Geographic distribution of trauma centers and injury-related mortality in the United States

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BACKGROUND: Regionalized trauma care improves outcomes; however, access to care is not uniform across the United States. The objective was to evaluate whether geographic distribution of trauma centers correlates with injury mortality across state trauma systems.

METHODS: Level I or II trauma centers in the contiguous United States were mapped. State-level age-adjusted injury fatality rates per 100,000 people were obtained and evaluated for spatial autocorrelation. Nearest neighbor ratios (NNRs) were generated for each state. A NNR less than 1 indicates clustering, while a NNR greater than 1 indicates dispersion. NNRs were tested for difference from random geographic distribution. Fatality rates and NNRs were examined for correlation. Fatality rates were compared between states with trauma center clustering versus dispersion. Trauma center distribution and population density were evaluated. Spatial-lag regression determined the association between fatality rate and NNR, controlling for state-level demographics, population density, injury severity, trauma system resources, and socioeconomic factors.

RESULTS: Fatality rates were spatially autocorrelated (Moran's $I = 0.35$, $p < 0.01$). Nine states had a clustered pattern (median NNR, 0.55; interquartile range [IQR], 0.48–0.60), 22 had a dispersed pattern (median NNR, 2.00; IQR, 1.68–3.99), and 10 had a random pattern (median NNR, 0.90; IQR, 0.85–1.00) of trauma center distribution. Fatality rate and NNR were correlated ($\rho = 0.34$, $p = 0.03$). Clustered states had a lower median injury fatality rate compared with dispersed states (56.9 [IQR, 46.5–58.9] vs. 64.9 [IQR, 52.5–77.1]; $p = 0.04$). Dispersed compared with clustered states had more counties without a trauma center that had higher population density than counties with a trauma center (5.7% vs. 1.2%, $p < 0.01$). Spatial-lag regression demonstrated that fatality rates increased by 0.02 per 100,000 persons for each unit increase in NNR ($p < 0.01$).

CONCLUSION: Geographic distribution of trauma centers correlates with injury mortality, with more clustered state trauma centers associated with lower fatality rates. This may be a result of access relative to population density. These results may have implications for trauma system planning and require further study to investigate underlying mechanisms. (*J Trauma Acute Care Surg.* 2016;80: 42–50. Copyright © 2016 Wolters Kluwer Health, Inc. All rights reserved.)

LEVEL OF EVIDENCE: Therapeutic/care management study, level IV.

KEY WORDS: Geospatial; spatial; trauma systems; fatality rate; nearest neighbor.

Injury is the leading cause of death for those age 46 years and younger in the United States, making trauma a leading public health problem.[1] Regionalization of trauma systems has led to improvements in trauma care and outcomes.[2–4] Despite this, access to trauma care is not uniform across the United States, and there is geographic variation in outcomes among trauma systems.[5–10] Oversight and organization of trauma systems have fallen to individual states, further contributing to variation in structure and access to the trauma system.[11]

Several authors have shown that geographic factors impact outcomes following injury. Our group demonstrated significant variation in outcome after helicopter transport based on US census region, while others reported that mortality from motor vehicle collisions (MVCs) is influenced by geographic region, population density, and vehicle miles traveled.[9,12–15] Some have also demonstrated that geospatial analysis can aid trauma system design and enhance resource allocation.[16,17] Jansen et al. have used sophisticated geospatial evaluation to help plan optimal trauma system resource placement in Scotland and provide detailed injury surveillance.[18,19]

Although data have shown that geographic factors can influence patient-level outcomes after trauma, it remains unclear what influence geospatial factors may have on outcome from a system perspective of existing resources. Thus, it was our objective to evaluate whether the geographic distribution of trauma centers correlates with injury mortality across state trauma systems in the United States. We hypothesized that a more evenly dispersed pattern of trauma centers would be associated with lower mortality.

PATIENTS AND METHODS

Data Sources

State characteristics including population density, land area classified as an urban, educational attainment, unemployment rate, poverty rate, and median income in 2010 were obtained from the US census bureau. In addition, county-level population density was obtained to evaluate population density within states. Age-adjusted injury fatality rates from 2008 to 2010, expressed as the number of injury fatalities per 100,000 persons, were obtained from the Centers for Disease Control Web-based Injury Statistics Query and Reporting System for each state.[20] The location of trauma centers was obtained from the University of Pennsylvania Cartographic Modeling Laboratory 2010 trauma center maps and the American Trauma Society Trauma Information Exchange Program.[17] The 2010 Atlas and Database of Air Medical Services was used to determine the number of medical helicopter bases within each state.[21]

The 2010 National Inpatient Sample was used to generate state-level mean Injury Severity Scores (ISSs). All patients with an external cause of injury code were included. DRG International Classification of Diseases—9th Rev. (ICD-9) diagnosis codes were translated into ISS using ICDPIC software.[22] The ISS for each patient was averaged at the state level by hospital location, generating a mean ISS for 44 states.

