Undertriage in trauma: Does an organized trauma network capture the major trauma victim? A statewide analysis

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BACKGROUND: Proper triage of critically injured trauma patients to accredited trauma centers (TCs) is essential for survival and patient outcomes. We sought to determine the percentage of patients meeting trauma criteria who received care at non-TCs (NTCs) within the statewide trauma system that exists in the state of Pennsylvania. We hypothesized that a substantial proportion of the trauma population would be undertriaged to NTCs with undertriage rates (UTR) decreasing with increasing severity of injury.

METHODS: All adult (age ≥15) hospital admissions meeting trauma criteria (ICD-9, 800–959; Injury Severity Score [ISS], > 9 or > 15) from 2003 to 2015 were extracted from the Pennsylvania Health Care Cost Containment Council (PHC4) database, and compared with the corresponding trauma population within the Pennsylvania Trauma Systems Foundation (PTSF) registry. PHC4 contains all hospital admissions within PA while PTSF collects data on all trauma cases managed at designated TCs (Level I-IV). The percentage of patients meeting trauma criteria who are undertriaged to NTCs was determined and Network Analyst Location-Allocation function in ArcGIS Desktop was used to generate geospatial representations of undertriage based on ISSs throughout the state.

RESULTS: For ISS > 9, 173,022 cases were identified from 2003 to 2015 in PTSF, while 255,263 cases meeting trauma criteria were found in the PHC4 database over the same timeframe suggesting UTR of 32.2%. For ISS > 15, UTR was determined to be 33.6%. Visual geospatial analysis suggests regions with limited access to TCs comprise the highest proportion of undertriaged trauma patients.

CONCLUSION: Despite the existence of a statewide trauma framework for over 30 years, approximately, a third of severely injured trauma patients are managed at hospitals outside of the trauma system in PA. Intelligent trauma system design should include an objective process like geospatial mapping rather than the current system which is driven by competitive models of financial and health care system imperatives. (*J Trauma Acute Care Surg.* 2018;84: 497–504. Copyright © 2017 Wolters Kluwer Health, Inc. All rights reserved.)

LEVEL OF EVIDENCE: Epidemiological study, level III; Therapeutic, level IV.

KEY WORDS: Undertriage; trauma center; nontrauma center; geospatial mapping; geospatial analysis.

The value of trauma systems and centers is well known. When injured patients are triaged appropriately to trauma centers (TCs), better patient outcomes are the result. The National Study on Costs and Outcomes of Trauma study reported a 25% reduction in mortality when patients are treated appropriately at accredited TCs.[1] Unfortunately, not all trauma patients receive the appropriate level of care—some patients with injuries warranting specialized treatment are undertriaged to non-TCs (NTCs).

A retrospective study including all ED and hospital admissions determined that 35% of trauma patients were undertriaged in the state of California over a 5-year period.[2] Xiang et al.[3,4] reported a similar rate of 34% of major trauma patients that were undertriaged nationally in the ED alone over the course of a single year with elderly patients aged 65 years or older having a significantly higher risk of undertriage. A national retrospective analysis of adult ED trauma deaths in 2010 reported 44.5% of trauma deaths were undertriaged to NTCs.[5] In addition, the investigation also highlighted the disparity in access to TCs with 35.6% of ED trauma deaths in urban locations undertriaged to NTCs while rural areas had disproportionately higher rate of 86.4% of ED deaths related to undertriage.[5] Given the inequality, it is not surprising to learn that greater than 90% of Level I and Level II TCs are located in metropolitan areas.[6] The prevalence of higher level TCs in these areas can be justified by the higher trauma volume and greater injury severity encountered in urban locations.[7] However, trauma is not confined to solely urban populations, and it is important to ensure that rural, under-served areas are adequately equipped to handle these situations as well.

The purpose of this investigation is to determine the percentage of patients that meet the trauma criteria but who receive care at NTCs in the state of Pennsylvania. The trauma system in Pennsylvania has been in existence for over three decades and is unique in its employment of an independent, nonprofit organization (Pennsylvania Trauma Systems Foundation [PTSF]) to supervise the accreditation of TCs in the state.[8] Despite the existence of a mature statewide system, given the rates of undertriage across the country, we hypothesized that a significant proportion of the total trauma population in the state of Pennsylvania would be undertriaged to NTCs with rates of undertriage diminishing with increasing severity of injury.

METHODS

A retrospective analysis from 2003 to 2015 of all adult (age, ≥15 years) hospital admissions meeting trauma criteria (see below) was conducted. Two databases were utilized in this study: the PTSF and Pennsylvania Health Care Cost Containment Council (PHC4). The PTSF is a statewide trauma registry with all documented trauma cases treated at accredited TCs that meet at least one of the following inclusion criteria: death secondary to trauma, ICU/step-down unit admissions, length of stay longer than 48 hours or between 36 hours and 48 hours with Injury Severity Score (ISS) ≥ 9 and admitted transfers in/out of the hospital. During the study interval, 38 TCs submitted injury data to the PTSF registry. The PHC4 is an administrative data set that contains all inpatient admissions (n = 185 facilities) within the state of Pennsylvania and essentially encompasses all trauma patients treated at TCs and NTCs. It should be noted that while PHC4 collects over 70 data fields, only a few fields were pertinent to this study: age, sex, unadjusted mortality rate and ICD-9 codes.

