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Access to Trauma Center Care: A Statewide System-Based Approach

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Abstract

Background: Timely access to specialized trauma care is a vital element in patient outcome after severe and critical injury requiring the skills of trauma teams in level I and II trauma centers to avoid preventable mortality. We utilized system-based models to estimate timely access to care. **Methods:** Trauma system models comprised of ground EMS (GEMS), helicopter EMS (HEMS), and designated level I - V trauma centers were constructed for five states. These models incorporated geographic information systems (GIS) along with traffic data and census block group data to estimate population access to trauma care within the "golden hour." Trauma systems were further analyzed to identify the optimal location for an additional level I or II trauma center that would provide the greatest increase in access. **Results:** The population of the states studied totaled 23 million people, of which 20 million (87%) had access to a level I or II trauma center within 60 minutes. Statewide specific access ranged from 60% to 100%. Including level III - V trauma centers, access within 60 minutes increased to 22 million (96%), ranging from 95% to 100%. The addition of a level I-II trauma center in an optimized location in each state would provide timely access to a higher trauma capability for an additional 1.1 million, increasing total access to approximately 21.1 million people (92%). **Conclusions:** This analysis demonstrates that nearly universal access to trauma care is present in these states when including level I-V trauma centers. However, concerning gaps remain in timely access to level I-II trauma centers. This study provides an approach to determine more robust statewide estimates of access to care. It highlights the need for a national trauma system, one in which all components of state-managed trauma systems are assembled in a national dataset to accurately identify gaps in care.

Level of Evidence: IV

Study Type: Original Research

Keywords: Prehospital, trauma, access to care, trauma system

Background

During the last several decades, advances in trauma care and trauma system development have substantially reduced injury-related death and disability.(1-3) Despite these improvements, injury remains the leading cause of death in individuals up to the age of 44 and the leading cause of morbidity and mortality among children in the United States (US).(4) There remains a substantial opportunity to further reduce the number of deaths in the prehospital setting, as an estimated 20% of trauma patients who die have potentially survivable injuries.(5, 6) This estimate suggests there are important opportunities to optimize emergency medical services (EMS) systems, bystander care, and timely transition from prehospital to trauma center care. Confirming this indication, in its report titled 'A National Trauma Care System: Integrating Military and Civilian Trauma Systems to Achieve Zero Preventable Deaths After Injury', the National Academies of Sciences, Engineering, and Medicine (NASEM) estimated that 30,000 of the 147,790 trauma decedents in 2014 had potentially survivable injuries.(5) This NASEM report provided justification to develop and implement a national trauma system supporting the ultimate goal of zero preventable deaths and disabilities from injury.

Timely access to specialized trauma care is a vital element in patient outcome after severe (ISS 16-24) and critical (ISS≥25) injury.(7-11) Several reports have found that longer prehospital transport times contribute to higher mortality rates among rural trauma patients compared to similarly injured urban patients with shorter transport times.(12-16) Furthermore, states with limited trauma care access incur more prehospital deaths, contributing to higher overall injury mortality.(8) Additionally, substantial geographic variation in prehospital mortality confirms that those sustaining injuries in rural locations have greater risk.(17) Relative trauma deserts have been identified even in urban locales based on timely access to care.(18) Though the impact of trauma care access on mortality and morbidity is undeniable, data linking prehospital time intervals to specific outcomes is lacking. Prehospital capabilities and interventions also contribute to patient outcome.

Researchers have investigated access to care through the analysis of prehospital time. Nearly all have incorporated some form of four major time intervals: those intervals between EMS system activation, response to scene of injury, provision of on-scene care, and transport to hospital.(19) The activation time interval is commonly defined as the time from 9-1-1 emergency call to ambulance dispatch. The response time interval is most typically the time from ambulance dispatch to arrival at the scene. The on-scene time interval is then measured as time from ambulance arrival at the scene to time of initiating transport to a hospital. Finally, the transport time interval is the time from transport movement toward a hospital to arrival at a hospital.