Geospatial Analysis

The location of Level I and II trauma centers were mapped within the contiguous 48 states. Injury fatality rates were tested for spatial autocorrelation using Moran's *I*. Spatial autocorrelation is the degree to which similar data values are grouped together geographically. Moran's *I* is a measure of spatial autocorrelation, ranging from −1 (completely dispersed in space) to +1 (perfectly correlated in space), and can be interpreted similarly to a correlation coefficient. This represents a measure of how dissimilar or similar a state's injury fatality rate is when compared with neighboring states. It evaluates whether states with similar injury fatality rates are grouped closer together or spread farther apart from each other.

A nearest neighbor analysis evaluated the geographic distribution of trauma centers within each state. This produced a nearest neighbor ratio (NNR) for each state, which is a measure of how clustered or dispersed trauma centers are within the state. The NNR is calculated as the observed mean distance between each trauma center and its nearest neighboring center divided by the expected mean distance between each center and its nearest neighbor assuming the centers are distributed in a random geographic pattern. The expected mean distance takes into account the total number of centers and the land area containing all centers in the state. A NNR less than 1 indicates trauma center clustering within the state because the actual distance between centers is less than what would be expected if distributed randomly, and therefore, centers are closer together. A NNR greater than 1 indicates trauma center dispersion within the state because the actual distance between centers is greater than what would be expected if distributed randomly, and therefore, centers are farther apart. Each state NNR was tested for significant difference from a random geographic pattern of trauma center distribution. A $p < 0.05$ for the NNR indicated that a state was significantly clustered if the NNR was less than 1 or significantly dispersed if the NNR was greater than 1. A nonsignificant $p > 0.05$ indicated that a state had a random geographic pattern of trauma center distribution.

County-level population density data were used to create a continuous surface of population density throughout the United States. Trauma centers were mapped to the continuous population density map to examine the location of trauma centers relative to within-state population density.

Statistical Analysis

The primary outcome was age-adjusted injury fatality rate. Spearman correlation was used to evaluate the relationship between state injury fatality rates and NNRs. Median fatality rates were compared between states with significant trauma center clustering and states with significant trauma center dispersion. To evaluate the interaction with population density, Spearman correlation was also used to evaluate state population density and injury fatality rates. Median population density was compared between states with trauma center clustering and dispersion. The number of trauma centers per 1 million persons in each state was correlated with fatality rates as well as compared between clustered and dispersed states.

At the county level, median population density was compared between counties with and without one or more Level I or II trauma centers as well as between clustered and dispersed states. In addition, the proportion of counties without a trauma center that have a population density higher than the median population density of counties with a trauma center was compared between clustered and dispersed states as a measure of how well trauma centers are matched to the population distribution within states.

To evaluate the potential effect of lower-level trauma center availability on injury fatality rates, the proportion of each state's population living in counties with a state-designated Level III, IV, or V trauma center but no Level I or II center was correlated with fatality rates as well as compared between clustered and dispersed states.

Ordinary least squares (OLS) regression was used to determine the association between injury fatality rate and NNR, controlling for state-level factors including population density, proportion of state classified as urban, mean ISS, medical helicopter bases per 1 million persons, trauma centers per 1 million persons, median household income, poverty rate, educational attainment, proportion of state population served by Level III, IV, or V trauma centers, and ratio of Level I to Level II trauma centers. The same model was performed using spatial-lag regression and compared with the OLS results using R^2, Akaike information criteria (AIC), and the likelihood ratio test (LRT). The spatial-lag model accounts for that fact that an outcome value at any given geographic location is affected by the outcome value at neighboring geographic locations.[23] If the outcome is spatially autocorrelated, a spatial-lag model will better explain variability in outcome values, evidenced by a higher R^2 value, lower AIC, and significant LRT.

Geospatial analysis was performed using ArcGIS version 10.2 (ESRI, Redlands, CA) and GeoDa version 1.6 (Arizona State University, Tempe, AZ). Data analysis was conducted using Stata version 13 (StataCorp., College Station, TX). Continuous data are presented as median (interquartile range [IQR]). Continuous data were compared using Mann-Whitney U-tests, and categorical data were compared using χ^2 test. A two-tailed $p \leq 0.05$ was considered significant.

Subgroup Analysis

The analyses mentioned earlier were performed separately in four subgroups of injury fatality rates available from the Centers for Disease Control. These included deaths from firearm-related injuries, violence-related injuries by any mechanism, MVC, and traumatic brain injury (TBI).

RESULTS

State injury fatality rates were spatially autocorrelated within the United States, with a Moran's I of 0.35 ($p < 0.01$), indicating that state injury fatality rates are more similar to geographically closer states than those farther away. When evaluating the NNR by state, 9 states had a significantly clustered pattern (median NNR, 0.55, IQR, 0.48–0.60), 22 had a significantly dispersed pattern (median NNR, 2.00; IQR, 1.68–3.99), and 10 had a random pattern (median NNR, 0.90; IQR, 0.85–1.00) of trauma center geographic distribution. Seven states had only one or no centers, and a NNR could not be calculated. Figure 1 illustrates state injury fatality rates and trauma center distribution patterns.