To identify trauma admissions from all admissions in the PHC4 database, patients with ICD-9 codes ranging from 800

Submitted: September 1, 2017, Revised: November 30, 2017, Accepted: December 14, 2017, Published online: December 28, 2017.
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This study was presented as a QuickShot presentation at the 76th Annual Meeting of the American Association for the Surgery of Trauma and Clinical Congress of Acute Care Surgery from September 13–16, 2017 in Baltimore, Maryland.

DOI: 10.1097/TA.0000000000001781

to 959 were selected. A prediction model (ICISS)[9] was applied to the ICD-9 scores to generate an analogous ISS value using an algorithm operationalized for Stata statistical software by Clark et al.[10] Patients with calculated ISS greater than 9 and/or greater than 15 were included in the analysis. By imposing a specific trauma criterion with particular ICD-9 codes on the PHC4 data set of all general hospital admissions, we hoped to better differentiate trauma cases from other general hospital admissions and provide a representative population perspective of trauma within the state. To make a homologous comparison between the two data sets, the PTSF data set was restricted to patients with ISS greater than 9 or ISS greater than 15.

Trauma patients in both data sets 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.[11–19] We extracted basic census demographics and TIGER zip code tabulation areas from the US Census Bureau.[20] Hospital demographic files were downloaded from the PA Department of Health website and included data points, such as address for geocoding, licensed bed size, and hospital type.[21] We included TCs outside of PA as a point of reference in our geospatial mapping particularly in border regions where PA residents may be cared for in TCs outside of PA by using the 2015 Trauma Information Exchange Program database from the American Trauma Society. To account for boundary effects where PA TCs may be providing significant trauma care for border regions outside the state or non-PA TCs providing care for border regions inside the state, we developed some quantitative and qualitative decision criteria for inclusion of zip codes outside the state. The PHC4 database was used to calculate the number of trauma cases per 1,000 population in each zip code inside the state and within a 60 mile radius of the state boundary. In zip codes outside PA where the number of trauma cases per 1,000 population was 1 or greater, we selected these zip codes and then added zip codes in any areas where geographic "holes" (a zip code with trauma/1,000 < 1 completely surrounded by zip codes with trauma/1,000 ≥ 1) occurred to produce a contiguous study area. In areas outside the state, we also eliminated zip codes with trauma/1,000 ≥ 1 where there was only 1 zip code with no adjoining zip codes selected. This was done to insure that outlier zip codes, particularly in rural areas with low trauma volumes, were not included. Patients with PO Box zip codes were included in the zip code area in which the PO Box is assigned.

Within each zip code, we calculated the undertriage rates (UTR) as the proportion of PHC4 cases that were not represented in the PTSF database for both cases with ISS > 9 and ISS > 15 as follows with PHC4 and PTSF representing all cases with ISS > 9 or >15 respectively:

$$UTR_{ISS>9} = \frac{(PHC4_{ISS>9} - PTSF_{ISS>9})}{PHC4_{ISS>9}}$$

$$UTR_{ISS>15} = \frac{(PHC4_{ISS>15} - PTSF_{ISS>15})}{PHC4_{ISS>15}}$$

We then calculated an empirical Bayesian smoothed rate for each zip code area which borrows information from neighboring zip codes in cases where there are small numbers of trauma cases. This was done to minimize unstable UTR in areas with small number of cases and provide better regional assessments of undertriage across the state. Each UTR per zip code was linked to a geospatial file and mapped along with hospital locations. To classify the color scheme for the mapping of the UTR, we used a box map which is similar to the classification in a standard box plot. Divisions are set at the four quartiles, and then outlier ranges on either end of the first and fourth quartile are calculated to be 1.5 times the interquartile range. This provides a visual representation that can be a "hot-spot" identifier for zip code areas with UTR outliers (high or low) relative to other zip code areas in the rest of the study area. In particular, the "hot-spot" areas subsequently referenced throughout the discussion refer to the outliers at the high end of the distribution. To investigate clustering of UTRs in communities with varying hospital service types, we identified zip code areas containing and immediately surrounding every hospital and then classified them according to various levels depending on the hospital types serving them (no hospital; NTC < 200 beds; NTC ≥ 200 beds; NTC ≥ 200 beds and NTC < 200 beds; TC ≥ 200 beds; TC ≥ 200 beds and NTC < 200 beds; TC ≥ 200 beds and NTC ≥ 200 beds; TC ≥ 200 beds, NTC ≥ 200 beds and NTC < 200 beds). A total number of 200 beds was chosen as the cutoff designation between small versus large NTCs on the assumption that a critical mass (medical staff, operating room availability, surgical specializations) was necessary to provide sufficient resourcing of a Level I or II TC designation. The smallest level II TCs in the state of PA have 245 and 254 licensed beds; therefore, imposing a restriction less than 200 for large NTCs seemed unrealistic when drawing comparisons between "large" NTCs and existing TCs. Linear models were used to assess the association between the smoothed UTRs and zip code area hospital service types with p values less than 0.05 were considered significant. ArcGIS 10.5.1 was used for spatial mapping, GeoDa 1.8.16.4 was used for geospatial analyses and calculation of the empirical Bayesian rates and Stata 15.0 was used for data preparation and statistical analyses. This study was reviewed and approved by the Lancaster General/Penn Medicine Institutional Review Board.