While multiple models exist to quantify timely access to trauma care,(15, 20-23) few of them incorporate all four prehospital time intervals into their analysis. When time intervals are not present, many models use surrogate time approximations. In this study, we construct a system-based model that incorporates the entire trauma response to more accurately estimate present and future desirable states of timely access to care post-injury, using five U.S. states and including four prehospital time intervals. This model can serve as a blueprint for creating standardized data collection and assessment, thereby facilitating the creation of a national trauma system as recommended in the NASEM report. Furthermore, we aim to detect geographic gaps in access to care and seek to identify the optimal location for additional level I or II trauma centers in each of the five states analyzed, targeting geographic gaps and providing improved access to timely advanced trauma care for the population. We hypothesize that upgrading level III-V trauma centers to level I-II will result in a substantial increase in population access to care within 60 minutes.

Methods

Setting

The five states selected for analysis were Connecticut (CT), Maryland (MD), New Mexico (NM), Oklahoma (OK), and Washington (WA). These states were selected based on their demographic representation of the U.S. population, varying population density, and geographic distribution. In total, the states represent a population of approximately 23 million. Trauma system elements were collected for all sites, including trauma center, GEMS, and HEMS locations.

Four of the five states (CT, MD, NM, OK), included in this analysis are part of the Multi-Institutional Multi-Disciplinary Injury Mortality Investigation in the Civilian Prehospital Environment (MIMIC) study funded by the Department of Defense. MIMIC was funded to develop a more comprehensive understanding of the epidemiology of civilian prehospital injury deaths and their potential for survivability. The MIMIC study sites were selected based on their centralized medical examiner system, utilization of an electronic case management system, demographic representation of the U.S. population, and varying levels of population density. For this analysis, Washington was added due to the easy availability of GEMS and HEMS location data needed for analysis.

Data

Location data for all trauma system elements were collected and geocoded using ArcMap V.10.8 (Environmental Research Systems Institute [ESRI]).(24) GEMS station locations were supplied by respective State Departments of Health. For rural depots in MD and NM where P.O. boxes were provided, locations were assigned more accurate physical addresses using Google Map Street View application software. HEMS base locations were obtained from the Atlas and Database of Air Medical Services (ADAMS),(25) a data resource created by the Association of Air Medical Services (AAMS). HEMS base locations within the study states and in respective adjacent states, when operationally functional, were included in the analysis, allowing for instances of HEMS interstate response and transport. Locations for level I - V trauma centers within and in respective adjacent states were collected from the 2018 American Trauma Society Trauma Information Exchange Program.(26) This comprehensive list includes physical addresses for all American College of Surgeons (ACS) and/or a specific State Department of Health designated level I - V trauma centers. Level I - II trauma centers provide 24-hour coverage by general surgeons and the specialties of orthopedic surgery, neurosurgery, anesthesiology, emergency medicine, radiology, and critical care. Level III trauma centers can provide prompt assessment, advanced trauma life support and life-saving surgery, but may need to transfer patients to a higher-level trauma center for critical and specialty care. Level IV and V centers are designed to provide initial stabilization and transfer seriously injured patients to a higher level of care.

The geographic unit used for analysis was the census block group, the smallest unit at which detailed demographic information is available. Block groups are statistical divisions of census tracts and never cross state or county boundaries. To determine the prehospital time for the population within a block group, we used the population-weighted centroid – the point at which a rigid, weightless map would balance perfectly, such that population members are represented as points of equal mass. Population-weighted, rather than traditional geometric centroids, can result in maps that better reflect the underlying population.(27) Population data were obtained from the 2015-2019 American Community Survey (ACS),(28) an ongoing survey conducted by the U.S. Census Bureau to give data estimates that fall between the 10-year census intervals.

