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Greater Spatial Access to Care is Associated with Lower Mortality for Emergency General Surgery

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Abstract

Background: Emergency General Surgery (EGS) diseases are time-sensitive conditions that require urgent surgical evaluation, yet the effect of geographic access to care on outcomes remains unclear. We examined the association of spatial access with outcomes for common EGS conditions.

Methods: Retrospective analysis of twelve 2014 State Inpatient Databases, identifying adults admitted with eight EGS conditions. We assessed spatial access using the Spatial Access Ratio (SPAR) – an advanced spatial model that accounts for travel distance, hospital capacity and population demand, normalized against the national mean. Multivariable regression models adjusting for patient and hospital factors were used to evaluate the association between SPAR with a) in-hospital mortality and b) major morbidity.

Results: 877,928 admissions analyzed, of which 104,332 (2.4%) were in the lowest-access category (SPAR=0) and 578,947 (66%) were high-access (SPAR≥1). Low-access patients were more likely to be white, male and treated non-teaching hospitals. Low-access patients also had higher incidence of complex EGS disease (low-access 31% vs high-access 12%, p<0.001), and in-hospital mortality (4.4% vs 2.5%, p<0.05). Adjusting for confounding factors, including presence of advanced hospital resources, increasing spatial access was protective against in-hospital mortality (aOR 0.95, 95% CI 0.94 −0.97, p<0.001). Spatial access was not significantly associated with major morbidity.

Conclusions: This is the first study to demonstrate that geospatial access to surgical care is associated with incidence of complex EGS disease, and that increasing spatial access to care is independently associated with lower in-hospital mortality. These results support the consideration of spatial access in the development of regional health systems for EGS care.

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AUTHOR CONTRIBUTIONS
All authors contributed to study design, data interpretation and critical revisions of the manuscript. MLM conducted the literature review and manuscript writing. CMA, JY and NW performed data analysis with contribution by MLM.

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Level of Evidence: Epidemiological, Level III

Keywords

Emergency general surgery; spatial access; geospatial methods

BACKGROUND:

The state of emergency general surgery (EGS) care in the United States is increasingly regarded as a growing public health crisis; progressive increases in EGS hospital admissions, worsening workforce shortages and hospital closures have contributed to demand that is quickly outpacing system capacity and significantly affecting patient access to care.[1–4] While EGS diseases are a heterogeneous group of conditions with wide-ranging severity, they are by-definition time-sensitive, requiring urgent evaluation and often emergent operative intervention. Physical access to hospitals with EGS services is therefore critical to the diagnosis and treatment of these diseases. This concept – the ease with which residents of a certain area can reach needed health services and facilities – is referred to as "potential spatial access."

Spatial access to care encompasses both the accessibility of service providers (commonly measured by distance or time to nearest hospital) and availability, which describes the number of service providers and their capacity to meet nearby population demand (often reported as provider-to-population ratios).[5] Distance to the nearest hospital is a known barrier to spatial access for surgical care for many rural patients; however, inadequate hospital capacity to serve patients requiring surgical care is pervasive throughout both urban and rural areas.[6] The Acute Care Congress in their 2009 report on "The Future of Emergency Surgical Care in the United States" noted that emergency department overcrowding and staff shortages have led to unacceptably long waits for emergent surgery, specifically highlighting the importance of considering hospital capacity in assessments of spatial access.[2] More recently, advanced geospatial methods such as gravity models, have emerged as a combined metric for both accessibility and availability.[7] Regardless of method, considerable population-level spatial access disparities have been noted in the United States, with rural, minority and uninsured populations disproportionately affected.[8–12] Despite this growing body of evidence documenting disparities, it remains unclear how spatial access to emergency surgical care contributes to outcomes for patients with EGS disease.

To address this critical gap in our knowledge of the connection between spatial access and clinical outcomes, we analyzed 12 inpatient state databases and used advanced geospatial modeling to evaluate the association of spatial access to emergency surgical care with in-hospital mortality and major morbidity for eight common EGS conditions. Given the time-sensitive nature of these diseases, we hypothesized that greater spatial access to EGS care would be associated with improved clinical outcomes.

METHODS:

Data Sources and Patient Selection

We used the Agency for Healthcare Research and Quality (AHRQ) Healthcare Cost and Utilization Project (HCUP) 2014 State Inpatient Databases (SID) from eleven states (Arizona, Colorado, Florida, Iowa, Kentucky, New York, North Carolina, Oregon, Utah, Washington) and the 2014 California Inpatient Discharge Dataset from the California Office of Statewide Health Planning and Development to identify all adults (≥18 years) with an urgent or emergent admission for a primary diagnosis of one of eight common EGS conditions: appendicitis, cholecystitis, diverticulitis, abdominal wall or intra-abdominal hernia, intestinal obstruction, mesenteric ischemia, peptic ulcer disease or pancreatitis using the International Classification of Diseases 9th Edition (ICD-9) codes (eTable 1).[13,14] These diseases were chosen both for their overall frequency, as well as the presence of AAST severity scales for each; states were selected based on availability of necessary data elements in the State Inpatient Databases. We used the dichotomized schema described by *Scott et al* to define "complex" vs "uncomplicated" disease for each diagnosis, which were developed by mapping ICD-9 codes to AAST severity scales.[14] Patients were excluded if they were less than 18 years old at time of EGS admission, were transferred out to another acute care hospital, or were missing home ZIP code (total missing n=5,750, 0.49%). Patients who were admitted as an interfacility transfer were included in the analysis and analyzed at the terminal location of acute care admission.