RESULTS

The study area included 1,968 zip code areas with 1,797 within PA and 171 in surrounding states (including New York, New Jersey, Delaware, Maryland, West Virginia, and Ohio). There were 255,263 total hospital admissions between 2003 and 2015 that met trauma criteria (ICD-9, 800–959; ISS, > 9) within the PHC4 database, while the PTSF database had 173,022 trauma cases with ISS greater than 9 during that interval for an overall statewide UTR ISS greater than 9 of 32.2%. There were 149,772 total hospital admissions between 2003 and 2015 that met trauma criteria (ICD-9, 800–959; ISS, > 15) within the PHC4 database while the PTSF database had 99,449 trauma cases with ISS greater than 15 during that interval for an overall statewide UTR ISS greater than 15 of 33.6%. Median (Q1–Q3) UTRs by zip code for ISS greater than 9 and ISS greater than 15 were 31.1% (23.4–38.7%) and 33.4% (26.3–39.7%) respectively (Table 1). A breakdown of patient demographics, injury severity, and unadjusted mortality rates between the

TABLE 1. UTR Based on Injury Severity as Determined by Zip Codes

	ISS > 9		ISS > 15	
	PHC4	PTSF	PHC4	PTSF
Total no. trauma cases	255,263	173,022	149,772	99,449
Median (Q1–Q3) total trauma cases per zip code	42 (12–146.5)	29 (8–97.5)	26 (7–85.5)	17 (5–57)
Median (Q1–Q3) trauma cases per 1,000 population per year per zip code	1.9 (1.4–2.5)	1.3 (0.9–1.8)	1.1 (0.8–1.5)	0.7 (0.5–1.0)
Median (Q1–Q3) smoothed UTR per zip code	31.1% (23.4–38.7%)		33.4% (26.3–39.7%)	

two databases is presented in Table 2. Of note, there was a difference in unadjusted mortality rates between the two data sets (Table 2). While the PTSF database reported greater mortality, it should be noted that this database also had a higher percentage of ISS of 26 or higher.

The UTRs were mapped to generate a geospatial representation that demonstrated the distribution and clustering of undertriage in the state of Pennsylvania (Figs. 1 and 2). Also included on the map are locations of PA TCs, non-PA TCs, and NTCs in PA. The NTCs are further subdivided based on bed size with smaller circles representing less than 200 beds and larger circles indicating the presence of an NTC with greater than 200-bed capacity. We noted that there are a few undertriage outlier areas clustered around some NTCs in regions of the state where there are no TCs in the immediate vicinity for both the ISS greater than 9 and ISS greater than 15 maps.

Figure 3 classifies UTR in zip code areas immediately surrounding a particular type of facility (TC, NTC < 200, NTC ≥ 200), a combination of facilities or in areas with no care centers present in its immediate vicinity. Approximately, 44% of the zip codes across the state of PA are not served by any hospitals and are associated with a UTR of approximately 30%.

TABLE 2. Study Population Demographics

	PTSF (ISS > 9)	PHC4 (ISS > 9)
Hospitals	38	185
Study population (n)	173,022	255,263
Sex		
Female	60,497 (35.0%)	106,611 (41.8%)
Male	112,501 (65.0%)	148,300 (58.1%)
Age, y		
15–24	29,305 (16.9%)	31,858 (12.5%)
25–34	20,394 (11.8%)	23,839 (9.3%)
35–44	18,862 (10.9%)	23,310 (9.1%)
45–54	23,255 (13.4%)	30,102 (11.8%)
55–64	20,405 (11.8%)	28,864 (11.3%)
65–74	17,376 (10.0%)	28,211 (11.1%)
75–84	24,155 (14.0%)	46,019 (18.0%)
85+	19,240 (11.1%)	43,059 (16.9%)
Inhospital mortality*	16,555 (9.6%)	14,251 (5.6%)
ISS		
10—15	73,573 (42.5%)	105,491 (41.3%)
16—25	65,508 (37.9%)	115,168 (45.1%)
≥26	33,941 (19.6%)	34,604 (13.6%)

*Reported mortality rates are unadjusted.

Undertriage rates are highest in areas served by a combination of NTCs of varying sizes (39%) or solely by a larger NTC (38%). The lowest UTRs are observed in areas surrounding TCs (27%) or served by combination of TC and NTC less than 200 (26%). There is a statistically significant association between the smoothed UTR and zip code area hospital service type for both ISS greater than 9 and ISS greater than 15 UTRs ($p < 0.001$; $p < 0.001$).