Injury fatality rates and NNR had a significant positive correlation (Spearman $\rho = 0.34$, $p = 0.03$), indicating that as the NNR increases and represents more dispersion of trauma centers, injury fatality rates also increase. States with a clustered pattern of trauma centers had a significantly lower median injury fatality rate than states with a dispersed pattern (Table 1, $p = 0.04$).

Injury fatality rates and population density were inversely correlated ($\rho = -0.60$, $p < 0.01$), indicating that as population density increased, injury fatality rates decreased. States with a dispersed pattern of trauma centers also had a significantly lower median population density than states with a clustered pattern (84.1 [IQR, 40.0–153.9] vs. 231.1 [IQR, 101.2–282.3] persons per square mile, $p = 0.02$). The number of trauma centers per 1 million persons was inversely but not significantly correlated with injury fatality rates ($\rho = -0.10$, $p = 0.51$). The median number of Level I or II centers per 1 million persons was not significantly different between clustered and dispersed states (0.64 [IQR, 0.36–1.01] vs. 0.41 [IQR, 0.36–0.77], $p = 0.51$; Supplemental Digital Content 1, http://links.lww.com/TA/A678).

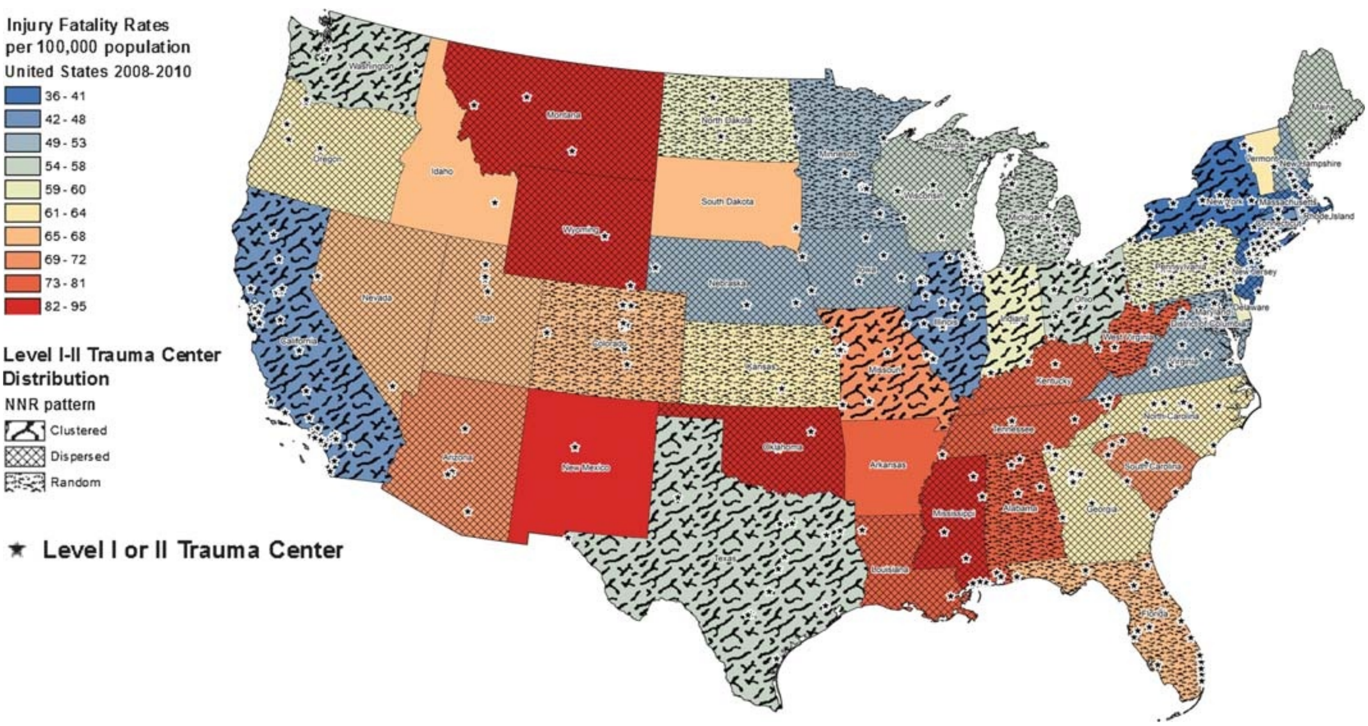

Figure 1. State injury fatality rate and geographic distribution of trauma centers in the United States. Injury fatality rate is represented by color ramp, with higher values represented in *red*, and lower values represented in *blue*. Trauma center geographic distribution based on significance of the NNR is represented by patterned overlay. Level I or II trauma center geographic locations are represented by *black stars*.

