A novel approach to optimal placement of new trauma centers within an existing trauma system using geospatial mapping

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BACKGROUND: Trauma system expansion is a complex process often governed by financial and health care system imperatives. We sought to propose a new, informed approach to trauma system expansion through the use of geospatial mapping. We hypothesized that geospatial mapping set to specific parameters could effectively identify optimal placement of new trauma centers (TC) within an existing trauma system.

METHODS: We used Pennsylvania Trauma Systems Foundation registry data of adult (age, ≥ 15 years) trauma for calendar years 2003 to 2015 (n = 408,432), hospital demographics, road networks, and US Census data files. We included TCs and zip codes outside of Pennsylvania to account for edge effects with trauma cases aggregated to the zip code centroid of residence. Our model assumptions included existing Pennsylvania Trauma Systems Foundation Level I and II TCs, a maximum travel time of 60 minutes to the TC, capacity based on mean statewide ratios of trauma cases per hospital bed size, Injury Severity Score, candidate hospitals with 200 or more licensed beds and 30 minutes or longer or 15 minutes or longer from an existing TC in nonurban/urban areas, respectively. We used the Network Analyst Location-Allocation function in ArcGIS Desktop to generate spatial models.

RESULTS: Of the 130 candidate sites, only 14 met the bed size and travel time criteria from an existing TC. Approximately 70% of zip codes and 91% of cases were within 60 minutes of an existing TC. Adding one to six new optimally paced TCs increased to a maximum of 82% of zip codes and 96% of cases within 60 minutes of an existing TC. Changes to model assumptions had an impact on which candidate sites were selected.

CONCLUSION: Intelligent trauma system design should include an objective process like geospatial to determine the optimum locations for new TCs within existing trauma networks. (*J Trauma Acute Care Surg.* 2017;83: 705–710. Copyright © 2017 Wolters Kluwer Health, Inc. All rights reserved.)

LEVEL OF EVIDENCE: Epidemiological study, level III.

KEY WORDS: Trauma; trauma center; geospatial mapping; geospatial analysis.

After the establishment of the first statewide trauma system in Illinois in the early 1970s,[1,2] and previous regionalized emergency service networks in Maryland[3] and Florida,[4] it became apparent that organized trauma systems could significantly improve outcomes in those afflicted by traumatic injury.[3–7] Although the association between established trauma systems and patient outcomes continues to be well affirmed in the literature, new concerns, particularly pertaining to the unregulated growth of trauma centers (TCs) within existing trauma networks have moved to the forefront—especially in regions governed by state trauma accrediting bodies. Although the "more is better" maxim may hold true in many situations, the potential repercussions of saturating an operational trauma network with additional centers remains unknown. In particular, it is unclear whether the case volume redistribution that would invariably coincide with the establishment of additional TCs would compromise patient outcomes by diluting individual TC patient exposure. Although the literature surrounding the impact of case volume on trauma patient outcomes is conflicting,[8–26] a recent study by Brown et al.[8] analyzing the National Trauma Data Bank registry from 2000 to 2012 found every 1% decrease in case volume to be associated with a twofold decreased odds ratio for patient survival. Taking this association into consideration, it is likely the unregulated growth of additional TCs within a trauma system could lead to untoward consequences.

In an effort to address the issue of unregulated trauma system growth, the purpose of this investigation is to propose a new, informed approach to the expansion of existing trauma networks using geospatial mapping. Although a multitude of previous research has focused on optimizing the care of trauma patients, few studies have sought to optimize *access* to care for these individuals through strategic trauma system development. We sought to identify optimal resource placement based on a number of key factors to determine whether geospatial mapping could inform health policy at a statewide level by identifying tactical locations for new TCs within Pennsylvania. In addition, we sought to provide preliminary insight into the global impact of strategically placed centers on mean annual case volume throughout the state. We hypothesized that geospatial mapping set to specific parameters could effectively identify optimum

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placement of new TCs within our existing trauma system, and that these additional centers would have minimal impact on the mean annual institutional case volume throughout the statewide trauma network.