Access Calculations

We defined timely access to care as ability to reach a designated trauma center within 60 minutes via GEMS or HEMS. Sixty minutes was used because the first hour after traumatic injury, referred to as the "golden hour," is a crucial period of care post-injury, often involving rapid assessment, resuscitation, and hemorrhage control in trauma centers.(29-31) We further classified access based upon level of trauma center designation, either level I - II or level I - V.

Using ESRI ArcMap V.10.8 and trauma system models built for each state, prehospital travel times were calculated from the nearest GEMS station to the block centroid and from that block centroid to the nearest trauma center. For GEMS response and transport times, the Streetmap Premium (North America V.2020.2) road network was used in conjunction with the Closest Facility tool within the Network Analyst to model vehicle transport routes, determining travel times and distances. The Streetmap Premium dataset uses historical TomTom GPS data to increase the accuracy of travel time estimates. For HEMS times, the Near Tool was used to identify the nearest HEMS base location and calculate the straight-line distance to site of injury. An average cruising speed of 142.6 mph (23) was used to calculate travel times. Median activation and on-scene time intervals from our analysis (19) of over 94 million records from the National Emergency Medical Services Information Systems (NEMSIS) database were summated with the ArcMap calculated response and transport times to form the complete prehospital time interval for each population-weighted block group centroid. Activation and on-scene time intervals were stratified by transport type and rurality. These models were utilized to analyze the impact of "upgrading" an existing level III - V trauma center to a level I or II. Current level III - V trauma center distribution was analyzed, and the centers providing the largest potential population increase in access were identified.

Results

Population within the five states totaled 23 million people, of which 20 million (87%) had timely access to a level I or II trauma center within 60 minutes via GEMS or HEMS. With the inclusion of level III-V, timely trauma center access within 60 minutes increased to 23 million (99%).

Results show variation among included states, with geographically smaller states, particularly Connecticut and Maryland, having greater timeliness to trauma care accessibility rates when compared to geographically larger states like New Mexico and Oklahoma (Table 1). Across the five states studied, access to level I and II trauma centers within 60 minutes ranged from 60% to 100% of the population, with a mean of 84%. Mapping of timely access to care shows large geographic areas in Oklahoma, New Mexico, and Washington where accessibility within 60 minutes to level I or II trauma center care is distinctly lacking (Figure 1). Oklahoma has major geographic gaps in timely trauma center access coverage in its panhandle and its southeast, with the latter region populated by many Native American reservations.(32) New Mexico, containing only a single level I trauma center (University of New Mexico in Albuquerque), provides the least timely access to higher level trauma center care for its citizens. Only 1.3 million (60%) of the 2.1 million New Mexicans, those living in 11% of the state's territory, are within 60 minutes of trauma center care within the state itself. As evidence of the importance of neighboring state resources, an additional 18% of New Mexicans find this timely care is provided through access to trauma center care in El Paso, Texas. Finally, Washington's trauma system coverage has gaps in both the state's interior and along the Pacific Coast. When including level III - V trauma centers in the analysis, all states provide timely access to trauma care to greater than 95% of their populations, with New Mexico and Oklahoma seeing the greatest increase in accessibility (Table 1).

As part of this analysis, adding a level I or II trauma center to the trauma system in a geographically optimal "gap filler" location in each state would provide timely access to care for an additional 1.1 million people across the five states, bringing the total of those with timely access to approximately 21.1 million people (92%). Absolute state-specific increases in timely access to care ranged from 3% to 9%, with relative increases in timely access to care ranging from 3% to 11% (Table 1). In Figure 1 a dot is used to depict the exact location of the additional trauma center that would increase the distribution for 60-minute access to level I-II care for each state.