Patient-level data was linked to the American Hospital Association (AHA) 2015 Annual Survey to obtain hospital-level data, including geographic location and clinical resources.[15] Spatial access was calculated as described below using our previously constructed Geographic Information Science (GIS) platform for EGS-capable hospitals in the United States, which uses data from the Census Topologically Integrated Geographic Encoding and Referencing file, and the StreetMap North America network data set from the Environmental Systems Research Institute.[10,16,17]

Patient and Hospital Characteristics

Patient characteristics examined included age, sex, race/ethnicity (Non-Hispanic White, Non-Hispanic Black, Hispanic, Asian or Pacific Islander, Native American or other race, rurality, rate of poverty in home census block group, primary payer (private, Medicaid, Medicare, self pay or other), and Charlson Comorbidity Index (CCI) derived from ICD-9 diagnosis codes. Hospital characteristics assessed included: teaching status, hospital bed size, and presence of advance clinical resources, which we have previously defined as number of ICU beds >25th percentile nationally, presence of CT and ultrasound imaging, advanced gastroenterology serviced (identified by Endoscopic Retrograde Cholangiopancreatography), or were in the top national quartile of inpatient operations (>2,753 procedures annually).[10]

Spatial Access

We used the Spatial Access Ratio (SPAR), an enhanced two-step floating catchment area (E2SFCA) model, to measure spatial access to EGS-capable hospitals.[10,18,16] E2SFCA models are a widely validated type of gravity model that incorporate both accessibility and availability of health services into a single measure of spatial access for a given population site.[6,7,19–21] In brief, this method uses provider-to-population ratios weighted by hospital capacity, potential patient volume and travel impedance (i.e. travel time). SPAR is presented as a ratio of the spatial access for the specific census block group (CBG) relative to the national mean. Greater values of SPAR denote better spatial access and SPAR values greater than one indicate better-than-national-average spatial access. We used an equal-interval scheme to stratify patients into four categories of access: very low (SPAR=0), low (0<SPAR<0.5), moderate (0.5≤SPAR≤1) and greater than average (SPAR>1).

To calculate SPAR we used measures of supply, demand and travel impedance. Supply, or hospital capacity, was measured using number of inpatient hospital beds. Demand was approximated by the population of each CBG and located at the population-weighted centroid. We set the catchment area to 60 minutes driving time, as this represents a common benchmark for access to surgical care.[8,22–25] Distance and travel time from population-weighted Zip Code Tabulation Area (ZCTA) centroid to hospital site was calculated using ArcMap software. Further details on calculation of E2SFCA models and SPAR can be found in Supplementary Methods (eMethods).

Primary and Secondary Outcomes

Our primary outcome was all-cause in-hospital mortality. Our secondary outcome was a composite measure of major morbidity comprised of respiratory failure, myocardial infarction, stroke/ cerebrovascular accident (CVA), venous thromboembolism (VTE) (deep vein thrombosis (DVT) or pulmonary embolism (PE)), acute renal failure, surgical site infections and urinary tract infection/cystitis identified using previously published ICD-9 codes (eTable 2).[26,27]

Statistical Analysis

We assessed differences in patient and hospital characteristics using chi-squared and Analysis of Variance tests for categorical and continuous variables as appropriate. Mixed effects univariable logistic regressions were used to calculate the unadjusted odds of mortality and morbidity (separately) for SPAR and all covariates of interest. All models included random effects for state and hospital, nested within state. A multivariable logistic regression model was then constructed using the SPAR of the patient's home geographic location (ZIP code) and the following base variables: age, sex, primary payer, CCI, hospital teaching status and presence of advanced hospital resources (Model 1). A second model (Model 2) was then constructed by adding the presence of complex disease to the variables in Model 1. While complex disease potentially falls on the causal pathway between spatial access to care and our mortality and major morbidity outcomes, it is also known to be strongly associated with the outcome. Variables that were highly related to the calculation of SPAR (e.g. rurality, distance to hospital), or advanced hospital resources (e.g. bed number) were not considered as separate covariates. Multicollinearity was assessed using variance inflation factors (VIF): all VIF values were less than 5, and thus no covariates were eliminated or combined due to multicollinearity. Model accuracy or the ability of our models to discriminate outcomes was measured using the area under the receiver operating characteristic curve with 95% confidence intervals (CIs). We analyzed all EGS conditions as a group, and then performed separate sub-analyses for each EGS condition for both mortality and major morbidity outcomes. Furthermore, as patients who require operative intervention, and those who undergo interhospital transfer might be particularly sensitive to the effects of spatial access to surgical care, we performed separate subgroup analyses for each of these two groups. Finally, we examined the differential effects of spatial access on populations known to be vulnerable to effects of decreased access to care through interactions between SPAR and each of race/ethnicity, insurance and poverty. Odds ratios (ORs) and adjusted odds ratios (aORs), 95% CIs and p-values were reported.

