An analysis of pediatric trauma center undertriage in a mature trauma system

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BACKGROUND: Improved mortality as a result of appropriate triage has been well established in adult trauma and may be generalizable to the pediatric trauma population as well. We sought to determine the overall undertriage rate (UTR) in the pediatric trauma population within Pennsylvania (PA). We hypothesized that a significant portion of pediatric trauma population would be undertriaged.

METHODS: All pediatric (age younger than 15) admissions meeting trauma criteria (*International Classification of Diseases, Ninth Revision*: 800–959) from 2003 to 2015 were extracted from the Pennsylvania Health Care Cost Containment Council (PHC4) database and the Pennsylvania Trauma Systems Foundation (PTSF) registry. Undertriage was defined as patients not admitted to PTSF-verified pediatric trauma centers (n = 6). The PHC4 contains inpatient admissions within PA, while PTSF only reports admissions to PA trauma centers. ArcGIS Desktop was used for geospatial mapping of undertriage.

RESULTS: A total of 37,607 cases in PTSF and 63,954 cases in PHC4 met criteria, suggesting UTR of 45.8% across PA. Geospatial mapping reveals significant clusters of undertriage regions with high UTR in the eastern half of the state compared to low UTR in the western half. High UTR seems to be centered around nonpediatric facilities. The UTR for patients with a probability of death 1% or less was 39.2%.

CONCLUSION: Undertriage is clustered in eastern PA, with most areas of high undertriage located around existing trauma centers in high-density population areas. This pattern may suggest pediatric undertriage is related to a system issue as opposed to inadequate access. (*J Trauma Acute Care Surg.* 2019;87: 800–807. Copyright © 2019 Wolters Kluwer Health, Inc. All rights reserved.)

LEVEL OF EVIDENCE: Retrospective study, without negative criteria, Level III.

KEY WORDS: Pediatric undertriage; pediatric trauma; trauma undertriage; geospatial mapping.

Improved mortality as a result of appropriate triage has been well established in the trauma population.[1,2] The goal of health care is to deliver the best quality of care in an efficient manner. The American College of Surgeons, Committee on Trauma recognizes the risk of undertriage and suggests a maximum undertriage rate (UTR) of less than 5% and an overtriage rate of 25% to 30%.[3] As a result, trauma systems strive to appropriately deliver severely injured patients to the right hospital at the right time. Pediatric patients present an especially unique quandary to the mechanism of triage. Oftentimes, children initially appear less injured than in reality or they may be unable to advocate or communicate for their own needs owing to developmental constraints; and yet, despite having a trauma center (TC) nearby, some children continue to be triaged to nontrauma centers (NTCs).[4] In 2018, van der Sluijs et al. conducted a systematic review on the triage of pediatric trauma patients. They found that the sensitivity of prehospital triage tools ranged from 49.1% to 87.3%.[5] Ground has been made in improving the accuracy of triaging tools[6–8]; however, the goal of 95% accurate triage rate remains elusive in the pediatric trauma population.[5]

A retrospective analysis of adult emergency department (ED) trauma deaths in 2010 highlighted the disparity in access to trauma centers across the nation. They found that in urban locations, 35.6% of ED trauma deaths were due to undertriage, compared to 86.4% of ED deaths related to undertriage in rural areas.[9] This may be even more accentuated in the pediatric population, where pediatric trauma centers (PTCs) are far and few across the state. In a literature review, Petrosyan et al.[10] determined that despite increasing the total number of PTCs from 34 in 1997 to 65 in 2009, only 10% of pediatric trauma patients were treated in a PTC and only 53% of injured children were treated at any trauma-designated hospital, adult or pediatric. Pennsylvania has developed a mature statewide trauma system that brings care to both urban and rural communities. The trauma system in Pennsylvania has been in existence for more than 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. We previously studied the statewide undertriage patterns and found that 30% of moderately and severely injured adults were being triaged to NTCs.[11] The purpose of our study was to determine if the same held true in the pediatric population of Pennsylvania. We hypothesized that a significant portion of the pediatric trauma population would be undertriaged.