Discussion

In this study, we quantify timely access to trauma care using a full spectrum of prehospital time intervals (EMS system activation, response to scene of injury, provision of on-scene care, and transport to hospital), utilizing traffic data for ground response, air transport, and the most up-to-date mean dispatch and on-scene times. Our analyses show that while our five study locations provide nearly universal timely access to trauma care when incorporating level I - V trauma centers, many gaps in timeliness persist, both in geography and population, specifically in access to level I-II trauma centers. These gaps represent serious risk to those most severely injured and who, by definition, require the specialized resources found only in these higher-level designated trauma centers. As shown by this study's modeling, the addition of an optimally upgraded level I - II trauma center can achieve meaningful improvements in timely access to that care. Trauma is a significant public health issue and one of the leading causes of death in the U.S. and worldwide. Increased understanding of the geographic distribution of timely access to trauma care is crucial to trauma system development and, in turn, to maximizing survivability and long-term functional recovery.

Given that many rural hospitals will not have the resources or patient volumes to support a level II center, states should ensure the engagement of these hospitals in the trauma system as level III or IV centers and assess the location and availability of critical care transport resources to support interfacility transport when needed. Nationwide, levels III-V trauma centers have been responsible for expanding access to underserved populations.(33) Inclusive systems have been correlated with lower mortality after severe injury.(34)

The first organized trauma system was the Maryland Institute of Emergency Medical Services System, created in 1973 by Governor Marvin Mandel. Wise application of the principles of organized care requires linking trauma center need with available resources. Too few trauma centers results in patients not having timely access to life saving care after injury; too many trauma centers can dilute patient experience and prevent individual centers from accumulating sufficient experience to mature and maintain competence. EMS transport via helicopter can reduce prehospital times, augmenting effective trauma center availability. Transfer within a system can help address concerns about access, but ensuring that necessary resources are available for initial patient care is essential for optimal results. One size does not fit all systems. Each municipality must weigh the costs with the need for access in order to devise the best local solution. Though we utilized a 60-minute metric, our proposed model can be tailored to be realistic and relevant to system based guidelines and requirements predicated upon different intervals such as 45 minutes, 30 minutes, etc.

Results from our study include GIS-calculated response interval from GEMS/HEMS depot to block group population weighted centroids, and therefore, provide a complete prehospital time estimate inclusive of dispatch, response, on-scene, and transport intervals. We believe other methodologies quantifying timely access to trauma care in the U.S. have greater limitations in their respective design(s). The Trauma Resource Allocation Model for Ambulances and Hospitals (TRAMAH)(21, 22, 35) lacks GEMS station locations and, instead, multiplies the transport time interval by empirically derived constants to estimate that time. Other models also use mean driving speeds based on rurality instead of real-time traffic data, and utilize mean dispatch and on-scene times from dated sources. Some methodologies use 60-minute service zones, which assume immediate patient transport to the nearest trauma center at the time of injury, and do not include EMS system activation, response to scene of injury, and on-scene care time intervals.(20, 36) Our approach can be easily replicated in other states with accessible GEMS and HEMS location data. This study will allow trauma system development teams to utilize our methodology to identify the "optimal" location that would make the biggest impact to accessibility to a Level I-II trauma center.

As with all studies, our research is not without its own limitations. Because this model utilizes both GEMS and HEMS, we acknowledge that results represent access to care in ideal circumstances, where the fastest of those two methods is employed. There is also significant overlap between GEMS and HEMS coverage in many geographic areas, with varying protocols or procedures that may determine which method of transport is activated and utilized. We understand that ideal choices cannot be made in every circumstance, and that there may be times where the best mode of transportation is not available at the time of injury (e.g., weather limitations to flight). Hence, this study's estimates represent the trauma system's peak potential with the infrastructure currently in place. Additionally, validation through a comparison of model-predicted and recorded time intervals would further refine the model, as would the addition of an 'injury to call' time interval. Due to topographic, infrastructure, and system-design differences, numerous validations from trauma centers across the U.S. would be necessary to more comprehensively calibrate the model. Also, while our research focuses on measuring geographic access to care by population distribution, not all populations have the same risk of injury, and thus, disparities exist in comparing severe and critical injury to population distribution.(20) Also, this analysis defines access solely based on geographic locations and does not consider other elements, such as capacity-to-demand ratios. Our study considers optimal time-based access to care with the assumption that this would improve outcomes. However, we do not have corresponding mortality outcomes data to support this assumption. Finally, our model is a mathematically objective model that does not consider the inherent geopolitical factors that guide trauma system development and trauma center placement, health care system competition, trauma transfers, direct trauma center utilization by the population, emergency medical services discretion, marketing, and many other salient "real life" barriers to trauma center and trauma system access.