METHODS

We queried the Pennsylvania Trauma Outcome Study (PTOS) data set of the Pennsylvania Trauma Systems Foundation (PTSF) for all adult (age, ≥ 15 years) trauma for calendar years 2003 to 2015. PTOS is a statewide trauma registry which collects data on all patients treated at state-accredited TCs that meet at least one of the following criteria: intensive care unit/step-down unit admission, hospital stay longer than 48 hours/hospital stay 36 hours to 48 hours with an Injury Severity Score (ISS) of 9 or higher, transfer in/transfer out, or trauma death. Trauma patients were aggregated to the zip code of residence as a proxy for location of injury similar to methods used in other geospatial studies involving trauma access and outcomes.[27–35] For each case, we applied the Trauma Mortality Predication Model (TMPM) and calculated the TMPM score, based on the ICD9 code, which is the probability of death.[36,37] TMPM score and ISS were tabulated by zip code of residence, treating facility and modeled treating facility. TMPM better predicts mortality compared with ISS, particularly when injuries are recorded in the ICD-9 lexicon.[36]

Hospital demographic files were downloaded from the Pennsylvania Department of Health website and included data points, such as address for geocoding, licensed bed size, and hospital type.[38] A road network consisting of major roads and highways along with speed limits for calculation of travel times was constructed using data sets from PA and all surrounding states within a 60-mile radius of the boundary from respective state department of transportation geospatial files. We extracted basic census demographics and TIGER zip code tabulation areas from the US Census Bureau. To account for edge effects outside the state, we included all zip codes and TCs within a buffer radius of 60 miles to account for the fact that in border areas, patients will be treated at the nearest facility. To further restrict zip codes to those most likely to be served by a PA TC, we calculated the number of trauma cases per 1,000 population. Zip codes were included if they were within the 60 mile radius of PA boundaries, the number of trauma per 1,000 population