Trauma centers were largely located in areas of each state with higher population density (Fig. 2). The median population density was higher for counties with one or more trauma centers located within it compared with counties without a trauma center (475.2 [IQR, 211.9–1,133.9] vs. 37.5 [IQR, 14.7–84.0] persons per square mile, $p < 0.01$). The median population density in counties with a trauma centers present was higher but not significantly different in clustered states when compared with dispersed states (569.5 [IQR, 233.6–1,335.1] vs. 405.7 [IQR, 184.4–1,116.3] persons per square mile, $p = 0.21$). However, dispersed states compared with clustered states had a significantly greater proportion of counties without a trauma center that had a higher population density than the median population density of counties with a trauma center (5.7% vs. 1.2%, $p < 0.01$). This indicates that clustered states nearly exclusively have trauma centers located in areas of highest population density, while dispersed states more often have centers in areas of lower population density relative to potential areas without a trauma center.

The proportion of state population living in counties served only by Level III, IV, or V centers did not correlate with state injury fatality rates ($\rho = 0.26$, $p = 0.10$). Dispersed states had a higher median population proportion in counties served only by Level III, IV, or V centers; however, this was not significantly different from clustered states (12% [IQR, 1–40%] vs. 6% [IQR, 0–8%], $p = 0.29$; Supplemental Digital Content 2, http://links.lww.com/TA/A679).

In OLS regression, NNR was associated with injury fatality rate ($p < 0.01$). Spatial-lag regression outperformed OLS regression with higher R^2 (0.86 vs. 0.73), lower AIC (273.0 vs. 282.8), and a significant LRT ($p < 0.01$). In spatial-lag regression, each one-unit increase NNR was independently associated with a 0.016 increase in injury fatality rate per 100,000 persons ($p < 0.01$) after adjusting for state-level confounders.

Fatality rates remained spatially autocorrelated across all subgroups (Table 2, $p < 0.01$ for all subgroups), indicating clustering of similar fatality rate values geographically. Injury fatality rates and NNRs had a significant positive correlation for MVC and TBI fatality rates, but not for firearm or violent fatality rates (Table 2). MVC and TBI median fatality rates were also significantly lower among clustered states compared with dispersed states, but there was no significant difference for firearm and violent fatality rates (Table 1). In regression analysis, spatial-lag models again outperformed OLS regression (LRT $p < 0.01$ for all subgroups). After adjusting for state-level factors, increasing NNR remained significantly associated with

TABLE 1. Median Injury Fatality Rates by Trauma Center Geographic Distribution Pattern

Injury Type/Intent*	Clustered, n = 9	Dispersed, n = 22	*p*
All injuries	56.9 (46.5–58.9)	64.9 (52.5–77.1)	0.04
Firearm	8.9 (6.8–11.0)	12.3 (8.0–14.9)	0.13
Violence	16.7 (14.2–17.7)	19.1 (15.4–23.4)	0.12
MVC	8.3 (7.9–12.8)	12.4 (9.8–18.3)	0.03
TBI	15.7 (11.3–18.5)	19.4 (17.3–21.3)	0.03

*Fatality rate per 100,000 persons, expressed as median (IQR).