DISCUSSION

Given the existence of a mature, state-wide trauma system in Pennsylvania for over 30 years, it is astonishing to note that over 30% of the moderately to severely injured (ISS > 9 and ISS > 15) trauma volume over the past 12 years was inappropriately triaged to NTCs. Previous research reported similar statistics nationally, with approximately one third of major trauma cases undertriaged in emergency departments across the United States.[3] Undertriage rate is unchanged across the spectrum of injury severity (33.6% for ISS > 15 vs. 32.2% for ISS > 9), which may be due to a disproportionate amount of severe trauma occurring in locales distant to TCs.

The geospatial maps (Figs. 1 and 2) suggest regions with limited access to TCs comprise the highest proportion of undertriaged trauma patients. There does not appear to be a significant difference in the overall pattern of undertriage across the state based on trauma severity when trauma cases with ISS greater than 9 were compared with ISS greater than 15. While this disagrees with the hypothesis of UTR diminishing with increasing severity of injury, it is important to note that undertriage continues to be a major concern across the spectrum of injury severity.

The positive impact of triage on the outcome of critical trauma patients has been well studied and widely reported throughout the literature.[1,22] There are multifactorial barriers to be addressed to improve the rates of undertriage. Given the considerable difference in UTR in urban versus rural settings, increasing access to accredited TCs in rural areas may prove to impact mortality.[5] In addition, there exists tremendous variation in the distribution of TCs among different states,[6] which may affect triage status of patients based on state of residency.

Further complicating access to appropriate level of care is the expectations of some major health care systems that their patients be treated solely in participating facilities, which can result in preferential undertriage to an affiliated NTC despite the existence of a TC in close proximity. The education level of health professionals and the accuracy of initial diagnosis may influence rates of undertriage as well. A study in France sought to determine