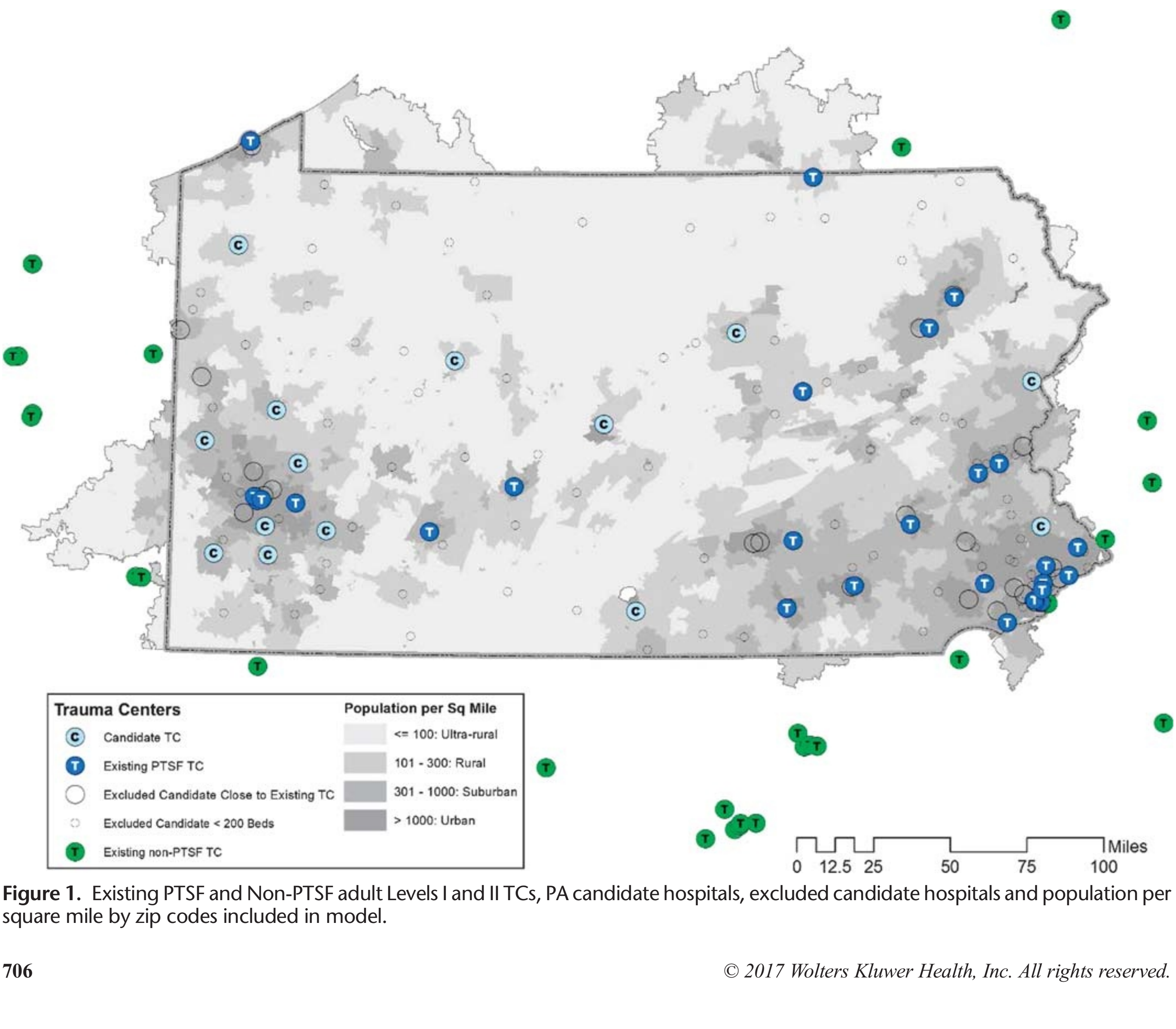

Figure 1. Existing PTSF and Non-PTSF adult Levels I and II TCs, PA candidate hospitals, excluded candidate hospitals and population per square mile by zip codes included in model.

was 0.5 or greater and also included to create a contiguous study area if there were gap zip code areas. Patients with PO Box zip codes were included in the zip code area in which the PO box is assigned.

The goal of our model was to identify new Level II or higher adult TC sites given the existing PA trauma network. A Level II or higher center would require significantly more resources providing care as opposed to lower-level centers that transfer many cases to Level I or II centers. TCs in PA were considered existing sites if they currently were a Level I or II adult center and if they were a current Level III or IV center, they were entered into the candidate TC pool if they met our other hospital selection criteria. To be considered a candidate hospital, the facility must be a general hospital, have 200 or more licensed beds and 30 minutes or longer or 15 minutes or longer from an existing TC in nonurban or metro-Philadelphia/Pittsburgh areas, respectively. The distance to the nearest TC included PA and surrounding state TCs (surrounding state TCs were extracted from the 2015 database of the American Trauma Society Trauma Information Exchange Program, Falls Church, VA). We selected 200 or more licensed beds as a cutoff criterion, with the assumption that a critical mass was necessary to provide sufficient resourcing of a Level I or II designation.

To generate the geospatial model where new TC placement would be optimized, we used the Network Analyst Location-Allocation function in ArcGIS Desktop 10.4 (ESRI, Redlands, CA) and coded this modeling to be managed using Python 2.7 (Python Software Foundation, https://www.python.org) using the ArcPy extension. The Python algorithm was set up to loop through the model incrementing the number of new TCs selected from one to six new sites from the 14 candidate sites given the existing 27 TCs which were set to required sites in the model. Additional model assumptions entered in the Network Analyst variables included a maximum travel time of 60 minutes from the centroid of the zip code to the existing or candidate TC and capacity of the hospital based on median statewide ratios of trauma cases per hospital bed size. To calculate this ratio, we determined the mean number of annual trauma cases for all existing TCs during the study timeframe and divided by the number of licensed beds in that hospital. The median (Q1–Q3) of this ratio of all existing TCs was used in the model for site capacity of required and candidate TC sites by multiplying by the licensed bed size of the hospital. We also used Stata 14.2 (Stata Corp., College Station, TX) to manage/transform data and all statistical analyses and R 3.3.1 (R Foundation for Statistical Computing, Vienna, Austria) for data preparation and geocoding. After models were created, we calculated some basic descriptive statistics for zip codes and determined the impacts on the zip codes and trauma cases within a 60-minute travel time and adult trauma volume in existing and new sites.

RESULTS

A total of 38 Levels I to IV TCs were identified within the PTSF database across the 13-year study period, providing data on 408,432 adult trauma cases (age ≥ 15). Twenty-three of these sites submitted data to the trauma registry for all 13 years, and the remaining 15 sites provided data for portions of the study period, as they entered/exited PTSF trauma designation. Based on mean annual trauma volume and licensed hospital bed data at these centers, a median (Q1–Q3) hospital capacity ratio of 2.1 (1.7-2.4) was calculated and inputted into our model as a measure of candidate site capacity.