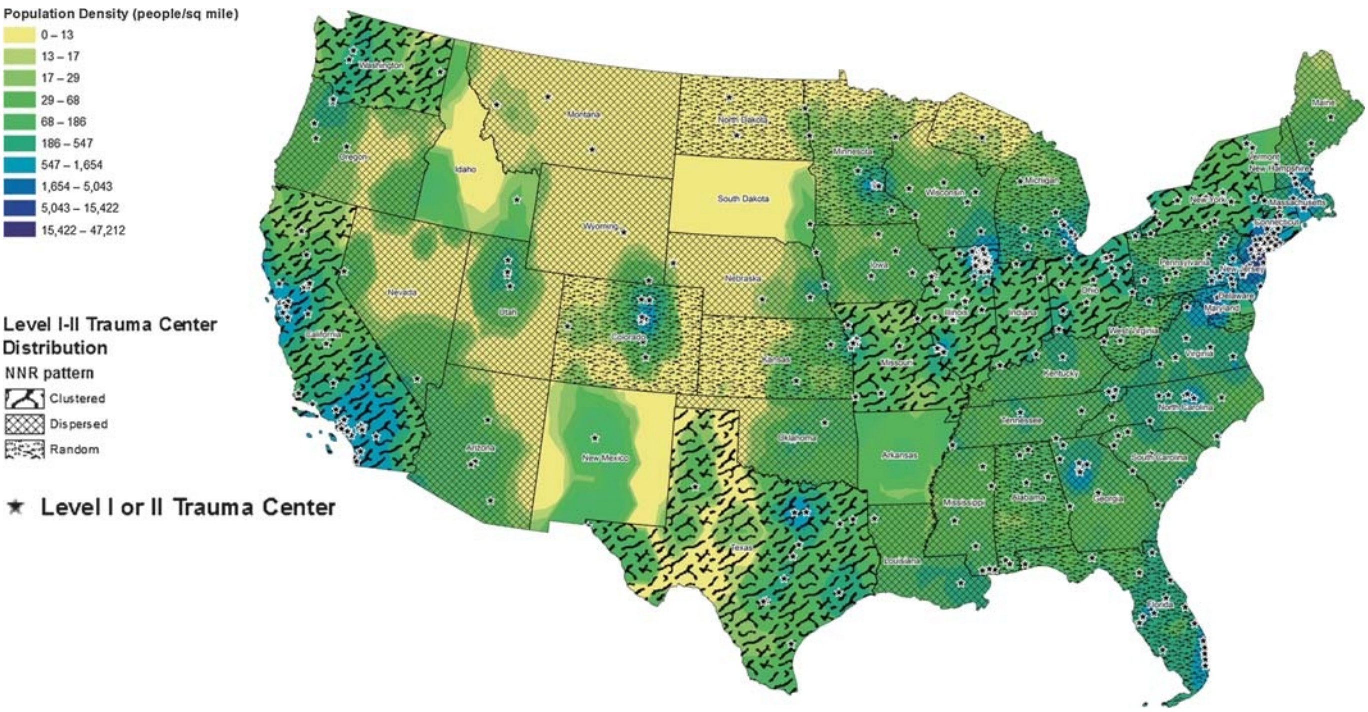

Figure 2. Continuous population density across the United States using county population density. Population density is represented by color ramp, with higher values represented in *blue*, and lower values represented in *yellow*. Trauma center geographic distribution based on significance of the NNR is represented by patterned overlay. Level I or II trauma center geographic locations are represented by *black stars*.

higher fatality rates in each subgroup; however, the size of these effects were an order of magnitude smaller (Table 2).

DISCUSSION

This data demonstrate that US injury fatality rates are spatially autocorrelated, indicating that state fatality rates are more similar to geographically neighboring states than more distant states. Most states in the United States have a dispersed pattern of trauma center distribution. Despite this, states with a clustered pattern of trauma center distribution had a lower injury fatality rate on average.

Spatial-lag regression was superior to OLS, which is not surprising given that fatality rates are spatially autocorrelated. Thus, spatial models should be considered when spatial dependencies are present in the data being modeled. The spatial-lag model demonstrated that increasing NNR values, which represent increasing dispersion of trauma centers, were independently associated with increasing injury fatality rates. This further suggests that geographic clustering of trauma centers at the state-level is associated with improved outcomes.

Subgroup analysis demonstrated that the association between trauma center clustering and improved outcome remained for MVC and TBI mortality, while this relationship was no longer seen for firearm and violent injury fatality rates. Regression again demonstrated that increasing NNR was associated with increasing injury fatality rates with a much smaller effect size, likely given the smaller fatality rates in each subgroup.

These findings are contrary to our original hypothesis. We originally hypothesized that a dispersed pattern of trauma centers would be associated with better outcome, reasoning that trauma centers more evenly distributed geographically would provide wider coverage of trauma care within the state and thus reduce injury fatality rates. However, the current results are likely attributable to differences in geographic trauma center distribution based on land area as represented by the NNR and population distribution throughout states. Populations are not uniformly distributed across land area. Thus, the association between trauma center clustering and lower fatality rates may represent improved

TABLE 2. Subgroup Analysis Results

Injury Type/Intent	Moran's *I*	Spearman ρ (95% CI)	Spearman ρ *p* value	NNR Spatial-Lag Regression Coefficient	Regression Coefficient *p*
Firearm	0.46	0.29 (−0.03 to 0.55)	0.07	0.004	<0.01
Violence	0.38	0.30 (−0.02 to 0.56)	0.06	0.004	<0.01
MVC	0.50	0.36 (0.05 to 0.61)	0.02	0.005	<0.01
TBI	0.46	0.39 (0.09 to 0.63)	0.01	0.005	<0.01

CI, confidence interval.

access to trauma care through better matching of system resources with the main population centers within these states. This is highlighted in Figure 2, as trauma centers are generally located in areas of higher population density within states. However, dispersed states have more centers located in lower population density areas than clustered states and thus may represent differential population access to trauma care. Access to care has been widely implicated in outcomes after injury, with variations based on geography.[5–7]

Furthermore, these results are likely attributable to the scale of geography studied. Although trauma systems are legislated at the state level, they may not operate as a single trauma system.[4] When evaluated from the perspective of statewide mortality, it may be that clustering of trauma centers best serves the population centers, while if evaluated on a smaller regional level, mortality may be lower in areas that have a more uniform distribution of trauma centers over a catchment area. Further study of the relationship between geographic distribution of trauma centers and outcome is warranted to elucidate the underlying mechanisms of these findings and expand our understanding of the geographic distribution of resources at varying levels within trauma systems.