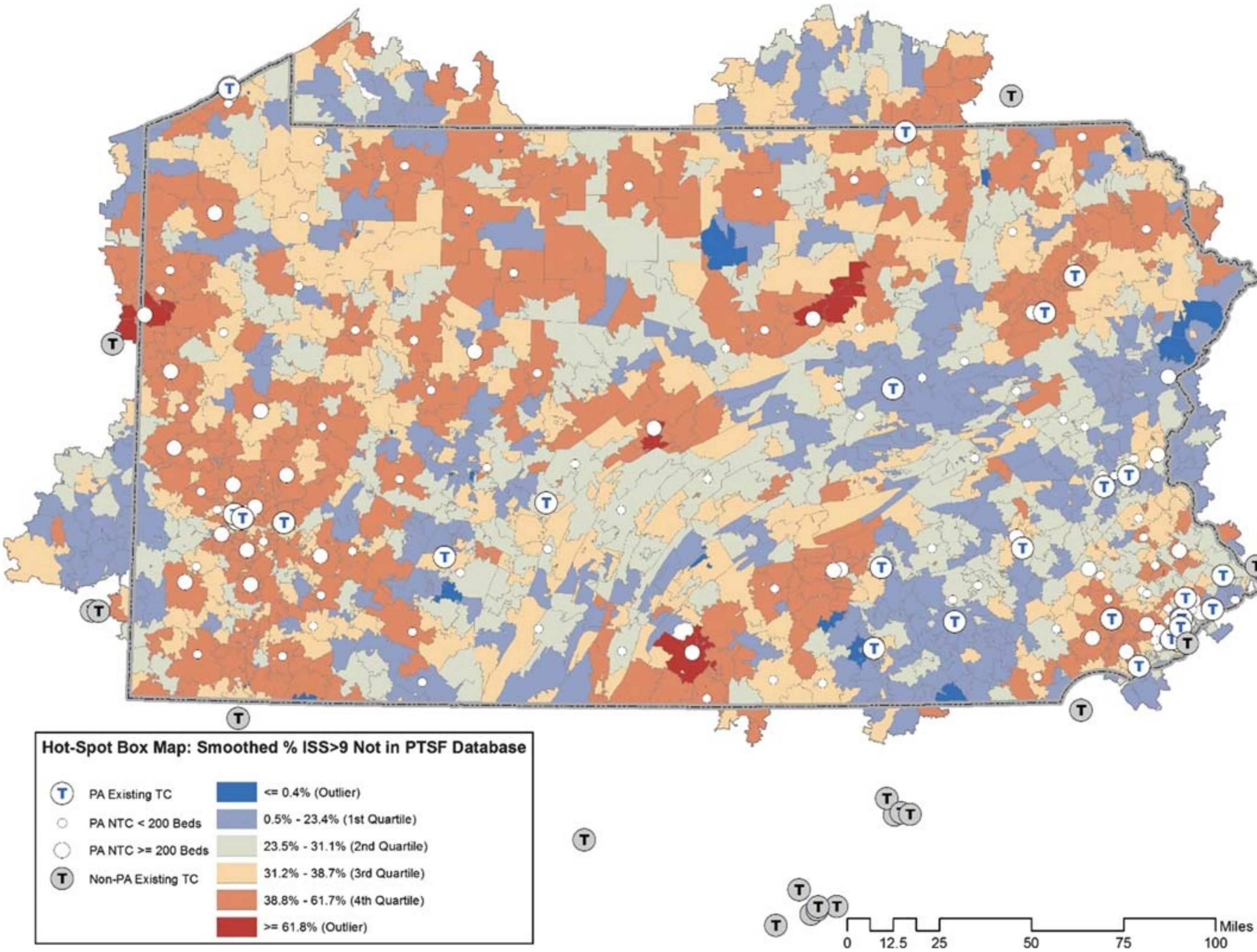


Figure 1. Box map of undertriage (smoothed % of trauma cases not in PTSF database) with ISS > 9 in Pennsylvania.

whether evaluation by a physician prior to arrival in the hospital would have an impact on rates of undertriage.[23] The investigation overwhelmingly demonstrated an increase in effective identification of patients with severe trauma and a significantly reduced risk of undertriage.[23] While it may not be feasible for a physician to assess and assign triage status at the scene of injury in our existing system, there are other modifications that can be enacted. For instance, the current system of TC accreditation is unfortunately driven more by the ambitions of individual hospitals rather than explicit need identified after a rigorous objective needs assessment.[24]

Figures 1 and 2 clearly demonstrate that the high outlier or "hot spot" zones (represented in dark red) are associated with an NTC suggesting that these facilities are providing care for patients who categorically require treatment at TCs. Figure 3 serves to further highlight this finding by demonstrating a significant increase in mean UTR in zip code areas surrounding high capacity NTC (≥200) when compared with UTR around TCs. In locations with dual TC and NTC of 200 or greater in close proximity, the UTR is higher than those in areas with solely a TC, suggesting that the presence of NTC with 200 or greater is responsible for siphoning a portion of the trauma volume from the TC, thereby contributing to the increase in observed UTR. These NTCs are essentially functioning as "defacto" TCs despite not being subject to the rigorous accreditation process of the PTSF. Interestingly, concurrent existence of TC and NTC < 200 results in lower rates of UTR than seen with TC and NTC of 200 or greater. While many factors likely contribute to this trend, one theory that could explain this phenomenon is that the presence of a small NTC in the vicinity of a major TC automatically precludes transport of any trauma to the small facility in favor of the bigger TC, thus decreasing rates of undertriage.

It also needs to be acknowledged that the existence of a TC does not eliminate UTR completely. There still appears to be a baseline level of undertriage in zip codes surrounding TCs that will likely persist no matter the measures introduced to address this issue. There are numerous factors likely contributing to this baseline UTR. There is an inherent problem in attempting to define small zip code catchment areas around hospitals, as zip codes can be adjacent to both areas with a sole TC and other areas with NTCs. In addition, other sources of bias that can influence UTR rates include regional variations in EMS