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METHODS

A retrospective analysis from 2003 to 2015 of all pediatric (age <15) 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 current PTSF guidelines state that any patients, 14 years of age or younger, who meet the following criteria should be transferred: persistent physiologic derangements, shock, hemodynamically unstable, ongoing transfusion needs; traumatic brain injury (significant structural abnormality on x-ray or computed tomography, sustained Glasgow Coma Scale score of 13 or less for more than 2 hours, or neurologic deterioration); intubation and mechanical ventilation not expected to be weaned and extubated within 24 hours; or children with special needs and those with other comorbid conditions such as congenital heart disease, chronic lung disease, or other disease processes that will benefit from the multidisciplinary care available at a PTC. Those who meet the following criteria should be considered for transfer: nonoperative management of solid organ injuries; any assessment of "negative points" on the Pediatric Trauma Score (negative points are assigned for the following: less than 10 kg, airway unmaintainable, systolic blood pressure <50 mm Hg, coma, major open or penetrating wound, and open or multiple fractures.); injury severity score (ISS) greater than 9; victim or nonaccidental injury that requires additional resources including a child protection team; or when it is anticipated that the complexity of ongoing care will exceed the capabilities of the local resources at the adult trauma center (ATC). The Pennsylvania Trauma Systems Foundation is a statewide trauma registry with all documented trauma cases treated at accredited trauma centers that meet at least one of the following inclusion criteria: death secondary to trauma, intensive care unit/step-down unit admissions, length of stay (LoS) of more than 48 hours or LoS between 36 and 48 hours with ISS of 9 or greater and admitted transfers in/out of the hospital. Pennsylvania Health Care Cost Containment Council is a comprehensive data set that contains all inpatient admissions within the state of Pennsylvania, which represented the population of all trauma patients treated at TCs or NTCs. It does not contain any information for patients who were treated in the ED and transferred before admission. To identify trauma admissions from all admissions in the PHC4 database, we selected patients with *International Classification of Diseases, Ninth Revision* (*ICD-9*) codes ranging from 800 to 959. A prediction model ICISS)[12] 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.[13] The Trauma Mortality Prediction Model (TMPM) score was calculated in both databases based on the *ICD-9* code to generate the probability of death.[14,15] To make a homologous comparison between the two data sets, we also extracted from the PTSF data set trauma cases treated at a Level I or Level II TC to represent the TC providing definitive care.

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.[14–22] We extracted basic census demographics and TIGER zip code tabulation areas from the US Census Bureau. 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.[23] We included TCs outside 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 TIEP (Trauma Information Exchange Program) database from the American Trauma Society. Due to smaller volumes of pediatric trauma cases when compared to adult trauma cases, we did not include zip code areas outside the state as was done in our analysis of adult trauma.[11] Patients with PO Box zip codes were included in the zip code area in which the PO Box is assigned.

Undertriage was defined as any pediatric patient in Pennsylvania that was cared for at an NTC or adult TC. Within each zip code, we calculated the pediatric UTR as the proportion of pediatric PHC4 cases that were not represented in the PTSF database as follows:

$$UTR = \frac{(PHC4 - PTSF)}{PHC4}$$

We then applied the same calculations with a restricted data set using only cases where the probability of death was 1% or higher to help eliminate minor injuries and identify if the geospatial distribution of undertriage differed. To more effectively analyze zip code areas with small volumes of trauma cases, we calculated a spatial empirical Bayesian smoothed undertriage rate using a queen contiguity spatial weighting scheme for each zip code area, which borrows information from neighboring zip codes in cases where there are small numbers of trauma cases and uses a localized prior distribution. We used the Getis-Ord Gi* procedure for identifying significant clustering of zip code areas with either high or low pediatric UTR rates.[24] The Getis-Ord Gi* is a modeling technique that calculates the ratio of the weighted average of values in neighboring locations to the sum of values including the location being assessed. General comparisons were made with appropriate categorical, nonparametric, or parametric statistical tests when data were aggregated by zip code area. In cases where individual case data were considered, multilevel models were constructed to account for clustering of patients in hospitals. $p < 0.05$ was considered significant in all analyses. GeoDa 1.8.16.4 was used for geospatial analyses, calculation of the spatial empirical Bayesian rates, and the Getis-Ord Gi* model. ArcGIS 10.5.1 was used for spatial mapping, and Stata 15.0 was used for data preparation and statistical analyses. This study was reviewed and approved by the Penn Medicine Lancaster General Health Institutional Review Board.