MVC and TBI fatality rates exhibited improved mortality for clustered trauma centers, while this was not seen for firearm and violent injury rates. This may be attributable to the fact that firearm and violent injury, as predominantly penetrating mechanisms, concentrate in urban areas with at least one trauma center. Thus, these patients would have rapid access to a trauma center, and the overall state-level distribution of trauma centers would play less of a role in outcome. Conversely, MVC and TBI are predominantly blunt mechanisms that are not restricted to urban centers but will occur more frequently in higher population density areas. Thus, outcome in these injuries may depend more on trauma system access, and clustering of trauma centers at the state level may provide better matching of resources to population centers.

This study is the first to evaluate geographic distribution pattern of trauma centers and injury fatality rates. Thus, there is little existing literature to compare these results with; however, the influence of geospatial factors on outcome after trauma is well documented. Minei et al.[8] reported significant variations in outcome among severely injured patients across several geographic regions in North America. Our group demonstrated significant geographic variation in outcomes after helicopter transport for trauma.[9] Some have found higher injury and mortality rates for MVC in the Southern United States.[13,15] Washington et al.[24] noted an eight-state Southeast region composed of Alabama, Florida, Georgia, Kentucky, Mississippi, North Carolina, South Carolina, and Tennessee consistently have higher fatal MVC rates than in other areas of the United States. Similarly, our findings demonstrate a clustering of higher injury fatality rates within the Southeast United States among these eight states. Furthermore, none of these eight states have a clustered pattern of trauma centers. Six have a dispersed trauma center pattern, while two have a random pattern. Authors have postulated that this disparity may exist as a result of differences in seat belt use, alcohol use, vehicle miles traveled, speed limits, and access to emergency medical services.[12,14,24] These factors deserve further investigation as potential mediators of the association between geographic trauma center distribution and injury fatality rates.

Rural versus urban location has also been strongly implicated in outcomes after injury. Several groups have shown that the risk of death is higher for MVC occurring in rural locations.[14,15] Travis et al.[25] reported similar findings, noting that higher speeds, lower seat belt use, and other precrash factors may be more important than limitations in emergency care. Gomez et al.[6] performed a population-based study in Canada, reporting a disproportionate number of deaths in rural versus urban nontrauma center emergency departments, suggesting that delay in trauma center access contributes to poorer outcomes in rural areas. Furthermore, Hsia et al.[7,10,26] have shown that patients in rural areas have significant barriers to trauma center access in the United States. These issues also factor in the results of this study, as seen by the interaction of population density, trauma center distribution, and injury fatality rates. Injury fatality rates rose as population density decreased, and dispersed states had a lower population density compared with clustered states. More rural states are less likely to have multiple large population centers to support higher-level trauma centers, leading to more dispersed patterns across these states. Dispersed states also seem to have greater availability of lower-level centers in areas where Level I or II centers are not present; however, this was not significantly different from clustered states, and coverage by lower-level centers was not correlated with fatality rates. This factor was also controlled for in the regression analysis, and it does not appear that lower fatality rates in clustered states are caused by a more developed network of rural lower-level centers that stabilize patients for transfer to higher-level centers clustered in urban areas. Our regression analysis also adjusted for population density and proportion of urban versus rural area, and thus, the rurality of states does not seem to exclusively explain the association between distribution of trauma centers and injury fatality rates.

Furthermore, analysis at the county level indicates that dispersed states may not have maximized placement of trauma centers in areas of highest population density when compared with clustered states. This also underscores the importance of population density to trauma system configuration and suggests that differences in state rurality may not be the sole factor driving the relationship between geographic trauma center distribution and injury-related mortality seen here.

Finally, although the number of trauma centers per 1 million persons is an important measure of trauma center distribution relative to the population, it did not correlate with injury fatality rates and was not significantly different between clustered and dispersed states. These results suggest that the specific geographic location of centers relative to the population density within trauma systems is potentially an equally important metric of trauma center distribution to consider in addition to an aggregate measure such as number of centers per 1 million persons.

These results are intriguing but should be interpreted with caution. It is unlikely that clustering of trauma centers at the state level intrinsically drives lower fatality rates. More likely, it is a marker of several other system-level factors, such as population distribution and access to trauma care on a wider scale as noted earlier. These results cannot define the optimal number of trauma centers for a given area or population, or the optimal number of population centers within states that should be served by Level I or II trauma centers. Furthermore, it assesses existing centers in their current configuration and cannot predict outcomes if centers were placed in different geographic distributions. Thus, these results should not be interpreted as a call to reorganize existing state trauma systems to force clustering of trauma centers. Rather, these results should been seen as support for a rational approach to trauma system design. The American College of Surgeons Committee on Trauma recently released a statement on trauma center designation based on system need, which advocates consideration of overall trauma system characteristics and population needs rather than solely evaluating individual hospital capabilities.[27] These results support that approach, in that geographic factors and distribution of trauma centers relative to population density should be considered among other factors as trauma systems in the US mature.

