Get With The Guidelines™
OSHPD	Office of Statewide Health Planning and Development
PCI	percutaneous coronary intervention
STEMI	ST-elevation myocardial infarction

REFERENCES

1. Antman EM, Anbe DT, Armstrong PW, Bates ER, Green LA, Hand M, Hochman JS, Krumholz HM, Kushner FG, Lamas GA, et al. ACC/AHA guidelines for the management of patients with ST-elevation myocardial infarction--executive summary. J Am Coll Cardiol. 2004;44:671–719. [PubMed: 15358045]
2. Keeley EC, Boura JA, Grines CL. Primary angioplasty versus intravenous thrombolytic therapy for acute myocardial infarction: a quantitative review of 23 randomised trials. Lancet. 2003;361:13–20. [PubMed: 12517460]
3. Thiemann DR, Coresh J, Oetgen WJ, Powe NR. The association between hospital volume and survival after acute myocardial infarction in elderly patients. N Engl J Med. 1999;340:1640–1648. [PubMed: 10341277]
4. Concannon TW, Nelson J, Kent DM, Griffith JL. Evidence of Systematic Duplication by New Percutaneous Coronary Intervention Programs. Circ Cardiovasc Qual Outcomes. 2013;6:400–408. [PubMed: 23838110]
5. Henry TD, Sharkey SW, Burke MN, Chavez IJ, Graham KJ, Henry CR, Lips DL, Madison JD, Menssen KM, Mooney MR, et al. A regional system to provide timely access to percutaneous coronary intervention for ST-elevation myocardial infarction. Circulation. 2007;116:721–728. [PubMed: 17673457]
6. AHA. Mission: Lifeline STEMI Systems Coverage.Published 2012. http://www.heart.org/HEARTORG/HealthcareResearch/MissionLifelineHomePage/Locate-Systems-of-Care_UCM_437492_Article.jsp. Accessed February 13, 2019.
7. Glickman SW, Greiner MA, Lin L, Curtis LH, Cairns CB, Granger CB, Peterson ED. Assessment of temporal trends in mortality with implementation of a statewide ST-segment elevation myocardial infarction (STEMI) regionalization program. Ann Emerg Med. 2012;59:243–252.e1. [PubMed: 21862177]
8. Jollis JG, Roettig ML, Aluko AO, Anstrom KJ, Applegate RJ, Babb JD, Berger PB, Bohle DJ, Fletcher SM, Garvey JL, et al. Implementation of a statewide system for coronary reperfusion for ST-segment elevation myocardial infarction. JAMA. 2007;298:2371–2380. [PubMed: 17982184]
9. Jollis JG, Al-Khalidi HR, Roettig ML, Berger PB, Corbett CC, Dauerman HL, Fordyce CB, Fox K, Garvey JL, Gregory T, et al. Regional Systems of Care Demonstration Project: American Heart Association Mission: Lifeline STEMI Systems Accelerator. Circulation. 2016;134:365–374. [PubMed: 27482000]