All statistical analyses were performed using R (Version 4.2.1), with statistical significance set at p<0.05.[28] The study followed the Strengthening of the Reporting of Observational Studies in Epidemiology (STROBE) guidelines and was classified as not human subjects research by policy of our Institutional Review Board as all data was deidentified. All research activities followed regulations within the HCUP and AHRQ data use agreements.

RESULTS:

Patient Cohort

Among 877,928 adult patients admitted with appendicitis (n=67,190; 6.8%), cholecystitis (n=44,251; 4.5%), diverticulitis (n=104,066; 11%), abdominal wall or intra-abdominal hernia (n=274,791; 28%), intestinal obstruction (n=141,182; 14%), mesenteric ischemia (n=38,710; 3.9%), peptic ulcer disease (n=139,706; 14%) or pancreatitis (n=176,275; 18%), nearly one-half were male (n= 409,519; 47%), majority were white (n=544,651; 62%), with private insurance (299,004; 26%) or Medicare (418,861; 48%), and a median SPAR of 1.6 [IQR 0.9, 2.4]. Compared to patients with spatial access at or above the national average (SPAR ≥ 1), very low access (SPAR=0) patients had a higher proportion of males (SPAR=0: 52% vs SPAR≥:1 47%), white race (66% vs 59%), and higher rates of Medicaid coverage (22% vs 20%). Median CCI was similar. Very low access patients were less likely to be admitted to teaching hospitals (SPAR=0: 13% vs SPAR≥:1 17%) and hospitals with advanced clinical resources (SPAR=0:59% vs SPAR≥1: 67%). (Table 1 for all.) Distribution of EGS conditions were roughly similar across all categories of SPAR, with slightly higher proportions of patients with cholecystitis (SPAR=0: 10% vs SPAR≥1: 5%) and diverticulitis (SPAR=0: 15% vs SPAR≥1: 12%) and lower proportion of intra-abdominal or abdominal wall hernia (SPAR=0: 26% vs SPAR≥1: 31%) in the very-low access group (Table 2). Patients from very low (SPAR=0) and low (SPAR 0–0.5) areas had a higher proportion of complex disease compared to patients with average or greater access (SPAR=0: 31%; SPAR 0–0.5; 15%; SPAR≥1: 12%), a pattern that was consistent for each individual EGS disease (Table 2).

Impact of Spatial Access on Mortality and Major Morbidity

For the study population, the overall incidence of in-hospital mortality was 2.49% and composite major morbidity was 27.1%. Mortality was greater in the very-low access group compared to the high-access group (SPAR=0: 4.4%; SPAR≥1: 2.5%). Major morbidity did not differ substantially across groups, however very-low access patients had a slight increase in incidence of pulmonary failure (SPAR=0: 7.5%; SPAR≥1: 5.6%) and acute renal failure (SPAR=0: 16%; SPAR≥1: 14%). (Table 3). In univariable analysis, increasing SPAR 1 point (eg. from 0 to the national average) was associated with 4% decrease in odds of mortality (OR 0.96, 95% CI 0.95–0.97, p<0.001) (eTable 3); it was not associated with composite major morbidity. After controlling for competing risk factors in multivariable analysis, the association of spatial access with reduced in-hospital mortality remained significant (Model 1: aOR 0.95, 95% CI 0.94–0.97, p<0.001). Addition of complex disease to the model attenuated this relationship slightly, but not entirely (Model 2: aOR 0.97, 95% CI 0.95–0.98, p<0.001) (Table 4). Within individual EGS conditions, SPAR was significantly associated with in-hospital mortality for those with cholecystitis (aOR 0.93, 95% CI 0.88–0.99, p=0.015), diverticulitis (aOR 0.93 95% CI: 0.88–0.99, p=0.02), abdominal wall or intra-abdominal hernia (aOR 0.96, 95% CI 0.93–0.98, p=0.001), and peptic ulcer disease (aOR 0.96, 95% CI 0.93–0.99, p=0.0018), but not appendicitis, intestinal obstruction, mesenteric ischemia or pancreatitis (Figure 1). There was no association of spatial access with major morbidity in univariable (eTable 4) or multivariable models (Table 5).

Subgroup Analysis

Separate analyses were conducted for a) patients who underwent operating room intervention and b) patients who underwent interhospital transfer from another acute care hospital (eTable 5). The operative cohort was comprised of 215,152 total admissions. Effect of SPAR was similar to that of the total cohort: in-hospital mortality aOR 0.96 (95% CI 0.94–0.99, p<0.01) and major morbidity aOR 0.98 (95% CI 0.97–0.99, p<0.01). The interhospital transfer cohort included 29,860 admissions. There was no significant effect of SPAR on either in-hospital mortality or major morbidity.