Several groups have used geospatial analysis to optimize trauma system development. Branas et al.[16] developed the Trauma Resource Allocation Model for Ambulances and Hospitals, which used a spatial model of injured patients in Maryland to optimally place trauma centers and medical helicopter bases. They reported improved access to trauma care within 30 minutes for the state population using their algorithm to relocate trauma centers and helicopter bases. Jansen et al.[19] designed the Geospatial Evaluation of Systems of Trauma Care (GEOS) model to help plan and optimize national trauma resource allocation in Scotland. The authors note that the GEOS model has several advantages over others, including the use of prehospital triage guidelines to guide patient flow and the ability to model constraints based on center resources, bed capacities, and helicopter availability. This group has also used incident-specific geospatial profiling of injuries in Scotland to further aid trauma system planning.[18] Others have also used geographic information system approaches to optimize the time benefits of helicopter versus ground transport of trauma patients.[28,29]

This study has several limitations. First, this is a retrospective ecologic study. We were limited to obtaining data available for the study period from several sources. This limited the data available for potential confounders and interactions among factors related to injury mortality. Second, data were evaluated at the state level; thus, the complexities of individual patients are not captured. Moreover, the current analysis cannot fully examine the potential mechanisms underlying the findings here. As noted earlier, analysis was at the state level; however, regional trauma systems more commonly regional exist within states, and catchment areas may include portions of neighboring states, which would not be captured here. Thus, different geographic distribution patterns may be associated with mortality when evaluated at different geographic levels. The NNR analysis considers land area in determining geographic distribution; however, these results clearly show that geographic population distribution is an important factor in trauma center distribution. The use of aggregated state-level data also assumes uniform geographic distribution of injuries across the state, while injuries cluster in population centers as well.[18] Unfortunately, more granular county-level injury fatality rates were not available for the study period. We only considered trauma centers; however, the geographic distribution of other trauma system resources such as helicopter bases can also influence outcome.[30] In addition to the geospatial configuration of trauma centers, appropriate triage and use of these resources varies geographically and impacts outcomes.

Despite these limitations, we believe this exploratory analysis demonstrates a compelling argument that geographic factors at the system level are associated with injury-related mortality in the United States and more directed study can begin to elucidate key elements of this relationship going forward.

CONCLUSION

The geographic distribution of trauma centers correlates with injury-related mortality, with clustering of state trauma centers associated with lower injury fatality rates. This may be attributable to superior access to trauma care through improved matching of system resources to population centers; however, further study is needed to investigate the mechanisms underlying these exploratory findings. These results point to the importance of geospatial factors in outcome after injury and may have implications for rational trauma system planning as this domain of work advances.

AUTHORSHIP

J.B.B. designed the study and performed the literature search, data collection, and data analysis. J.B.B., M.R.R., and J.L.S. participated in the initial manuscript preparation. All authors contributed to the data interpretation and critical revision of the manuscript.

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DISCUSSION

Dr. James Haan (Wichita, Kansas): I'd like to congratulate Dr. Brown on actually looking at something that we have held for a long time, the belief that the equal dispersion of trauma centers leads to better outcomes and lower fatality rates.

It is unique using geospatial mapping to match the population density to the distribution of trauma centers within the region or nearest neighbor ratio (NNR). It is very interesting that this hypothesis of dispersion is better was disproven by your actual methods. And I think this is of great interest. However, I do have several concerns.

One is it doesn't take into account EMS availability. You looked at whether and how many helicopters were within a state but how available are the true EMS resources at the ground level.

Two, you listed as a limitation that you're using state-based population densities for trauma centers, and trauma centers are regional providers of care that don't care about state boundaries. I agree and when I look at it for my own state, Kansas, using your system we are random. I don't believe that is true. To go into specifics, Wichita has two Level I trauma centers, largest population area. The capitol, Topeka, has one Level II trauma center. Kansas City, also high population, only has one Level II. A mile away in Missouri, however, is a Level I trauma center that also manages that area.

I would be suspicious if you brought that into play in this and several of your other random states they may be reclassified as clustered. And I hate to say it—my state has a moderately high fatality rate, so you may actually change the results of this paper.

So my take-away is I think the statistics are great but occasionally you have to use your own clinical eye say, am I using the right statistics but not answering the question the way it should be answered.

Another thing—this was brought up in an earlier paper, as well—why aren't Levels III and IV involved? I like the idea and it makes sense to say let's match the highest-density areas with the most intensive resources and we have better outcomes.

Is it that this is this only partially true? Do these states also have well-developed IIIs and IVs that do rapid resuscitation and transport? It would strengthen the paper to look at this as well, after obviously going back and making sure the random are the random and the disbursed are the disbursed.

Looking at it as an overall I think this is a very good preliminary paper. I would strongly encourage going back, though, and using your own human eye to make sure you are properly assigning your states, as some of them could actually change the overall result, and to take into account some of the other things such as Level III, Level IV, and EMS availability in your future study to try and validate this.

I thank the AAST for the privilege of the podium and I thank you for the timely submission of your manuscript.

Dr. Stephen Flaherty (El Paso, Texas): Yes, I just want to pick up on the third point, again. You know, when you are looking at mortality and a Level III trauma center's goal is to impact the immediate life-threatening care of the patient and then transfer them someplace else, how could you possibly leave them out of this? And how can we interpret this data?