RESULTS

The study area included 1,669 zip code areas with 63,954 total hospital admissions between 2003 and 2015 that met trauma criteria (*ICD-9*: 800–959) within the PHC4 database, and the PTSF database had 32,909 trauma cases managed at a PTC during that interval for an overall statewide UTR of 45.8%. Of these 31,045 patients who were undertriaged, 4,698 (15.1%) were admitted to an adult TC, while 26,347 were admitted to a NTC. The statewide UTR when cases managed either at PTCs or ATCs were included decreased to 41.2%. Median (Q1–Q3) smoothed

UTRs by zip code were 38.6% (26.8%–46.9%) for all cases and 43.6% (7.8%–58.7%) for the cases restricted to probability of death 1% or greater (Table 1). Data from PHC4 suggest that the median (Q1–Q3) overall pediatric trauma per 1,000 pediatric population per year is higher than what is indicated in the PTSF database with 2.1 (1.5–3.1) versus 1.3 (0.8–2.0), respectively. In both databases, a higher percentage of trauma cases are male and in the age 10-to-14 range, although a considerable percentage of trauma cases occur in the infant population age younger than 1 year. The PHC4 database has a higher percentage of trauma cases in the ISS 1-to-9 range and a smaller percentage of cases with AIS head or chest injuries 3 or greater or multisystem injuries. Undertriage rates were mapped to generate a geospatial representation that demonstrated the distribution and clustering of undertriage in the state of Pennsylvania for all cases (Figs. 1 and 2) and cases where the probability of mortality was 1% or greater (Figs. 3 and 4). Also included on the map are locations of PA TCs, non-PA TCs and NTCs in PA. Nontrauma centers are further subdivided based on bed size, with smaller circles representing less than 200 beds and larger circles indicating the presence of NTC with more than 200 beds. Figures 1 and 3 show the smoothed pediatric UTR color coded in quintiles, whereas Figures 2 and 4 highlight the statistical high and low UTR clusters as identified by the Getis-Ord Gi* procedure at $p < 0.05$. Clustered zip code areas with high pediatric UTR are generally located in the eastern part of the state, whereas clustered zip code areas with low pediatric UTR are generally located in the western part of the state.

When comparing population density in both databases for all cases, high UTR zip codes were more urban, whereas low UTR regions tended to be more rural ($p < 0.001$ for both PHC4 and PTSF). There were also differences in the percentage of patients admitted to PTCs ($p < 0.001$) with the low UTR zip code areas having higher percentages in all cases. There was no difference in adjusted (adjusted for PTC, multisystem injury, head or chest AIS ≥ 3, ISS, and age as well as patient clustering in hospitals) mortality rates across the UTR clustering categories (Table 2 and Table 3). In both the PHC4 and PTSF databases, there were differences in the proportion of patients in each of the ISS categories as well as differences in the distribution of AIS scores and multisystem injuries. There were 392 (23.5%) zip code areas that changed significant/nonsignificant UTR cluster status when going from all cases to restricted cases with probability of mortality of 1% or greater. Only 8.0% of the zip code areas transitioned from a nonsignificant to significant UTR cluster, and 15.5% transitioned from a significant to nonsignificant UTR cluster.

DISCUSSION

The statewide trauma system in Pennsylvania has been in existence since 1985, and thus is a mature system with years of data and performance improvement initiatives based on these data. However, statewide, the overall UTR of pediatric trauma patients is 45.8%. It is quite shocking that in a system as mature as this, the pediatric UTR would be as high as it is. This is markedly