Within the Commonwealth of Pennsylvania, 157 hospitals were classified as general hospitals in the department of health data set. Of these, 27 (17.2%) were designated adult PTSF Level I or II TCs. Of the remaining 130 candidate general hospitals, 37 were 200 beds or more and of those, only 14 remained as candidate facilities that were 30 minutes or longer or 15 minutes or longer from an existing TC in nonurban or metro-Philadelphia/Pittsburgh areas, respectively (see Fig. 1). There were 1,960 zip code areas included in the study with 1,782 (90.9%) coming from Pennsylvania and the remaining from the six surrounding states. These zip codes contained 378,843 or 92.8% of the 408,432 adult cases with a median (Q1–Q3) of 60 cases (17–203.5) per zip code area during the 2003 to 2015 timeframe. The median (Q1–Q3) annual trauma cases per 1,000 adult population per zip code was 2.8 (1.9–3.7) and the median (Q1–Q3) TMPM probability of death and ISS was 0.020 (0.016TMPM0.025) and 9 (9–10), respectively. Of zip codes, 62.3% representing 86.2% of trauma cases were less than 60 minutes travel time to an existing TC. With the existing trauma network of 27 sites, 70.0% of zip code areas were within 60 minutes of the nearest TC representing 91.6% of all trauma cases. Adding up to six new sites increased the percentage of zip codes within 60 minutes of the nearest TC to 81.3% (Fig. 2) and increased the percentage of trauma cases within 60 minutes of the nearest TC to 96.2%.

Figure 3 shows a map of model results with the new TCs sized and labeled with the number of times each was selected in the six models. As the number of new TC sites increased, three of the 14 candidate sites were consistently selected in the one to three sites added models, but with the fourth to sixth sites added, different sites were selected in these later stages. All three of the new TCs that were most consistently selected in four, five, and six of the models are located in regions of the state where there are no TCs, and although existing trauma cases in these areas

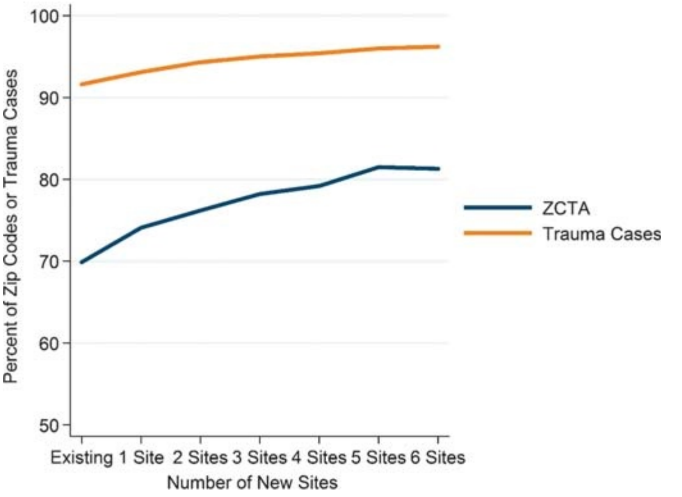

Figure 2. Percent of zip codes by existing trauma network and number of new sites within 60 minutes travel time to the nearest TC.