10. Rokos IC, Sporer K, Savino PB, Mercer MP, Shontz SS, Sabbagh S, Hsia RY. A Novel Survey Tool to Quantify the Degree and Duration of STEMI Regionalization Across California. Crit Pathw Cardiol. 2016;15:103–105. [PubMed: 27465005]
11. Hsia RY, Sabbagh S, Sarkar N, Sporer K, Rokos IC, Brown JF, Brindis RG, Guo J, Shen Y-C. Trends in Regionalization of Care for ST-Segment Elevation Myocardial Infarction. West J Emerg Med. 2017;18:1010–1017. [PubMed: 29085531]
12. Yeh RW, Sidney S, Chandra M, Sorel M, Selby JV, Go AS. Population trends in the incidence and outcomes of acute myocardial infarction. N Engl J Med. 2010;362:2155–2165. [PubMed: 20558366]
13. Shen YC, Hsia RY. Association Between Ambulance Diversion and Survival Among Patients With Acute Myocardial Infarction. JAMA. 2011;305:2440–2447. [PubMed: 21666277]
14. Epstein AJ, Polsky D, Yang F, Yang L, Groeneveld PW. Coronary revascularization trends in the United States, 2001-2008. JAMA. 2011;305:1769–1776. [PubMed: 21540420]
15. Agency for Healthcare Research and Quality. Clinical Classifications Software (CCS).Published 2015. https://www.hcup-us.ahrq.gov/toolssoftware/ccs/ccs.jsp. Accessed October 1, 2018.
16. Peterson ED, Wright SM, Daley J, Thibault GE. Racial variation in cardiac procedure use and survival following acute myocardial infarction in the Department of Veterans Affairs. JAMA. 1994;271:1175–1180. [PubMed: 8151875]
17. Shen YC, Hsia RY. Does decreased access to emergency departments affect patient outcomes? Analysis of acute myocardial infarction population 1996-2005. Health services research. 2012;47:188–210. [PubMed: 22091922]
18. Centers for Medicare and Medicaid Services. 30-day risk-standardized readmissions measures. In: Specifications Manual for National Hospital Inpatient Quality Measures. Version 4.0. ; 2012.
19. O'Gara Patrick T, Kushner Frederick G, Ascheim Deborah D, Casey Donald E, Chung Mina K, de Lemos James A, Ettinger Steven M, Fang James C, Fesmire Francis M, Franklin Barry A, et al. 2013 ACCF/AHA Guideline for the Management of ST-Elevation Myocardial Infarction. Circulation. 2013;127:529–555. [PubMed: 23247303]
20. Rubin DB, Schenker N. Multiple imputation in health-care databases: an overview and some applications. Stat Med. 1991;10:585–598. [PubMed: 2057657]
21. Benjamini YHY. Controlling the false discovery rate: a practical and powerful approach to multiple testing. JR Statist Soc B. 1995;57:289–300.
22. Wang TY, Nallamothu BK, Krumholz HM, Li S, Roe MT, Jollis JG, Jacobs AK, Holmes DR, Peterson ED, Ting HH. Association of door-in to door-out time with reperfusion delays and outcomes among patients transferred for primary percutaneous coronary intervention. JAMA. 2011;305:2540–2547. [PubMed: 21693742]
23. Menees DS, Peterson ED, Wang Y, Curtis JP, Messenger JC, Rumsfeld JS, Gurm HS. Door-to-balloon time and mortality among patients undergoing primary PCI. N Engl J Med. 2013;369:901–909. [PubMed: 24004117]
24. Jollis JG, Al-Khalidi HR, Roettig ML, Berger PB, Corbett CC, Doerfler SM, Fordyce CB, Henry TD, Hollowell L, Magdon-Ismail Z, et al. Impact of Regionalization of ST-Segment-Elevation Myocardial Infarction Care on Treatment Times and Outcomes for Emergency Medical Services-Transported Patients Presenting to Hospitals With Percutaneous Coronary Intervention. Circulation. 2018;137:376–387. [PubMed: 29138292]
25. Granger Christopher B, Bates Eric R, Jollis James G, Antman Elliott M, Nichol Graham, O'Connor Robert E., Gregory Tammy, Roettig Mayme L., Andrew Peng S., Ellrodt Gray, et al. Improving Care of STEMI in the United States 2008 to 2012. J Am Heart Assoc. 2019;8:e008096. [PubMed: 30596310]
26. Ting HH, Rihal CS, Gersh BJ, Haro LH, Bjerke CM, Lennon RJ, Lim C-C, Bresnahan JF, Jaffe AS, Holmes DR, et al. Regional systems of care to optimize timeliness of reperfusion therapy for ST-elevation myocardial infarction. Circulation. 2007;116:729–736. [PubMed: 17673456]
27. Cannon CP, Gibson CM, Lambrew CT, Shoultz DA, Levy D, French WJ, Gore JM, Weaver WD, Rogers WJ, Tiefenbrunn AJ. Relationship of symptom-onset-to-balloon time and door-to-balloon time with mortality in patients undergoing angioplasty for acute myocardial infarction. JAMA. 2000;283:2941–2947. [PubMed: 10865271]