TABLE 1. Descriptive Summary of PHC4 and PTSF Pediatric Trauma for 2003–2015

	All Patients		Patients with Probability of Death ≥ 1%	
	PHC4	PTSF	PHC4	PTSF
Total pediatric trauma cases	63,954	37,607	33,263	22,800
Median (Q1–Q3) smoothed UTR per zip code	38.6% (26.8%–46.9%)		43.6% (7.8%–58.7%)	
Admitted to pediatric trauma center	44,809 (70.1%)	32,909 (87.5%)	23,698 (71.2%)	20,240 (88.8%)
Sex				
Female	23,443 (36.7%)	13,414 (35.7%)	11,865 (35.7%)	7,723 (33.9%)
Male	40,445 (63.2%)	24,185 (64.3%)	21,347 (64.2%)	15,072 (66.1%)
Age				
<1	7,455 (11.7%)	4,313 (11.5%)	4,750 (14.3%)	3,251 (14.3%)
1–4	16,754 (26.2%)	10,551 (28.1%)	8,029 (24.1%)	5,752 (25.2%)
5–9	16,313 (25.5%)	10,361 (27.6%)	7,854 (23.6%)	5,704 (25.0%)
10–14	23,432 (36.6%)	12,382 (32.9%)	12,630 (38.0%)	8,093 (35.5%)
Primary payer				
Medicaid	27,234 (42.6%)	14,950 (40.0%)	13,681 (41.1%)	8,769 (38.8%)
Commercial	33,371 (52.2%)	16,794 (45.0%)	17,752 (53.4%)	9,598 (42.4%)
Self	2,414 (3.8%)	1,820 (4.9%)	1,345 (4.0%)	1,286 (5.7%)
In-hospital mortality	409 (0.6%)	641 (1.7%)	354 (1.1%)	573 (2.5%)
ISS				
1–9	49,418 (77.3%)	26,136 (70.4%)	24,380 (74.3%)	12,599 (55.6%)
10–15	4,034 (6.3%)	4,532 (12.2%)	3,015 (9.2%)	3,882 (17.1%)
16–25	4,347 (6.8%)	4,595 (12.4%)	4,100 (12.5%)	4,339 (19.1%)
≥26	6,155 (9.6%)	1,885 (5.1%)	1,316 (4.0%)	1,845 (8.1%)
AIS head ≥3	6,718 (10.5%)	7,713 (20.5%)	6,432 (19.3%)	7,399 (32.5%)
AIS chest ≥3	1,921 (3.0%)	2,018 (5.4%)	1,865 (5.6%)	1,836 (8.1%)
AIS multisystem injury	13,810 (21.6%)	16,243 (43.2%)	8,831 (26.6%)	12,280 (53.9%)

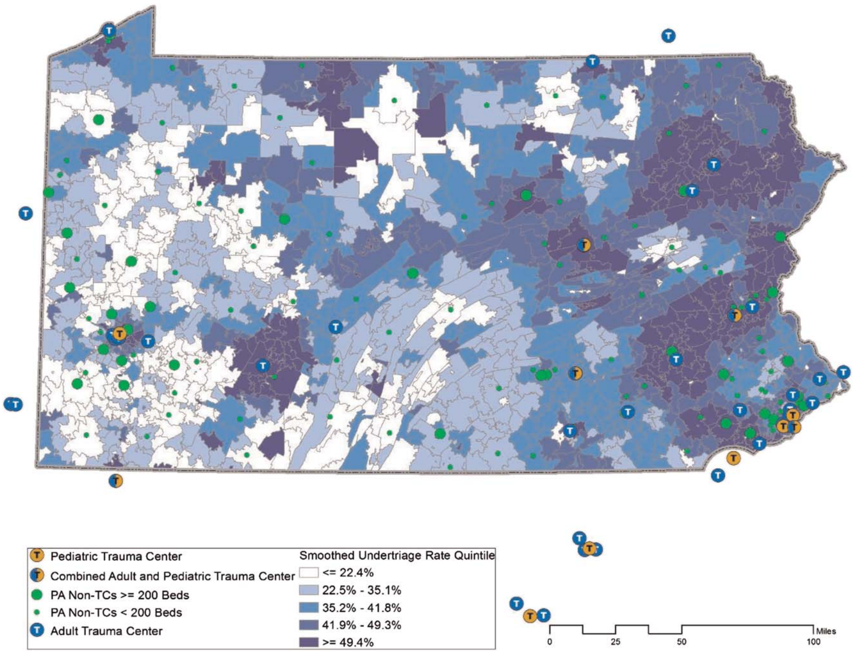

Figure 1. Smoothed pediatric UTRs by zip code area: all cases.

higher than the 21.7% rate previously calculated from Nationwide Emergency Department Sample (NEDS).[25]

The definition of pediatric undertriage presents a unique predicament and may explain the challenge of studying the aforementioned. The definition of undertriage by Peng et al.[25], which aligns closest to that of the American College of Surgeons, Committee on Trauma[3] triage recommendation, is patients with an ISS greater than 16 who were taken to a Level III TC or an NTC. In a study by Hewes et al., hospitals were categorized based on their triage pattern. Undertriage was defined as transfer of 85% or less of patients with an ISS of 16 or greater, excluding PTCs.[2] Gurria et al.[4] define primary undertriage as follows: transfer of a patient from the scene to an ATC or NTC when a PTC is within 30 minutes. For this study, the UTR was calculated to align with PTSF standards, which state legislation requires must comply, at a minimum, with ACS guidelines.