Interaction of Spatial Access with Patient and Disease Characteristics

We conducted additional analyses to evaluate possible interaction between spatial access and patient and disease characteristics hypothesized to be differentially affected by access to care, and did not observe any clear patterns of effect modification between SPAR and each of race/ethnicity, payor or complex disease.

DISCUSSION:

Disparities in spatial access to surgical services have been widely documented in the United States, yet the relationship between spatial access and clinical outcomes has not yet been characterized. In this study of 877,928 EGS patients in twelve states, we found that greater spatial access to hospitals with emergency surgical capability was associated with a small but significant reduction in mortality, even after adjusting for other relevant aspatial factors including insurance status and neighborhood poverty. Increasing spatial access from the lowest access category to that of the current national mean was associated with a 5% decrease in odds of mortality. The higher mortality in low-spatial access areas can be at least partially explained by the markedly increased proportion of complex EGS disease compared to areas with average or above spatial access.

To our knowledge, this is the first analysis of the relationship between spatial access and outcomes for EGS conditions using a comprehensive metric that captures both accessibility and availability of surgical care. Prior studies of spatial access to surgical care have largely focused on traumatic injury and evaluated only the accessibility component through use of time or distance to hospital.[29–32] For trauma, this may be appropriate, both because the development of regional trauma systems have included triage algorithms that direct patients to hospitals with appropriate resources and capacity for their level of injury, and because time to intervention for hemorrhagic shock plays an outsized role in averting early mortality in trauma. However, for other emergent disease states like EGS, for which no organized regional systems exist, the influence of hospital capacity relative to population demand becomes more important, supporting the use of comprehensive spatial metrics that take into account both distance to care and hospital capacity. While data on the effect of spatial access on EGS outcomes is sparse, a single-center analysis of EGS patients in Maryland by Diaz *et al.* found distance to their tertiary center to be associated with in-hospital mortality.[33] Our analysis extends these findings using a comprehensive metric of spatial access and a large, multi-state patient population; the results suggest that the effect of low-spatial access on mortality is not limited to trauma, and spatial access is relevant to the design of optimal health systems of non-trauma emergency surgical systems as well.

We were surprised by the markedly increased rate of complex EGS disease in patients with low spatial access to surgical care, with a nearly 2.5-fold greater incidence in the very-low access group compared to those with average or greater access. Complex disease on presentation generally represents greater disease progression and may be an indicator of delays in arriving at appropriate care. Studies of oncologic disease using gravity models of spatial access have shown a similar pattern, with poor access associated with increased rates of late-stage breast and colorectal cancer diagnosis in the United States.[34–36] In these cases, poor spatial access to primary care physicians, as well as aspatial components such as socioeconomic status and minority race/ethnicity were identified as factors underlying this relationship. Given the EGS conditions in our analysis that were most sensitive to the effect of spatial access on outcomes (ie. cholecystitis, diverticulitis, hernias and peptic ulcer disease), it is possible that similar forces are at play, with poor spatial access to healthcare in general contributing to delayed diagnoses and more severe disease at time of presentation to surgical care.

Access to care is a complex topic, which includes not just spatial access, but also aspatial components including acceptability (eg cultural appropriateness), affordability (eg. insurance coverage), and accommodation (eg service organization, hours of operation etc). Interactions between spatial and aspatial components of access must also be considered in the development and treatment of EGS conditions, with the individual effects difficult to separate. Minoritized communities, those with high rates of uninsured residents, and neighborhoods with high social vulnerability have been shown to have poor spatial access to both primary care and specialized hospital services including surgical and intensive care.[8,12,37] High neighborhood social vulnerability has also been linked to both low primary care utilization and increased risk of presentation with emergent versus elective general surgery disease, greater severity of emergency surgical disease at time of presentation and worse perioperative outcomes.[37–42] Both lack of primary care availability (spatial) as well as affordability or language or cultural barriers (aspatial) might lead to delays in seeking care for a condition that could initially be treated electively or early in their course, but instead progress to more severe or complex emergent surgical conditions. Further research investigating mechanisms underlying delays in diagnosis, development of complex EGS disease, and barriers to realizing care will be critical to reducing burden of mortality and morbidity associated with EGS disease. Together, research suggests social and structural elements are both likely at play across the spectrum of primary care to emergency surgical care.