28. Bradley SM, Carey EP, Michael Ho P. US growth in PCI care--less than ideal, but is the ideal less? J Am Heart Assoc. 2013;2:e000552. [PubMed: 24252846]
29. Wang HE, Yealy DM. Distribution of specialized care centers in the United States. Ann Emerg Med. 2012;60:632–637. [PubMed: 22633341]
30. Langabeer JR, Henry TD, Kereiakes DJ, Dellifraine J, Emert J, Wang Z, Stuart L, King R, Segrest W, Moyer P, et al. Growth in percutaneous coronary intervention capacity relative to population and disease prevalence. J Am Heart Assoc. 2013;2:e000370. [PubMed: 24166491]
31. Canto JG, Every NR, Magid DJ, Rogers WJ, Malmgren JA, Frederick PD, French WJ, Tiefenbrunn AJ, Misra VK, Kiefe CI, et al. The volume of primary angioplasty procedures and survival after acute myocardial infarction. National Registry of Myocardial Infarction 2 Investigators. N Engl J Med. 2000;342:1573–1580. [PubMed: 10824077]
32. Rathore SS, Epstein AJ, Nallamothu BK, Krumholz HM. Regionalization of ST-segment elevation acute coronary syndromes care. J Am Coll Cardiol. 2006;47:1346–1349. [PubMed: 16580519]
33. Concannon TW, Kent DM, Normand SL, Newhouse JP, Griffith JL, Cohen J, Beshansky JR, Wong JB, Aversano T, Selker HP. Comparative effectiveness of ST-segment-elevation myocardial infarction regionalization strategies. Circulation Cardiovascular quality and outcomes. 2010;3:506–513. [PubMed: 20664025]
34. Hsia RY, Shen YC. Percutaneous Coronary Intervention in the United States: Risk Factors for Untimely Access. Health Serv Res. 2016;51:592–609. [PubMed: 26174998]
35. Concannon TW, Nelson J, Goetz J, Griffith JL. A Percutaneous Coronary Intervention Lab in Every Hospital? Circ Cardiovas Qual Outcomes. 2012;5:14–20.
36. Shen YC, Hsia RY, Kuzma K. Understanding the risk factors of trauma center closures: do financial pressure and community characteristics matter? Med Care. 2009;47:968–978. [PubMed: 19704354]
37. Hsia RY, Shen YC. Rising closures of hospital trauma centers disproportionately burden vulnerable populations. Health Aff (Millwood). 2011;30:1912–1920. [PubMed: 21976335]

Clinical Perspective

What is Known

- Regionalization of ST-elevation myocardial infarction systems of care has been championed nationally over the past decade.
- Timely access to percutaneous coronary intervention has been shown to improve outcomes, but it is unknown if and how regionalization has affected the care and outcomes of patients.

What the Study Adds

- Among patients with STEMI in California from 2006 to 2015, STEMI regionalization was associated with increased access to a PCI-capable hospital, greater use of PCI, lower 7-day mortality, and 30-day readmissions.
- Benefits in longer-term mortality were not detected.