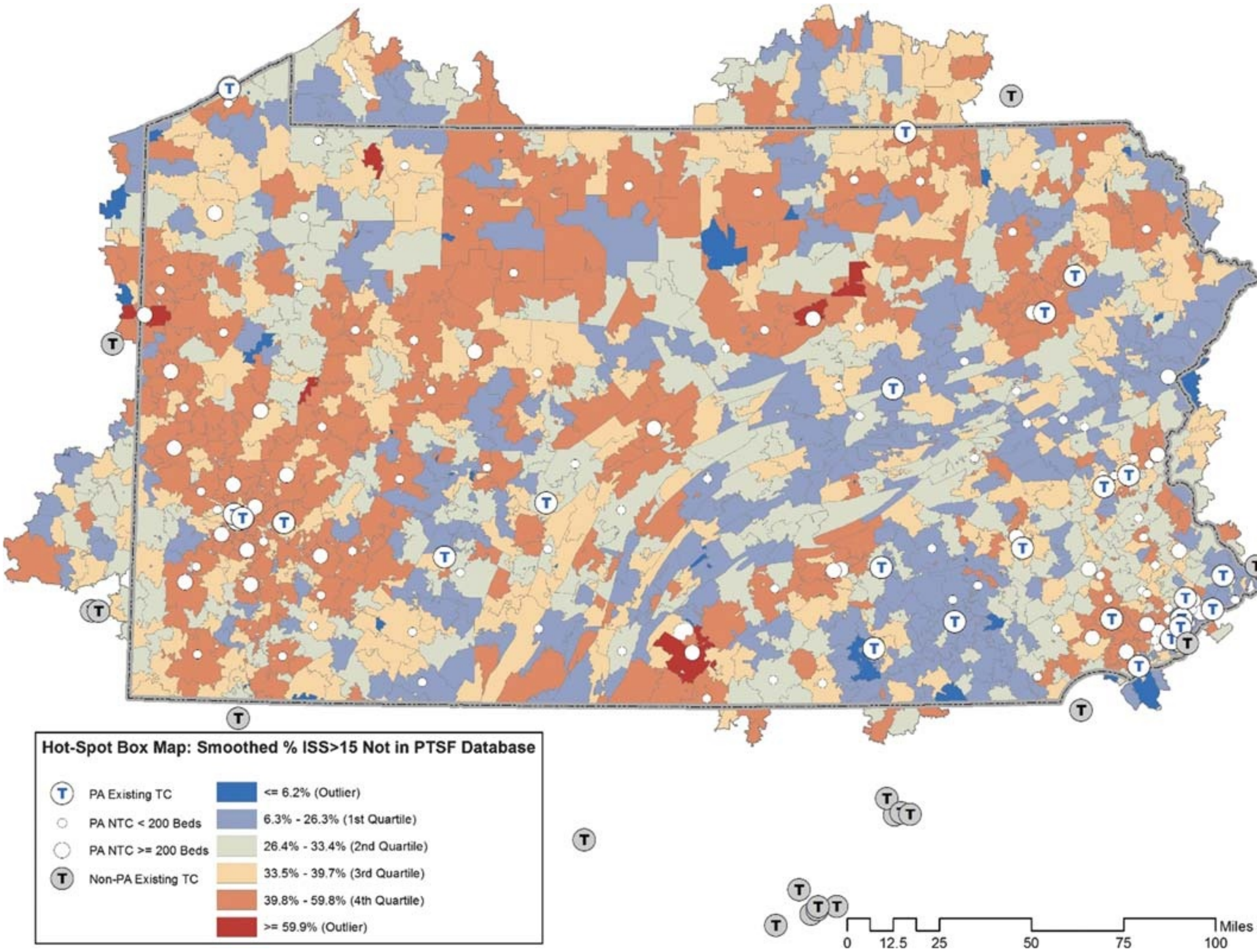
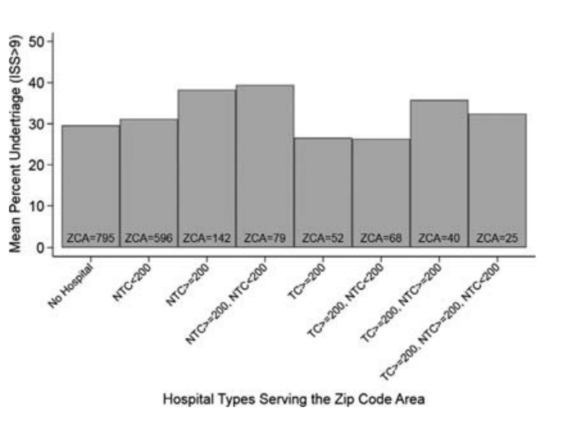


Figure 2. Box map of undertriage (smoothed % of trauma cases not in PTSF database) with ISS > 15 in Pennsylvania.

education and rules regarding patient transport to TCs vs. NTCs as well as misleading initial presentations of occult traumatic injuries as minor injuries such that NTC appears preferable over TC.

Figure 3 also demonstrates the overwhelming number of zip code areas that are not served by any hospitals. Figures 1 and 2 depict visual representations of these areas, which are not isolated to one geographic area but are scattered across the state. These pockets of underserved areas, especially "hot spot" regions associated with sentinel hospitals, could act as a guide in future trauma system development. New TCs should be strategically accredited to lower the disparity in access to appropriate level of care. An objective process, such as geospatial mapping, may prove to be a more effective approach to improving the trauma system network by identifying undertriage patterns within the state and subsequently guiding the placement of new TCs in consideration of the existing framework.[25]

It should be noted that there is a robust national effort underway in trauma care to translate advances in care of injured patients learned from recent military conflicts to the civilian sector. This effort, termed "zero preventable deaths," initiated by the National Academies of Sciences, Engineering, and Medicine and cosponsored by the American College of Surgeons Committee on Trauma, National Highway Traffic Safety Administration, US Department of Defense and the National Institutes of Health aims to introduce military advances in trauma care that



***Note**: ZCA refers to the number of zip code areas included in the analysis for each hospital type

Figure 3. UTR for zip code areas (ZCA) based on type of center.

have yet to breach civilian TCs.[26] The goal is to understand the differences in culture between the military and civilian domains and optimize the strengths of each to help alleviate the undertriage present in PA. One of the primary known differences is the military's autocratic, hierarchical organization that may be able to better identify best practices for eliminating preventable deaths. While Pennsylvania has a civilian state administrative oversight agency, additional measures are needed to resolve the issue of undertriage. One proposal would be to introduce legislation offering incentives to candidate NTCs located in under-served areas to provide them with essential resources and encourage them to pursue TC accreditation.

This study has its limitations. The trauma criteria imposed on the two data sets retrospectively may have caused the exclusion of trauma cases, which should have theoretically been included in the calculation of the trauma volume. The authors were also constrained by the nature of the data sets, which were both de-identified without any patient identifying information, making it impossible to link patients between data sets. In addition, there was limited data available in the PHC4 database, resulting in some error in the calculation of the UTRs. This was especially true when considering patients who were transferred out from PHC4 facilities—information on receiving facility was vague and did not specify the type of facility (TC vs. NTC). Therefore, patients who were initially sent to a NTC but were transferred to a TC for definitive care could have been included in the undertriage population. As there is currently no way to link the two data sets to identify transfer-in and -out patients, the lack of adjustment for transfers was considered a necessary evil in this analysis.