We must understand the challenges of our current state and regional systems before moving toward a national trauma system. One of the current challenges with the U.S. trauma system is that, in many states, there are too many level I-II trauma centers in urban areas and too few level II centers in rural regions. There is a potential role for level III -V trauma centers in closing this gap. The imbalance is compounded by dysregulated air ambulance services in most states. Optimal trauma volume and health care costs are critical issues to consider in this complex system planning process. Enhanced, streamlined communication and transfer processes; better en route care; and increased awareness and enhanced self- and bystander-care capabilities in populations at risk could be good first steps to reducing preventable death. Time to capability (EMS providers/resources) versus time to trauma center will be a critical concept in our efforts to close the gaps that occur in trauma deserts.

This study provides statewide access estimates to definitive trauma care utilizing the entirety of each included state's trauma system. Using GIS-based methods and a system-based approach, we identified high population-level access to level I and II and level I -V trauma centers within 60 minutes. These findings demonstrate that GIS modeling can be a valuable tool for identifying "trauma deserts" and highlight the need for a national trauma system wherein all components of state-managed trauma systems are assembled to form a coherent national dataset. Creating a national data resource of trauma centers, GEMS stations, and HEMS base locations would provide the required data essential to identifying all potential gaps in timely access to trauma care. With the U.S. expected to grow in population by nearly 79 million residents over the next four decades,(37) a national trauma system with the capability to accurately identify and correct gaps in timely access to its resources is vital to improving patient outcomes and saving lives. The time has come to connect daily injury care and mass casualty readiness across the United States in a National Trauma and Emergency Preparedness System (NTEPS) built on the strengths of highly functional state and regional trauma systems and Regional Medical Operations Centers.(38)

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Figure 1. Geographic distribution of 60-minute access to level I-II trauma care for MD (A), OK (B), WA (C), NM (D), and CT (E). Grey area is existing accessibility and black is increased accessibility with the addition of one level I-II trauma center. The dot represents the location where the trauma center would be located to provide the additional increased accessibility shown in black.

Figure 2. Geographic distribution of existing accessibility to 60-minute access to level I-V trauma care for MD (A), OK (B), WA (C), NM (D), and CT (E). Grey area is existing accessibility.