The geospatial representations (Figs. 1 and 2) suggest that the western portion of the state has low UTR, while the

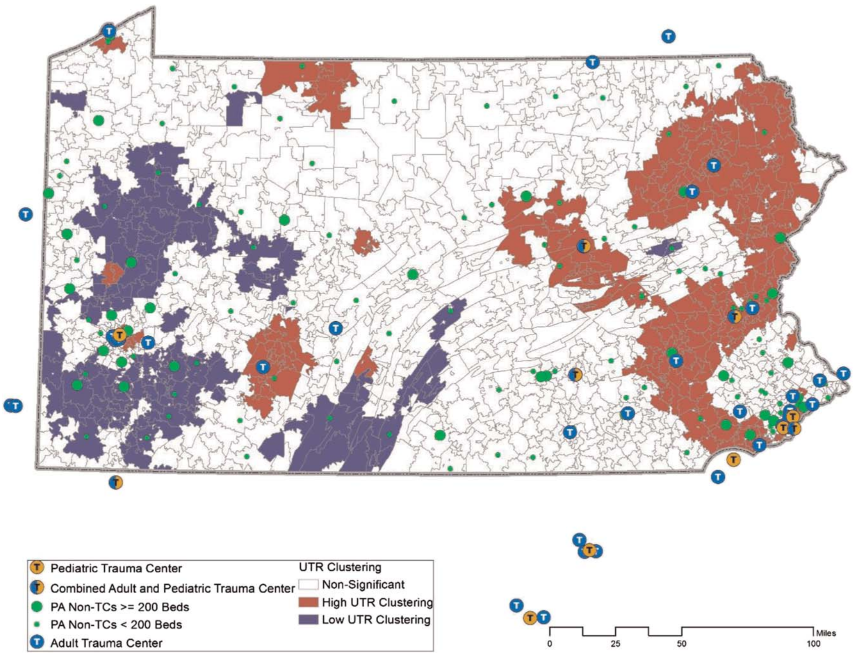

Figure 2. Statistical clustering of pediatric UTRs: all cases.

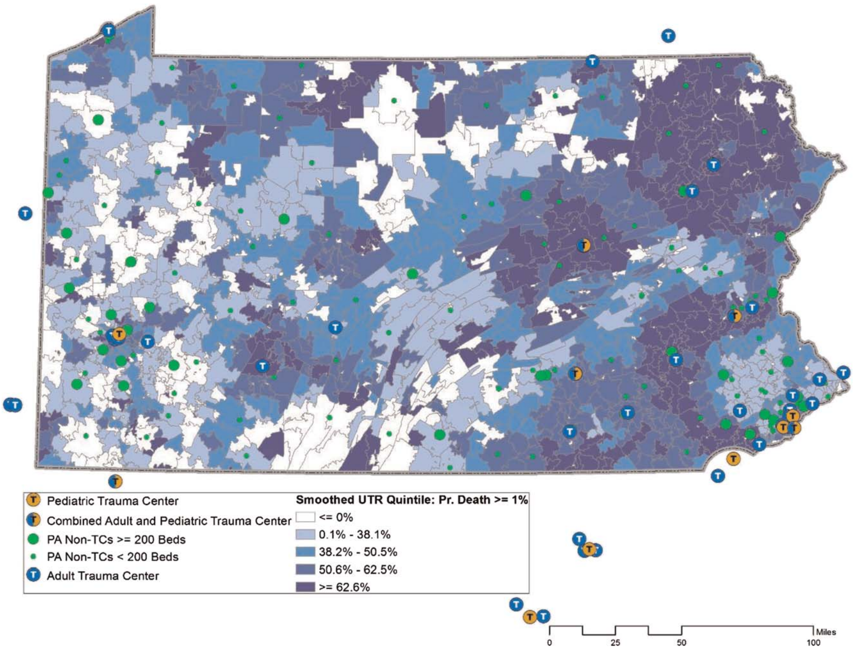

Figure 3. Smoothed pediatric UTRs by zip code area: probability of death ≥ 1%.

eastern potion has high UTR. Limited access to trauma centers in the rural northwestern region seems to not have a significant effect on UTR. There are significant “hot spot” zones that are associated with both NTC and ATC, suggesting that these hospitals are not transferring trauma patients to the appropriate PTC and rather opting to manage pediatric trauma patients at their own hospital.