Regionalization of care through the development of organized and coordinated systems has been adopted as a solution for other time-sensitive conditions with large disparities in spatial access to care, such as trauma, stroke and acute myocardial infarctions.[43] While our analysis showed that better spatial access to surgical care was associated with decreased mortality for common EGS conditions, the effect size was fairly small, which brings to question whether regionalized systems should be considered for EGS as well. The purpose of regionalization is to match patients with the appropriate clinical resources through policy that directs a) the distribution of physicians, b) the distribution of equipment and facilities and c) the control of patient movement within the system.[44,45] While our data suggest that improving spatial access to surgical facilities and resources alone might result in a small improvement patient outcomes, it is possible that developing systems to improve the movement of patients through the healthcare system is a more important lever. This extends from primary care, through arrival at urgent or emergent care, potential interhospital transfer and finally through definitive hospital care. The overall absence of organized regional systems for EGS care may be one reason why mortality for patients with complex EGS disease in our analysis was similar regardless of potential spatial access to care. Once patients present with complex disease, effective systems are needed to consistently and rapidly direct them to high quality hospitals with appropriate resources in a timely manner, and these mechanisms are currently lacking across much of the United States. Regionalization offers the potential of addressing disparities in spatial access for many populations (eg. minoritized or uninsured communities) through identifying locations for additional care, and it would additionally offer the benefits of triage and transfer protocols, benchmarked data registries, and quality improvement programs.[43] Further work on the potential benefits of regionalization for EGS should consider the influence of these components on clinical outcomes.

Several limitations should be considered when interpreting the results of this study. As with all studies using administrative data, the results are subject to residual confounding due to unmeasured factors such as unmeasured comorbidities, sociodemographic factors, and severity of disease. We did attempt to control for severe disease by including the presence of "complex disease" in our model, however this remains a proxy measure and does not fully account for the broad range of physiologic derangement seen in even complex EGS patients. Second, patient severity of disease is further subject to misclassification, as our identification of complex disease was based on ICD-9 codes. Third, SPAR is a measure of potential spatial access and does not account for the myriad of real-world impendences that may occur in realizing access to care, including interrupted or lack of transportation and patient choice of hospital. The construction of the SPAR metric, weighting supply-demand ratios by impedance measures further makes it difficult to separate the effect of distance to care from hospital capacity from any specific region. Fourth, we could not assess spatial access to other forms of healthcare, including primary care availability, which may influence time to diagnosis and arrival at surgical care. Finally, our patient cohort was derived from twelve inpatient state database, will not capture patients who are discharged directly home from the post-operative recovery room or who have short duration stays coded as "observation" status, and may not be generalizable to the entire United States given differences in policy and geographic differences in other contexts.

CONCLUSIONS:

In a large cohort of adult patients admitted for one of eight common EGS conditions, greater spatial access to care was associated with a small, but significant decrease in in-hospital mortality, even after accounting for other forces influencing access to care including insurance status and neighborhood poverty. Low spatial access was associated with markedly increased proportion of complex EGS disease compared to patients with spatial access at or above the national mean. These data emphasize the importance of health system design, including geographic placement and relationship of hospital capacity to population need, to EGS outcomes. Further research should seek to investigate how spatial and aspatial factors influence severity of EGS disease at diagnosis, delays in reaching surgical care, and implications for development of effective and equitable systems for emergency surgical care.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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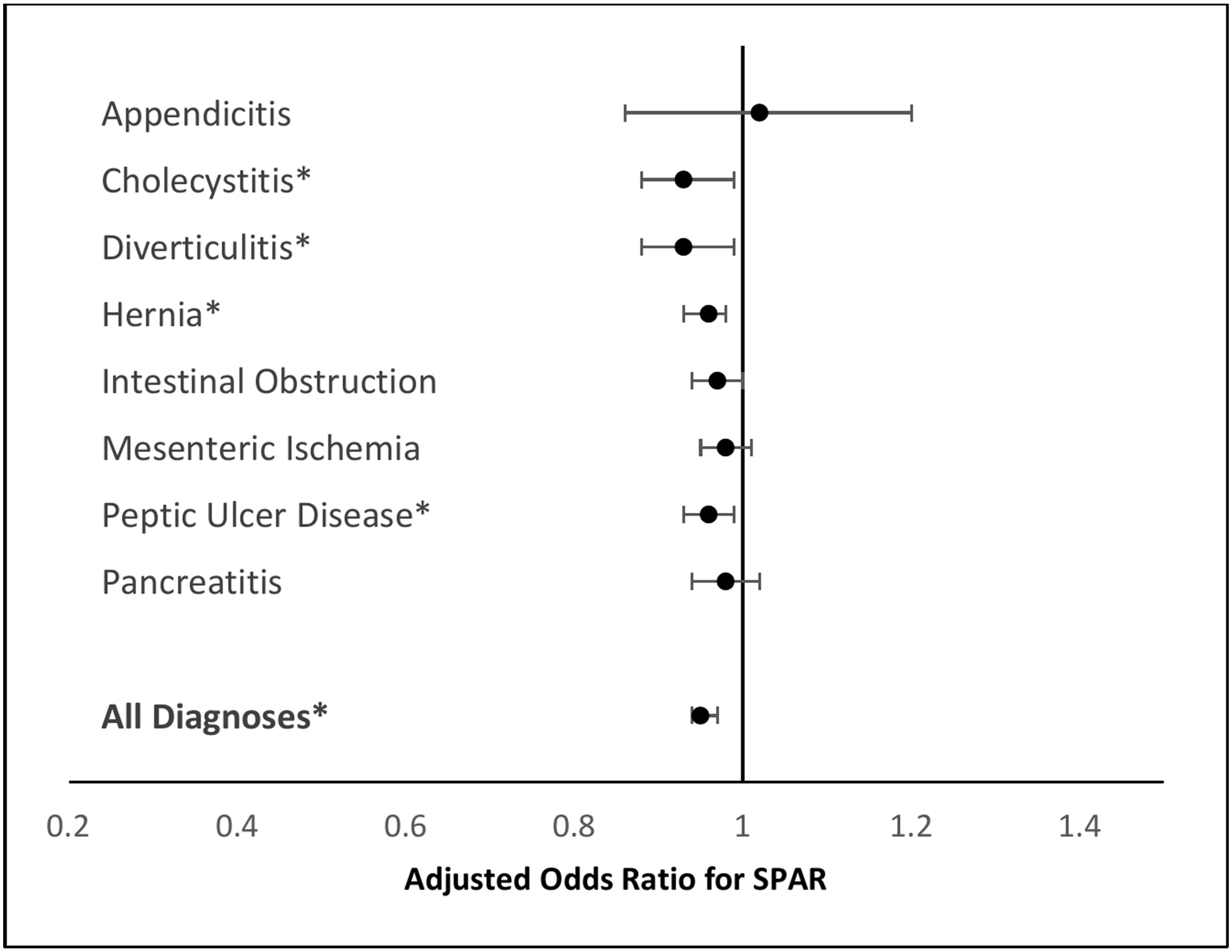