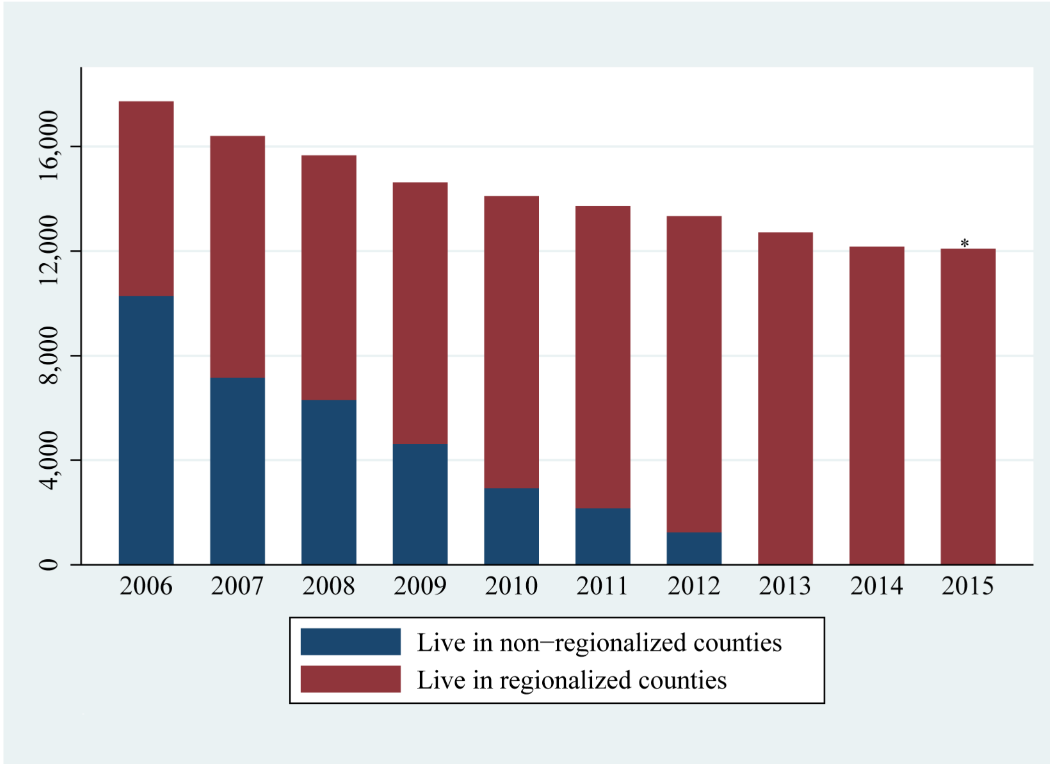

Figure 1. Patient distribution by regionalization status

*Number is extrapolated based on data that end in September 30, 2015

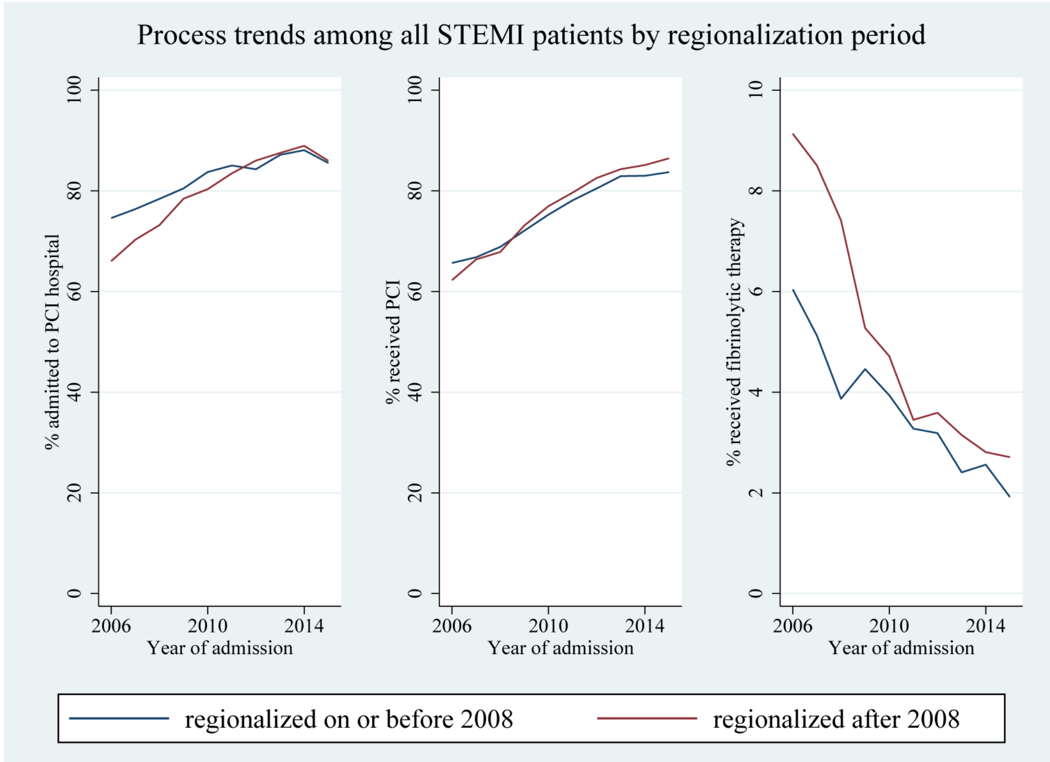

Figure 2. Process trends among all patients with STEMI by regionalization period

Abbreviations: PCI – percutaneous coronary intervention; STEMI – ST-elevation myocardial infarction