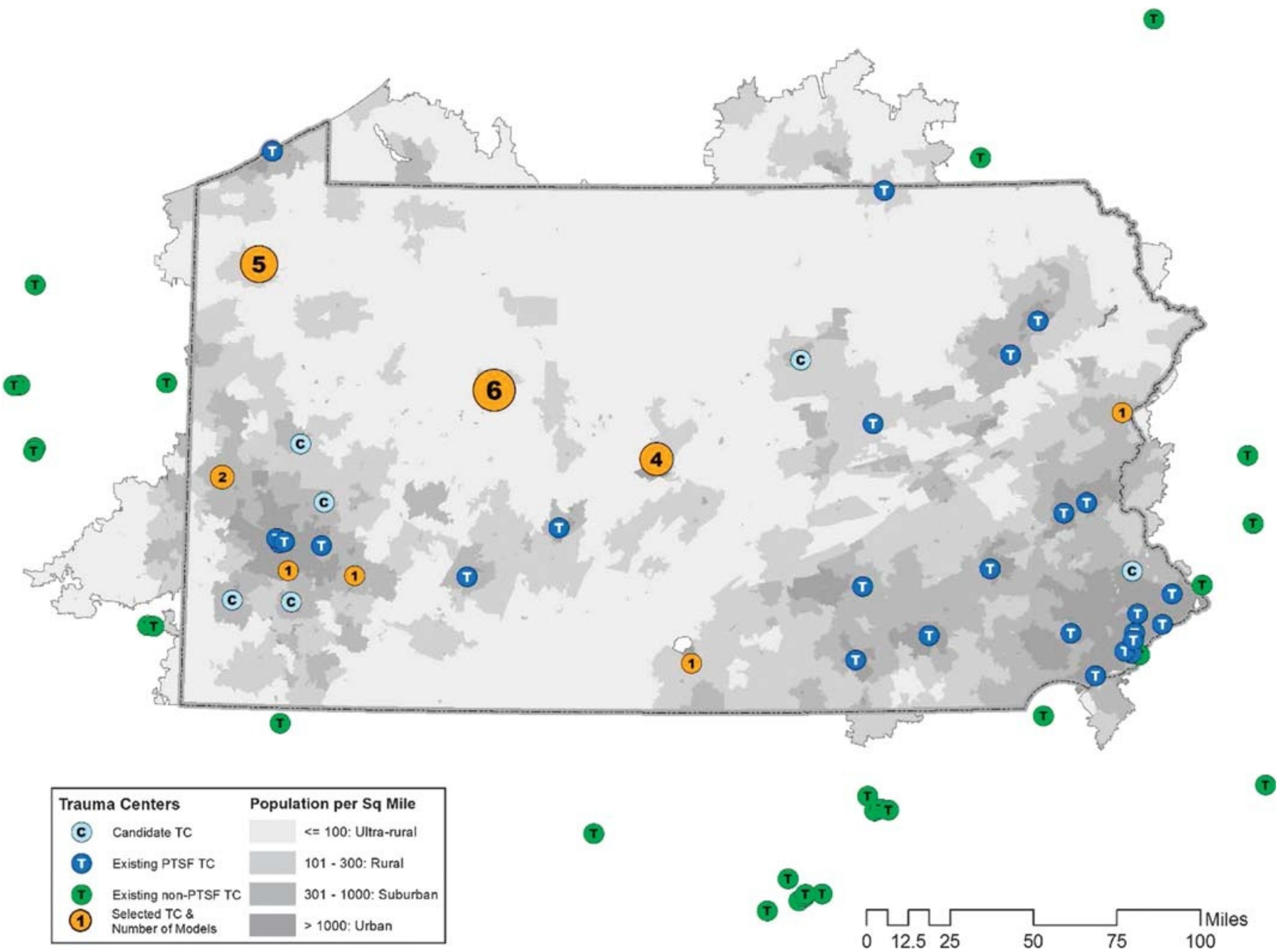

Figure 3. Map of selected new TCs labeled with number of models where the center was selected, existing PTSF and non-PTSF adult Levels I and II TCs, PA candidate hospitals and population per square mile by zip codes.

would experience long travel times or air transport, these new sites would optimize travel time with the model parameters of 60 minutes of ground transport.

The median (Q1–Q3) existing 13-year mean annual adult trauma volume for the TCs was 1,033 (751–1,232) which changed as additional sites were added to the trauma network. Projected median (Q1–Q3) annual adult trauma case volume ranged from 950 (642–1,175) to 772 (619–1,121) when one to six sites were added, respectively (Fig. 4), representing an overall per TC drop in adult trauma volumes as new sites are added to the existing trauma network. Looking only at the new sites added, the annual adult trauma volume ranged from 450 with only one new site to a median (Q1–Q3) of 580 (434–703) with six new sites. In addition, the new sites provided coverage/access within the model parameter of 60-minute ground travel time to 91, 144, 196, 236, 312, and 436 zip code areas with one, two, three, four, five, and six new sites, respectively.

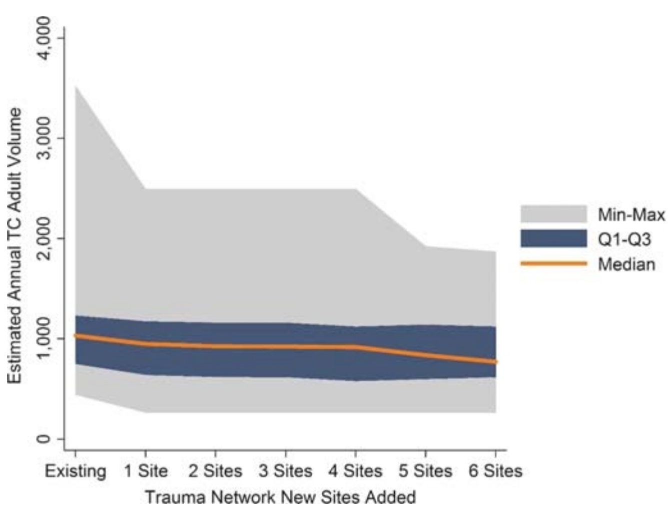

Figure 4. Estimated impact on annual TC adult trauma volume by number of new sites added.