Figure 1.

Association of Spatial Access with In-Hospital Mortality by EGS Condition

*Denotes significance with p<0.05

Table 1.

Patient Demographics

	SPAR = 0 N=21,358	0 < SPAR < 0.5 N=82,974	0.5 ≤ SPAR < 1.0 N=194,649	1.0 ≤ SPAR N=578,947
Age				
[median (IQR)]	63 (49, 74)	62 (49, 75)	62 (48, 76)	62 (48, 76)
Sex				
Male	11,007 (52%)	39,218 (47%)	89,883 (46%)	269,411 (47%)
Race/Ethnicity				
White	14,067 (66%)	60,899 (73%)	130,400 (67%)	339,285 (59%)
Asian or Pacific Islander	469 (2%)	1,117 (1%)	8,449 (4%)	28,281 (5%)
Black	2,066 (10%)	3,959 (5%)	12,796 (7%)	68,002 (12%)
Hispanic	2,662 (12%)	13,250 (16%)	33,100 (17%)	115,268 (20%)
Native American	534 (3%)	1,114 (1%)	1,046 (1%)	23,89 (0%)
Not Reported	533 (2%)	1,268 (2%)	3,507 (2%)	6,149 (1%)
Other	1,027 (5%)	1,367 (2%)	5,351 (3%)	19,573 (3%)
Expected Primary Payor				
Private	4,852 (23%)	22,098 (27%)	55,474 (29%)	146,580 (25%)
Medicaid	4,787 (22%)	14,388 (17%)	35,737 (18%)	113,341 (20%)
Medicare	9,814 (46%)	40,825 (49%)	91,866 (47%)	276,356 (48%)
No Charge	160 (1%)	283 (0%)	428 (0%)	3,520 (1%)
Other	548 (3%)	1863 (2%)	4,142 (2%)	12,003 (2%)
Self pay	1,191 (6%)	3,483 (4%)	6,966 (4%)	26,978 (5%)
Charlson Comorbidity Index				
[median (IQR)]	1 (0, 2)	1 (0, 3)	1 (0, 3)	1 (0, 3)
Transfer In from Acute Care Hospital	1,842 (9%)	5,772 (7%)	7,389 (4%)	14,857 (3%)
Major Operative Intervention	6,454 (30%)	21,433 (26%)	46,405 (24%)	140,860 (24%)
Poverty of Census Block Group				
[median (IQR)]	0.2 (0.1, 0.3)	0.1 (0.1, 0.2)	0.1 (0.1, 0.2)	0.1 (0.1, 0.2)

	SPAR = 0 N=21,358	0 < SPAR < 0.5 N=82,974	0.5 ≤ SPAR < 1.0 N=194,649	1.0 ≤ SPAR N=578,947
Rurality				
Urban	7,732 (36%)	47,719 (58%)	165,156 (85%)	530,352 (92%)
Rural	13,626 (64%)	35,255 (42%)	29,489 (15%)	48,531 (8%)
Teaching Hospital	2,826 (13%)	6,464 (8%)	13,299 (7%)	99,694 (17%)
Hospital Bed size				
Small	2,389 (11%)	14,384 (17%)	19,801 (10%)	27,344 (5%)
Medium	10,830 (51%)	49,224 (59%)	126,017 (65%)	315,196 (54%)
Large	7,505 (35%)	15,330 (18%)	38,654 (20%)	215,623 (37%)
Advanced Resources	12,683 (59%)	38,842 (47%)	105,584 (54%)	388,966 (67%)

* Missing values: Sex:277; Expected Primary Payer = 314; Hospital bed size unknown: 46838

Table 2.