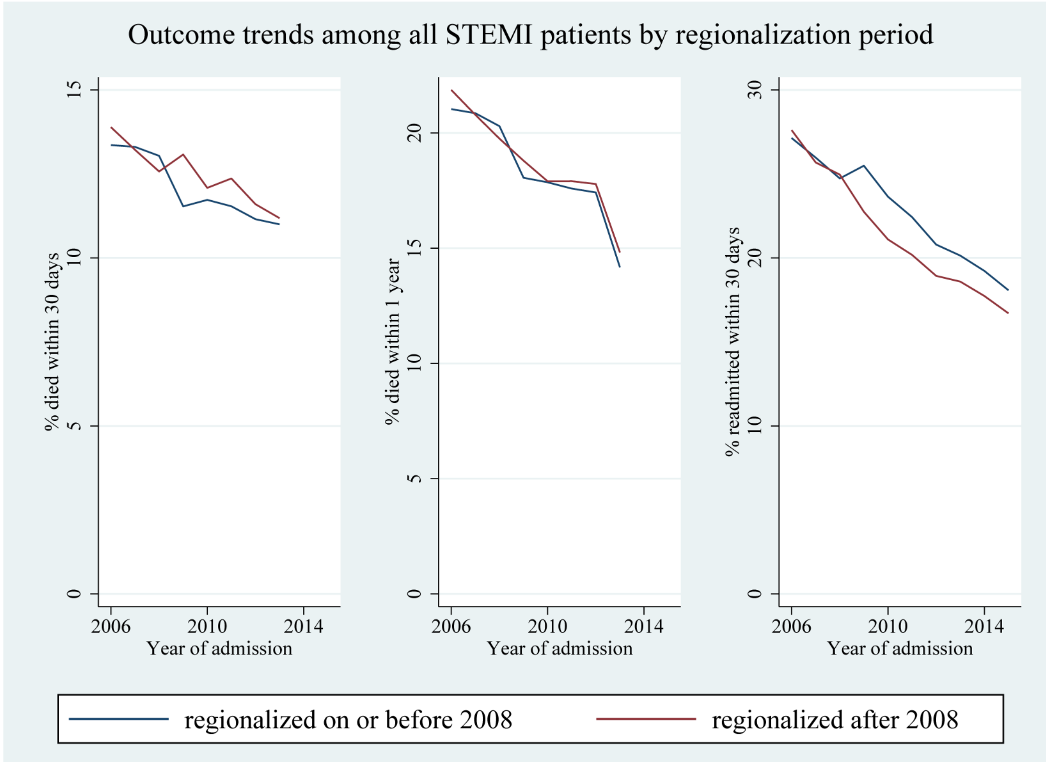

Figure 3. Outcome trends among all patients with STEMI by regionalization period

Abbreviations: PCI – percutaneous coronary intervention; STEMI – ST-elevation myocardial infarction

Table 1.

Patient, hospital, and community characteristics by STEMI regionalization status

	All patients between 2006 and 2015	Patients in counties that were regionalized on or before 2008	Patients in counties that were regionalized after 2008
Number of patients	139494 (100%)	77357 (100%)	62137 (100%)
Gender			
Male	93694 (67%)	52202 (67%)	41492 (67%)
Female	45800 (33%)	25155 (33%)	20645 (33%)
Race/Ethnicity			
White (non-Hispanic)	86392 (62%)	44276 (57%)	42116 (68%)
Hispanic	24778 (18%)	16143 (21%)	8635 (14%)
Asian	12620 (9%)	7423 (10%)	5197 (8%)
Other/mixed	7900 (6%)	4551 (6%)	3349 (5%)
African-American (non-Hispanic)	7804 (6%)	4964 (6%)	2840 (5%)
Age (in years)			
<40	3304 (2%)	1869 (2%)	1435 (2%)
40-54	28568 (21%)	15725 (20%)	12843 (21%)
55-64	35391 (25%)	19524 (25%)	15867 (26%)
65-69	16419 (12%)	9014 (12%)	7405 (12%)
70-74	13831 (10%)	7556 (10%)	6275 (10%)
75-79	12862 (9%)	7207 (9%)	5655 (9%)
80-84	12423 (9%)	6939 (9%)	5484 (9%)
85-99	16459 (12%)	9369 (12%)	7090 (11%)
Insurance (expected source of payment)			
Private	44058 (32%)	24547 (32%)	19511 (31%)
Medicare	67898 (49%)	37115 (48%)	30783 (50%)
Medicaid	13230 (9%)	7829 (10%)	5401 (9%)
Indigent (county or other)	3913 (3%)	2364 (3%)	1549 (2%)
Patient	7243 (5%)	3909 (5%)	3334 (5%)
Other	3152 (2%)	1593 (2%)	1559 (3%)
Transfer status			