Dr. Alan Cook (Chandler, Arizona): Thank you for your paper. And I appreciate your patience with describing your methodology. Geospatial analysis is a new language for the trauma literature.

One question: in your last map or next-to-last map, it was the smoothed analysis of your observed to expect mortality, at that level of gradient did you see any oversaturation of trauma centers because there is a growing literature that when trauma centers are in too close a proximity they compete for resources of specialists, payers, et cetera? And in the low saturated areas, of course, patients suffer—their potential outcomes suffer.

I appreciate your comments and it's a very interesting paper. Thank you.

Dr. Robert J. Winchell (New York, New York): Again, I think it's a great and a novel approach. It's a retrospective look at all of our trauma centers which have arisen from where the trauma centers are.

But I'm not sure it really answers the other question. I'd ask you: would you use this data to tell me where I should build the next one? Because this clustered idea of building them all in the metropolitan areas doesn't necessarily address the bigger picture, especially given that we didn't build those states with that intent when it happened.

So, again, I think it's great work. The question is how do we use it planning going forward?

Dr. Arthur Cooper (New York, New York): I am just curious as to how these results square with what we learned this morning, suggesting that the longer the pre-hospital time the better the outcome.

Dr. Ronald Stewart (San Antonio, Texas): First of all, very nicely presented and really a statistical *tour de force* from a great group.

I wonder though, looking at the map, if you talked about population density but if you look at those clustered states, I would guess those states are not only more populous but they also are more affluent and, therefore, likely have more resources in multiple different ways that may be hard to measure. I'd be interested in your thoughts on that issue or maybe how to measure it.

Dr. Joshua B. Brown (Pittsburgh, Pennsylvania): Thank you, Dr. Haan, for an excellent discussion and everyone for their questions. I think you bring up several good points and especially in terms of system boundaries.

Number one, when we looked at this data, we were surprised and intrigued by the findings. We looked at the state level because that's where, again, organization and oversight falls but, looking at our home state, what happens in Western Pennsylvania may be very different from what happens in the Philadelphia area. So I think, the next step we see coming out of this is, one, how do we group the functional trauma systems because, as you mentioned, people come to our trauma center from West Virginia and from Southern New York and so how do we sit down and really identify those catchment areas and evaluate this at a trauma-system level which we have heard a lot about here? I think that becomes an important issue going forward.

I can tell you, we did this as a preliminary study to say does this geographic configuration issue really affect anything? And based on the results here, it does look like an important factor to consider that deserves more attention and study.

And from here we have started to look at our state level and not only incorporate trauma centers but we are looking at where our helicopter bases are located. We are also looking at what percentage at the county level is covered by a helicopter versus ground ambulance, so bringing in those EMS resources I think is an important next step.

In terms of why we didn't include the Level III or IV trauma centers, we do have that data and we looked at it. And actually including in the overall analysis gives results that were fairly similar. But the reason that we went, at least for the time being, with the Level I and II centers is because what constitutes a Level III or IV center in some states is very different. In addition, a lot of states just don't use Level III; they only have Level I or II. Some states will use Level III, IV, and V. And some states, if you look at the map of the whole spectrum of centers, they are just peppered with what they call Level V and so we felt like the standardization across the states, because we are looking at the whole U.S., was probably going to be the closest for what a Level I and II trauma center was going to be. But certainly we can include that in a sensitivity analysis and look at how they might affect outcome in relation to their configuration relative to higher level centers.

In terms of the smoothed gradient map, that's actually just looking at the population density. And so, unfortunately, we tried to get county-level fatality rates, but the CDC only provides those aggregated for 2004 to 2010. And so we really didn't feel like over that time period it would be useful to use such a large span of years, as things probably changed significantly in terms of the configuration of the trauma centers. So the county level smoothed map is just looking at the population density.

But I will say, I think there are important considerations in terms of over and under populating areas with trauma centers. And so I think that is where things like how do we position our helicopter bases and how do we configure our EMS systems in coordination with the larger trauma system comes in to play.

I think the question about what do we do with this data is a great one. Do we go home from Las Vegas and try to rearrange all of our trauma centers? Obviously, I don't think that's the answer based on this data. But I think it is more of a plea for rational trauma system design. Especially, looking at the College's statement that was published earlier in the year, to really think about designating trauma centers based on system need.

I think really what this data argues for is not only does the center check off all the boxes in terms of the requirements for a trauma center, but how does it fit into the larger system? Does it support a population center? Or is there a better place where a trauma center might serve the whole system better?

In terms of the longer prehospital times, that certainly is something that plays a role and as we start to get down and look at the county level within our own state, we're looking at the prehospital times and the EMS availability so that's where we are going next with this.

And then, finally, Dr. Stewart, in terms of the affluence, it certainly is a big potential confounder so we did include median household income, poverty rate, and unemployment rate in our regression model to adjust for those issues.

Again, thank you for the privilege of the floor.