Emergency General Surgery Diagnosis of Study Cohort

	SPAR = 0 N=21,358	0 < SPAR < 0.5 N=82,974	0.5 ≤ SPAR < 1.0 N=194,649	1.0 ≤ SPAR N=578,947
Appendicitis				
All	2128 (10%)	5948 (7%)	14182 (7%)	44932 (8%)
Uncomplicated	1305 (6%)	4375 (5%)	12965 (7%)	36597 (6%)
Complex	823 (4%)	1573 (2%)	1217 (1%)	8335 (1%)
Cholecystitis				
All	2106 (10%)	4893 (6%)	7374 (4%)	29878 (5%)
Uncomplicated	310 (1%)	1555 (2%)	4235 (2%)	10630 (2%)
Complex	1796 (8%)	3338 (4%)	3139 (2%)	19248 (3%)
Diverticulitis				
All	3152 (15%)	10587 (13%)	21506 (11%)	68821 (12%)
Uncomplicated	1658 (8%)	7734 (9%)	19187 (10%)	54189 (9%)
Complex	1494 (7%)	2853 (3%)	2319 (1%)	14632 (3%)
Abdominal Wall or Intra-Abdominal Hernia				
All	5475 (26%)	25477 (31%)	62450 (32%)	181389 (31%)
Uncomplicated	4556 (21%)	23577 (28%)	60759 (31%)	171357 (30%)
Complex	919 (4%)	1900 (2%)	1691 (1%)	10032 (2%)
Intestinal Obstruction without Hernia				
All	3390 (16%)	13894 (17%)	32807 (17%)	91091 (16%)
Uncomplicated	2512 (12%)	12283 (15%)	31437 (16%)	82707 (14%)
Complex	878 (4%)	1611 (2%)	1370 (1%)	8384 (1%)
Mesenteric Ischemia				
All	1300 (6%)	4147 (5%)	8151 (4%)	25112 (4%)
Uncomplicated	595 (3%)	2856 (3%)	7102 (4%)	18697 (3%)
Complex	705 (3%)	1291 (2%)	1049 (1%)	6415 (1%)
Peptic Ulcer Disease				

	SPAR = 0 N=21,358	0 < SPAR < 0.5 N=82,974	0.5 ≤ SPAR < 1.0 N=194,649	1.0 ≤ SPAR N=578,947
All	2890 (14%)	12022 (14%)	30923 (16%)	93871 (16%)
Uncomplicated	2394 (11%)	11126 (13%)	29984 (15%)	88280 (15%)
Complex	496 (2%)	896 (1%)	939 (0%)	5591 (1%)
Pancreatitis				
All	4106 (19%)	16971 (20%)	40428 (21%)	114770 (20%)
Uncomplicated	3107 (15%)	14943 (18%)	38674 (20%)	104118 (18%)
Complex	999 (5%)	2028 (2%)	1754 (1%)	10652 (2%)
Total				
Uncomplicated	14814 (69%)	70374 (85%)	183682 (94%)	510703 (88%)
Complex	6544 (31%)	12600 (15%)	10967 (6%)	68244 (12%)

Table 3.

Primary and Secondary Outcomes

	SPAR = 0 N=21,358	0 < SPAR < 0.5 N=82,974	0.5 ≤ SPAR < 1.0 N=194,649	1.0 ≤ SPAR N=578,947
In-Hospital Mortality	940 (4%)	2,510 (3%)	3,693 (2%)	14,542 (3%)
Composite Major Morbidity	5,667 (27%)	22,864 (28%)	50722 (26%)	156,052 (27%)
Pulmonary Failure	1,592 (7%)	5,275 (6%)	9648 (5%)	32,276 (6%)
Pneumonia	673 (3%)	2,420 (3%)	5085 (3%)	16,197 (3%)
Myocardial Infarction	422 (2%)	1,649 (2%)	3205 (2%)	10,115 (2%)
Cerebrovascular Accident	137 (1%)	660 (1%)	1492 (1%)	4,635 (1%)
Venothromboembolic Disease (DVT/PE)	256 (1%)	1,182 (1%)	2419 (1%)	7,163 (1%)
Acute Renal Failure	3,412 (16%)	12,076 (15%)	25888 (13%)	83,306 (14%)
Surgical Site Infection	109 (1%)	475 (1%)	823 (0%)	2,533 (0%)
Urinary Tract Infection/Cystitis	1,737 (8%)	7,887 (10%)	18317 (9%)	57,276 (10%)

Table 4.