Another significant disadvantage is the utilization of ISS (calculated at discharge) as a triage criteria for TC admission, which was unavoidable given the few overlapping pre-hospital variables collected between the two data sets. Since ISS values were calculated from ICD-9 codes for the PHC4 data set, it was important to ascertain the accuracy of the algorithm used by calculating ISS values in the PTSF data set and comparing with actual ISS values. The correlation between actual and calculated ISS values was determined to be 0.75. However, correlation was deemed to not be the best measure of agreement. Instead, the Bland-Altman method was used, which is a statistical method used to determine level of agreement between measurements and plots the difference between the two measures versus the mean of the two measures.[27] On average, the calculated ISS is about four points higher than the actual ISS in the PTSF database. It should be noted that this pattern is not consistent across the ISS scale such that at lower ISS values (10–30), calculated ISS is higher than the actual ISS. Around ISS values of 40 to 50 to a maximum of 75, the calculated ISS is lower than the actual ISS. Given the lack of complete agreement between calculated and actual ISS values, the authors acknowledge some errors in calculation of ISS values from ICD-9 codes that may have misrepresented true UTRs across the state of PA.

In addition, though the main objective was to determine the rate of undertriage in the state of Pennsylvania alone, the nature of the investigation necessitated the inclusion of patients within a 60-mile radius of the state boundary. The reality is that trauma in border areas would be treated at the nearest facility irrespective of the state in which the trauma occurred making the adoption of rigid state boundaries impractical. Another limitation is the authors' inability to perform a thorough risk-adjusted mortality analysis to draw correlations between undertriage and mortality given the paucity of information in the PHC4 data set. While the authors' main focus was in determining the UTRs across the state, they acknowledge the importance of examining the consequences of undertriage, perhaps by correlating UTRs with patient outcomes, which is missing from the present analysis. The natural successive step to this initial analysis is to further explore the outcome of existing undertriage, especially pertaining to mortality given the differences in unadjusted mortality rates reported between the two databases. Future research should also be directed toward identifying patient and hospital characteristics associated with undertriage and developing solutions to address this issue in an objective manner. Trauma system development should prioritize increasing access to undertriage areas in "hot spot" areas by identifying the needs of candidate hospitals in those regions and assisting in the transition to TC accreditation where possible.

CONCLUSION

Despite the existence of a mature, state-wide trauma network for decades, approximately one third of patients in Pennsylvania meeting the trauma criteria are being managed at NTCs. The deficiencies inherent in this system need to be recognized and addressed so future expansion can help shape a network that is more responsive to its population.

AUTHORSHIP

M.A.H. participated in the study design, data collection, data analysis, interpretation of data, article preparation. S.J. participated in the study design, data analysis, article preparation, editorial oversight. B.W.G. participated in the study design, data collection, data analysis, and article preparation. A.D.C. participated in the study design, data analysis, editorial oversight. E.H.B. participated in the data interpretation and editorial oversight. J.A. participated in the data collection. D.V.N. participated in the article preparation. M.M. participated in the article preparation. F.B.R. participated in the study design, data interpretation, editorial oversight.

DISCLOSURE

The authors report no proprietary or commercial interest in any product mentioned or concept discussed in this article. This study was funded in part by a grant from the Louise von Hess Medical Research Institute.

REFERENCES

1. MacKenzie Ellen J, Rivara FP, Jurkovich GJ, Nathens AB, Frey KP, Egleston BL, Salkever DS, Scharfstein DO. A national evaluation of the effect of trauma-center care on mortality. *N Engl J Med*. 2006;354:366–378.
2. Staudenmayer K, Lin F, Mackersie R, Spain D, Hsia R. Variability in California Triage from 2005 to 2009: a population-based longitudinal study of severely injured patients. *J Trauma Acute Care Surg*. 2014;76(4):1041–1047.
3. Xiang H, Wheeler KK, Groner JI, Shi J, Haley KJ. Undertriage of major trauma patients in the US emergency departments. *Am J Emerg Med*. 2014;32(9):997–1004.
4. Chang DC, Bass RR, Cornwell EE, Mackenzie EJ. Undertriage of elderly trauma patients to state-designated trauma centers. *Arch Surg*. 2008;143(8):776–781.
5. Holst JA, Perman SM, Capp R, Haukoos JS, Ginde AA. Undertriage of trauma-related deaths in U.S. emergency departments. *West J Emerg Med*. 2016;17(3):315–323.
6. MacKenzie EJ, Hoyt DB, Sacra JC, Jurkovich GJ, Carlini AR, Teitelbaum SD, Teter H Jr. National inventory of hospital trauma centers. *JAMA*. 2003;289(12):1515–1522.