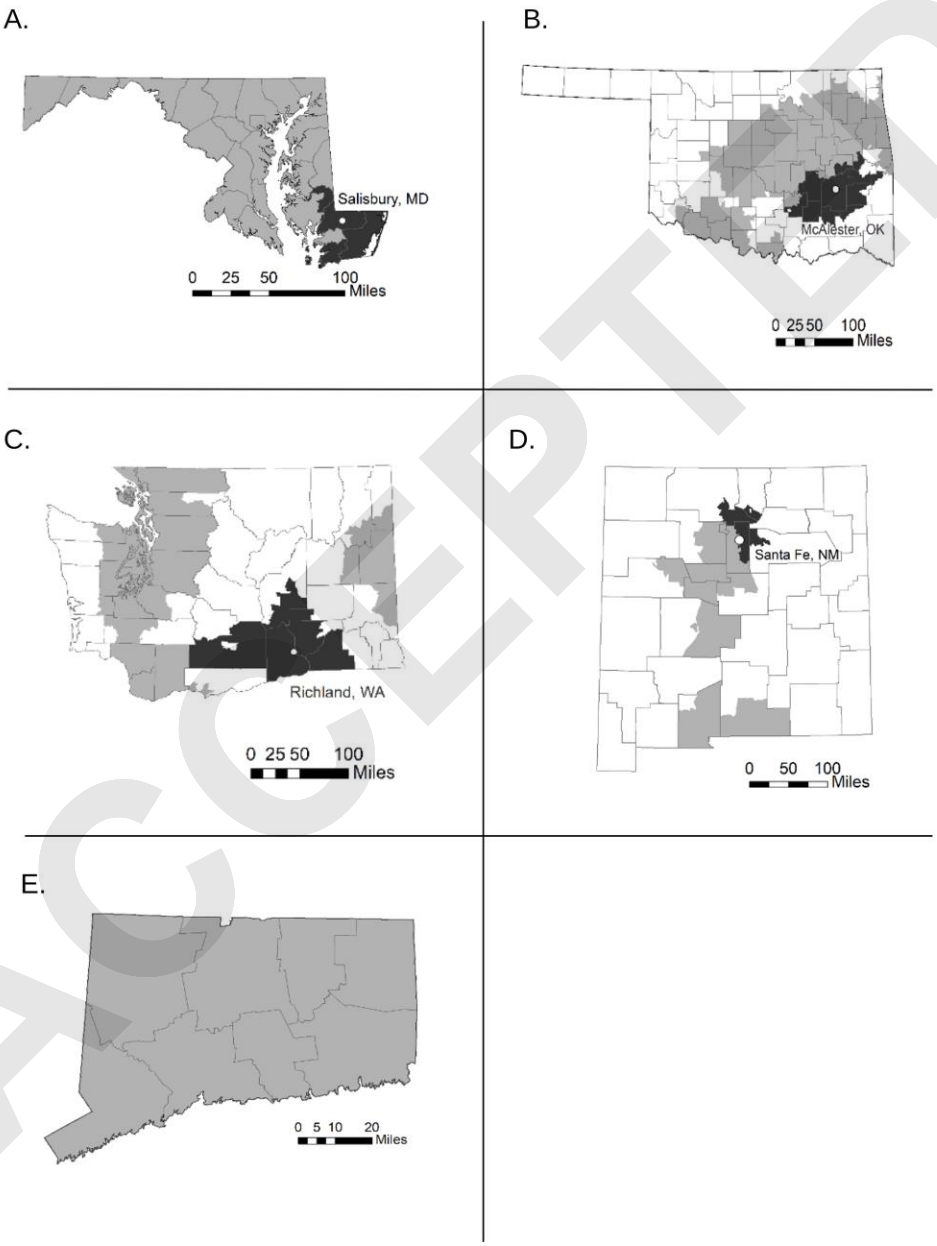
Table 1. Population accessibility (%) to trauma care within 60 minutes and increases in access after optimal addition of one trauma center

	Level I - II			Level I - V			Optimal Addition of Level I-II		
State	GEMS	HEMS	Both	GEMS	HEMS	Both	Absolute % Increase	Relative % Increase	Population Access
Connecticut	97.6	100.0	100.0	96.9	100.0	100.0	-	-	-
Maryland	77.7	96.7	96.7	87.2	100.0	100.0	3.3	3.4	100.0
New Mexico	41.3	60.2	60.2	82.9	95.1	95.1	4.8	7.8	65.0
Oklahoma	51.6	79.7	79.7	94.0	99.8	99.9	2.7	3.4	82.4
Washington	70.8	84.3	84.4	95.6	99.4	99.5	9.3	11.0	93.7

Supplemental Digital Content

1. MIMIC Study Group Members

Figure 1. Geographic distribution of 60-minute access to level I-II trauma care for MD (A), OK (B), WA (C), NM (D) and CT (E). Grey area is existing accessibility and black is increased accessibility with the addition of one level I-II trauma center. The dot represents the location where the trauma center would be located to provide the additional increased accessibility shown in black.