Multivariable Model for In-Hospital Mortality

	Model 1 aOR (95% CI)	p-value	Model 2 aOR (95% CI)	p-value
SPAR	0.95 (0.94, 0.97)	<0.001	0.97 (0.95, 0.98)	<0.001
Age	1.04 (1.04, 1.04)	<0.001	1.04 (1.04, 1.04)	<0.001
Sex				
Female	- Reference -		- Reference -	
Male	1.10 (1.07, 1.13)	<0.001	1.05 (1.02, 1.09)	<0.001
Race/Ethnicity				
White	- Reference -		- Reference -	
Asian or Pacific Islander	0.93 (0.87, 1.00)	0.037	0.81 (0.76, 0.87)	<0.001
Black	0.92 (0.87, 0.97)	0.001	0.98 (0.92, 1.03)	0.41
Hispanic	0.85 (0.81, 0.89)	<0.001	0.83 (0.79, 0.88)	<0.001
Native American	1.02 (0.83, 1.26)	0.84	0.99 (0.80, 1.24)	0.95
Not Reported	1.81 (1.60, 2.05)	<0.001	1.72 (1.51, 1.96)	<0.001
Other	0.95 (0.87, 1.04)	0.31	0.91 (0.83, 0.99)	0.039
Expected Primary Payor				
Private	- Reference -		- Reference -	
Medicaid	1.28 (1.21, 1.36)	<0.001	1.41 (1.33, 1.50)	<0.001
Medicare	1.04 (1.00, 1.09)	0.073	1.10 (1.05, 1.15)	<0.001
No Charge	0.76 (0.50, 1.15)	0.19	0.85 (0.56, 1.29)	0.44
Other	1.32 (1.18, 1.48)	<0.001	1.42 (1.26, 1.60)	<0.001
Self pay	1.19 (1.06, 1.33)	0.002	1.33 (1.19, 1.49)	<0.001
Charlson Comorbidity Index	1.28 (1.27, 1.28)	<0.001	1.28 (1.28, 1.29)	<0.001
Census Block Group Poverty	1.41 (1.16, 1.71)	<0.001	1.53 (1.28, 1.82)	<0.001
Teaching Hospital				
No	- Reference -		- Reference -	
Yes	1.28 (1.18, 1.40)	<0.001	1.09 (1.00, 1.19)	0.056
Advanced Resource Hospital				
No	- Reference -		- Reference -	
Yes	1.16 (1.09, 1.22)	<0.001	1.07 (1.01, 1.13)	0.028
Diagnosis Category				
Uncomplicated			- Reference -	
Complex			9.41 (9.13, 9.69)	<0.001

SPAR: Spatial Access Ratio

Table 5.

Multivariable models for major morbidity

	Model 1 OR (95% CI)	p-value	Model 2 OR (95% CI)	p-value
SPAR	0.99 (0.99, 1.00)	<0.001	1.00 (0.99, 1.00)	0.14
Age	1.03 (1.03, 1.03)	<0.001	1.03 (1.03, 1.03)	<0.001
Sex				
Female	- Reference -		- Reference -	
Male	0.92 (0.91, 0.93)	<0.001	0.90 (0.89, 0.91)	<0.001
Race/Ethnicity				
White	- Reference -		- Reference -	
Asian or Pacific Islander	0.83 (0.81, 0.86)	<0.001	0.80 (0.78, 0.82)	<0.001
Black	1.09 (1.07, 1.11)	<0.001	1.11 (1.09, 1.13)	<0.001
Hispanic	0.86 (0.84, 0.87)	<0.001	0.85 (0.84, 0.87)	<0.001
Native American	0.94 (0.87, 1.01)	0.091	0.94 (0.87, 1.01)	0.11
Not Reported	1.05 (0.99, 1.12)	0.092	1.03 (0.97, 1.09)	0.34
Other	0.95 (0.92, 0.98)	0.002	0.94 (0.91, 0.97)	<0.001
Expected Primary Payer				
Private	- Reference -		- Reference -	
Medicaid	1.35 (1.33, 1.38)	<0.001	1.39 (1.36, 1.42)	<0.001
Medicare	1.31 (1.29, 1.33)	<0.001	1.34 (1.32, 1.36)	<0.001
No Charge	1.14 (1.04, 1.25)	0.004	1.16 (1.06, 1.27)	0.001
Other	1.20 (1.16, 1.25)	<0.001	1.23 (1.18, 1.28)	<0.001
Self pay	1.11 (1.07, 1.15)	<0.001	1.14 (1.10, 1.17)	<0.001
Charlson Comorbidity Index	1.23 (1.22, 1.23)	<0.001	1.23 (1.22, 1.23)	<0.001
Census Block Group Poverty	1.44 (1.34, 1.56)	<0.001	1.47 (1.37, 1.59)	<0.001
Teaching Hospital				
No	- Reference -		- Reference -	
Yes	1.05 (0.98, 1.12)	0.17	0.99 (0.93, 1.06)	0.77
Advanced Resource Hospital				
No	- Reference -		- Reference -	
Yes	1.19 (1.15, 1.24)	<0.001	1.17 (1.12, 1.21)	<0.001
Diagnosis Category				
Uncomplicated			- Reference -	
Complex			2.60 (2.56, 2.64))	<0.001

SPAR: Spatial Access Ratio