	All patients between 2006 and 2015	Patients in counties that were regionalized on or before 2008	Patients in counties that were regionalized after 2008
Transferred to another hospital	23096 (17%)	10989 (14%)	12107 (19%)
Received PCI treatment after transfer	15968 (69%)	7366 (67%)	8602 (71%)
Admitting hospital characteristics			
Ownership			
For-profit	20787 (15%)	11375 (15%)	9412 (15%)
Government	17386 (14%)	11511 (17%)	5875 (11%)
Teaching hospital *	13941 (11%)	8035 (12%)	5906 (11%)
Hospital is part of a system	88624 (75%)	46854 (72%)	41770 (78%)
Median number of beds (IQR)	293 (163)	316 (174)	264 (161)
Mean occupancy rate (SD) †	0.66 (0.14)	0.67 (0.14)	0.66 (0.14)
Median HHI within 15 miles based on total discharge (IQR) ‡	0.14 (0.23)	0.08 (0.18)	0.19 (0.26)
CABG availability	103655 (76%)	59491 (78%)	44164 (74%)
PCI lab availability §	113810 (84%)	64039 (85%)	49771 (83%)
Community characteristics			
Median county population (IQR)	2017673 (2519404)	3169776 (8359181)	1019640 (1592743)
Median per capita income (IQR)	42265 (15326)	44474 (8533)	36243 (19785)
Live in low-income ZIP code communities (lowest quartile of family income distribution)	33102 (24%)	7590 (10%)	25512 (41%)
Live in counties with high share of Black population	42354 (30%)	22257 (29%)	20097 (32%)
Live in counties with high share of Hispanic population	39205 (28%)	27820 (36%)	11385 (18%)

Abbreviations: STEMI – ST- evaluated myocardial infarction; PCI – percutaneous coronary intervention; IQR- interquartile range; SD – standard deviation; CABG – coronary artery bypass grafting; HHI - Herfindalh-Hirschman Index

* If residents-to-bed ratio>0.25

† Total inpatient days/available beds

‡ HHI is a measure of hospital market's competitiveness and ranges from 0 (perfectly competitive) to 1 (monopoly).

§ PCI lab availability follows a volume-based definition of 50 or more PCI procedures in a given year.

Table 2.

Changes in process outcomes between counties that changed regionalization status and counties that did not during the same period

	Primary Outcomes (Process)			
	Admitted to PCI hospital	**Received PCI on the same day**	**Received PCI during the episode**	**Received fibrinolytic therapy**
Number of patients	135579	139257	139257	139257
Sample mean at baseline (%)	72.7%	49.7%	64.2%	7.4%
Unadjusted for site of care PCI capacity				
Percentage point change on and after county is regionalized	5.34	3.54	2.97	−1.84
95% CI	[1.58,9.10]	[0.61,6.48]	[0.10,5.85]	[−3.31,−0.37]
Unadjusted p-value	0.006	0.019	0.043	0.015
Adjusted p-value for multiple comparison	0.024	0.038	0.043	0.038
Adjusted for site of care PCI capacity				
Percentage point change on and after county is regionalized	NA	−0.35	0.56	−1.47
95% CI	NA	[−2.17,1.46]	[−1.40,2.53]	[−2.70,−0.23]
Unadjusted p-value	NA	0.699	0.568	0.021
Adjusted p-value for multiple comparison	NA	0.699	0.699	0.063

Abbreviations: PCI – percutaneous coronary intervention; CI – confidence interval; NA – not applicable

Full regression controls for patient demographics, insurance category, prior AMI admission, comorbid conditions, county fixed effects, and year dummies are presented in Supplemental Table I.

Table 3.

Changes in health outcomes between counties that changed regionalization status and counties that did not during the same period

	Secondary Outcomes (Health)				
	7-day mortality	**30-day mortality**	**90-day mortality**	**1-year mortality**	**30-day readmission**
Number of patients	117896	117896	117896	117896	139257
Sample mean at baseline (%)	9.1%	13.6%	16.6%	21.4%	27.4%
Unadjusted for site of care PCI capacity					
Percentage point change on and after county is regionalized	−0.53	−0.46	−0.38	−0.32	−1.75
95% CI	[−1.00,−0.06]	[−1.12,0.20]	[−1.05,0.28]	[−0.87,0.23]	[−3.39,−0.11]
Unadjusted p-value	0.027	0.170	0.250	0.250	0.037
Adjusted p-value for multiple comparison	0.045	0.212	0.250	0.250	0.053
Adjusted for site of care PCI capacity					
Percentage point change on and after county is regionalized	−0.37	−0.24	−0.15	−0.03	−0.70
95% CI	[−0.90,0.16]	[−0.98,0.49]	[−0.87,0.58]	[−0.58,0.51]	[−2.01,0.62]
Unadjusted p-value	0.167	0.508	0.684	0.908	0.292
Adjusted p-value for multiple comparison	0.835	0.908	0.908	0.908	0.908

Abbreviations: CI – confidence interval; PCI – percutaneous coronary intervention

Full regression controls for patient demographics, insurance category, comorbid conditions, county fixed effects, and year dummies are presented in Supplemental Table I.