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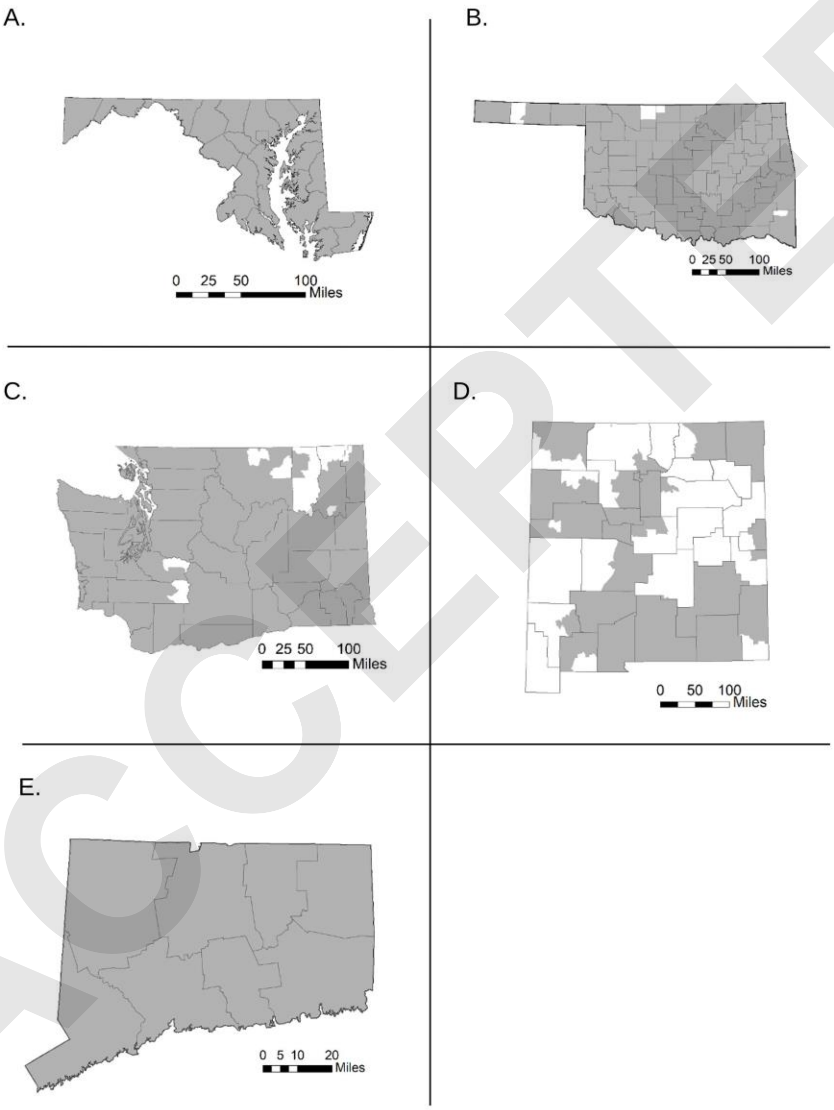

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CNTR COALITION FOR NATIONAL TRAUMA RESEARCH

Access to Trauma Center Care : A Statewide System-Based Approach

METHODS

Prehospital deaths in five states were analyzed via a trauma system model including GEMS, HEMS and trauma center locations and incorporating GIS and traffic and census block data to determine population access to care and ideal locations for level I-II trauma centers

RESULTS

Of 23 million residents in the five states studied, 87% had access to level I-II centers and 96% to level I-V centers within one hour. Optimized addition of level I-II centers could improve access to high level trauma care to 92%.

CONCLUSION

While there is nearly universal access to level I-V trauma care within an hour, gaps exist in the provision of level I-II care for the most severely injured. A robust approach highlights need for national trauma care system.

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