DISCUSSION

The results of this investigation suggest that geospatial mapping set to specific parameters can effectively identify optimal locations for future TCs within an existing trauma network. In addition, strategically placing these new centers was found to have minimal impact on mean annual institutional trauma volumes throughout the trauma system. Viewing these results in composite, our hypotheses pertaining to the usefulness of geospatial mapping in identifying new trauma sites, and the impact of these strategically placed centers on mean annual institutional case volume are supported.

Because organized trauma systems are tasked with streamlining the prehospital and in-hospital management of individuals suffering traumatic injury to ensure the best possible outcomes, analyzing every facet of proposed adaptations—and the repercussions of such changes—to existing trauma networks is critical before their implementation. Although the impact of oversaturating an existing trauma system with multiple new TCs is unknown and beyond the scope of this study, previous research into uninformed trauma system expansion has yielded alarming results—particularly pertaining to the case volume redistribution effect new centers have on existing sites. As reported by Tepas et al.[24] in 2014, the activation of a Level II TC with no prior needs assessment in a stable region resulted in a 9.4% decrease in trauma volume to their Level I center. In addition, the establishment of another regional TC led to a doubling in societal cost due to personnel needs. Similarly, work by Carr et al.[10] analyzing the impact of additional Level II and III TCs in a regional trauma system experienced an 11.9% volume reduction at their Level I center. Although no immediate impact on worsening outcomes was observed, it is possible over time that this decrease in volume could compromise patient care. It is the opinion of the authors that these works beckon for a new, informed approach to trauma network expansion to mitigate some of the potential untoward consequences detailed in these referenced works.

Rather than operating under the assumption that every viable hospital across the United States should be accredited as a TC, we feel strategic expansion guided by geospatial mapping as detailed in this work should move to the forefront of future trauma system foundation policy pursuits. As demonstrated through the results of this investigation, geospatial mapping is an indispensable technology that can be adapted at multiple levels to fit the tailored specifications of any trauma system across the United States. By analyzing previous levels of trauma volume throughout the Commonwealth of Pennsylvania, and identifying underserved regions that would benefit from the addition of Level II or higher TCs through various models, we were able to identify the most strategic candidate hospital sites for future centers. Although not every potential candidate site was identified in every model, having the ability to consider multiple models and identify which sites are recurrently chosen to be designated as TCs allows us to make informed, objective decisions regarding trauma system expansion.

This study is not without its limitations. Because the nature of this investigation was retrospective, and trauma registry data from the PTSF was the sole source of injury data used in this analysis, trauma volume was invariably geographically biased to locations close to existing TCs. In addition, because our analysis encompassed a trauma-specific population managed at PTSF-accredited TCs, our mapping was unable to account for undertriaged patients who were treated at non-TCs. Because this study focused on identifying optimal locations for new TCs within an existing framework, neither the potential impact of further reinforcing existing centers through additional resource allocation nor factors pertaining to the quality of care at individual facilities throughout Pennsylvania's trauma network were considered or analyzed. In terms of transport time to TCs, our modeling only accounted for ground transportation. Although some trauma patients would arrive to TCs via air, because the majority of patients arrive through ground transportation, we felt as though this would be the most useful mode to include in our geospatial modeling. Finally, because the PTOS data set only includes information on patients' home zip codes, trauma cases were aggregated to the centroid of the patient residence, not where the incident occurred, which caused allocation of trauma cases within the zip code to one TC. Aggregating trauma cases to zip code centroids does not account for variations in quality of passable roads/road network distances from actual injury sites, which is a notable limitation of this work.

CONCLUSION

Strategic trauma system expansion may benefit from needs assessment protocols and objective methodology to identify optimal locations for new TCs within existing frameworks. Although no single strategy is likely able to account for all the complex considerations involved in effective trauma system development, geospatial mapping methodology may be a means by which to guide informed decision-making. Intelligent trauma system design should consider including an objective process like geospatial mapping when modifying existing trauma networks.

AUTHORSHIP

M.A.H. participated in study design, data collection, data analysis, interpretation of data, article preparation. B.W.G. participated in study design, interpretation of data, article preparation, editorial oversight. A.D.C. participated in study design, interpretation of data, article preparation. T.M.O. participated in study design, interpretation of data, article preparation. E.H.B. participated in study design, interpretation of data, article preparation. F.B.R. participated in study design, interpretation of data, article preparation, editorial oversight.

DISCLOSURE

The authors report no proprietary or commercial interest in any product mentioned or concept discussed in this article.
The authors declare no conflicts of interest.

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