7. Rogers FB, Shackford SR, Hoyt DB, Camp L, Osler TM, Mackersie RC, Davis JW. Trauma deaths in a mature urban vs rural trauma system. A comparison. *Arch Surg*. 1997;132(4):376–382.
8. Rogers FB, Beyer F, Gross BW. A historical perspective of the Level II Trauma Center at Lancaster General Hospital. *JLGH*. 2014;9(4).
9. Osler T, Rutledge R, Deis J, Bedrick E. ICISS: an International Classification of Disease-9 based Injury Severity Score. *J Trauma*. 1996;41(3): 380–388.
10. Clark D, Osler T, Hahn D. 2009. "ICDPIC: Stata module to provide methods for translating International Classification of Diseases (Ninth Revision) diagnosis codes into standard injury categories and/or scores," Statistical Software Components S457028, Boston College Department of Economics, revised 29 Oct 2010. Accessed via https://ideas.repec.org/c/boc/bocode/s457028.html on 27 July, 2017.
11. Ashley D, Pracht EE, Medeiros RS, Atkins EV, NeSmith EG, Johns TJ, Nicholas JM. An analysis of the effectiveness of a state trauma system: treatment at designated trauma centers is associated with an increased probability of survival. *J Trauma Acute Care Surg*. 2015;78(4):706–714.
12. Ciesla D, Pracht E, Cha J, Langland-Orban B. Geographic distribution of severely injured patients: implications for trauma system development. *J Trauma Acute Care Surg*. 2012;73(3):618–624.
13. Ciesla D, Tepas JJ 3rd, Pracht EE, Langland-Orban B, Cha JY, Flint LM. Fifteen-year trauma system performance analysis demonstrates optimal coverage for most severely injured patients and identifies a vulnerable population. *J Am Coll Surg*. 2013;216(4):687–695.
14. Durham R, Pracht E, Orban B, Lottenburg L, Tepas J, Flint L. Evaluation of a mature trauma system. *Ann Surg*. 2006;243(6):775–785.
15. Hsia R, Shen YC. Possible geographical barriers to trauma center access for vulnerable patients in the United States: an analysis of urban and rural communities. *Arch Surg*. 2011;146(1):46–52.
16. Hsia RY, Wang E, Saynina O, et al. Factors associated with trauma center use for elderly patients with trauma: a statewide analysis, 1999–2008. *Arch Surg*. 2011;146(5): 585–592.
17. Hsia RY, Wang E, Torres H, Saynina O, Wise P, Perez-Stable EJ, Auerbach A. Disparities in trauma center access despite increasing utilization: data from California, 1999–2006. *J Trauma*. 2010;68(1):217–224.
18. Wang NE, Saynina O, Vogel LD, Newgard CD, Bhattacharya J, Phibbs CS. The effect of trauma center care on pediatric injury mortality in California, 1999 to 2011. *J Trauma Acute Care Surg*. 2013;75(4):704–716.
19. Zarzaur B, Bell T, Croce M, Fabian TC. Geographic variation in susceptibility to ventilator-associated pneumonia after traumatic injury. *J Trauma Acute Care Surg*. 2013;75(2):234–240.
20. TIGER/Line Shapefiles and TIGER/Line Files. United States Census Bureau. Accessed via https://www.census.gov/geo/maps-data/data/tiger-line.html on 27 July, 2017.
21. Health, PA Department of. n.d. *Hospital Reports*. 2016. Accessed via http://www.statistics.health.pa.gov/HealthStatistics/HealthFacilities/HospitalReports/Pages/HospitalReports.aspx#.V9HFlaPD-Uk on 27 July, 2017.
22. Haas B, Gomez D, Zagorski B, Stukel TA, Rubenfeld GD, Nathens AB. Survival of the fittest: the hidden cost of undertriage of major trauma. *J Am Coll Surg*. 2010;211(6):804–811.
23. Bouzat P, Ageron FX, Brun J, Levrat A, Berthet M, Rancurel E, Thouret JM, Thony F, Arvieux C, Payen JF. A regional trauma system to optimize the prehospital triage of trauma patients. *Crit Care*. 2015;19:111.
24. Tepas JJ 3rd, Kerwin AJ, Ra JH. Unregulated proliferation of trauma centers undermines cost efficiency of population-based injury control. *J Trauma Acute Care Surg*. 2014;76(3):576–581.
25. Horst MA, Rogers RB, Gross BW, Cook AD, Osler TM, Bradburn EH. A novel approach to optimal placement of new trauma centers within an existing trauma system using geospatial mapping. *J Trauma Acute Care Surg*. 2017;83(4):705–710.
26. *A National Trauma Care System: Integrating Military and Civilian Trauma Systems to Achieve Zero Preventable Deaths After Injury*. Washington, DC: The National Academies Press; National Academies of Sciences, Engineering, and Medicine. 2016.
27. Bland JM, Altman DG. Statistical methods for assessing agreement between two methods of clinical measurement. *Lancet*. 1986;1(8476):307–310.