Additional factors, which may potentially lead to hot spot zones, are the influence of major health care systems and prehospital triage. Some systems expect that patients admitted to their facilities only be transferred within their network, which can influence the UTR. Unfortunately, this study was not able to calculate the impact of hospital systems on the transfer practices of pediatric patients. Competition between hospitals, which may influence UTR, remains understudied. Despite proximity, there may be a tendency to not transfer patients out of network to an unaffiliated TC. The education and training of health care professionals also influence UTR. The importance of prehospital triage is undeniable, and the true cost of undertriage has

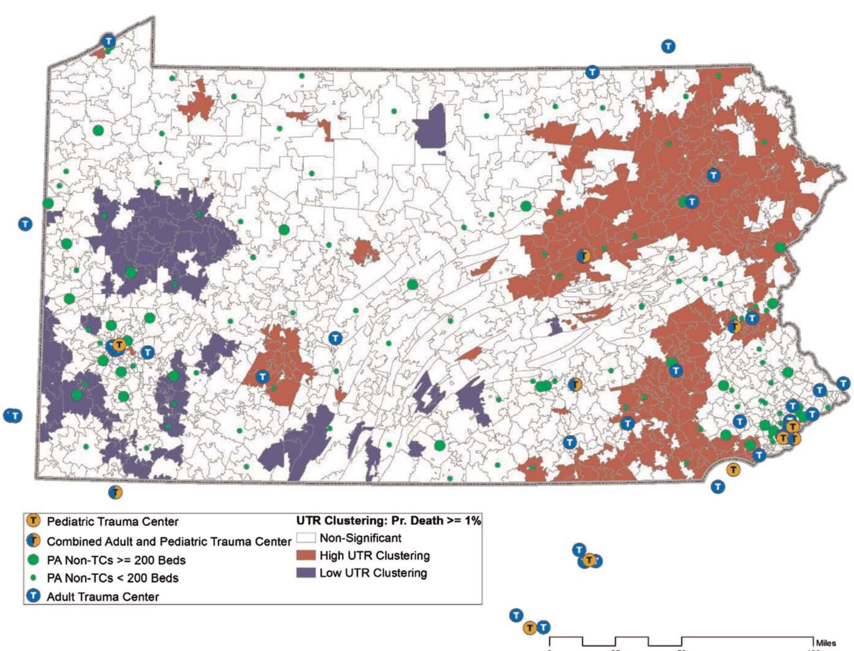

Figure 4. Statistical clustering of pediatric UTRs: probability of death ≥ 1%.

TABLE 2. Comparison of Pediatric Trauma UTR Zip Code Area Clustering Categories by Study Database: Patients with Probability of Death ≥1%

	PHC4			PTSF		
	Nonsignificant Clustering	High UTR Clustering	Low UTR Clustering	Nonsignificant Clustering	High UTR Clustering	Low UTR Clustering
N	23,751	8,164	1,348	16,777	4,726	1,297
Admitted to pediatric trauma center	74.5%	61.0%	76.8%	90.2%	81.4%	97.4%
In-hospital mortality	1.1%	1.1%	1.1%	2.4%	3.2%	1.9%
ISS						
1–9	74.5%	74.1%	71.8%	56.7%	50.8%	58.6%
10–15	9.0%	9.7%	9.5%	16.6%	18.9%	17.1%
16–25	12.7%	11.7%	13.9%	18.9%	20.5%	17.6%
≥26	3.8%	4.5%	4.8%	7.8%	9.8%	6.7%
AIS head ≥3	19.3%	19.3%	19.7%	31.9%	35.7%	28.4%
AIS chest ≥3	5.4%	6.3%	5.1%	7.7%	9.8%	6.0%
AIS multisystem injury	26.0%	27.7%	30.0%	53.0%	56.6%	55.1%

potentially been underappreciated and subject to survivor bias.[26] France's trauma system, TRENAU (Trauma Réseau Nord Alpin des Urgences), where an emergency medicine physician makes an on-scene assessment and refers each patient to the appropriate trauma center, successfully optimizes prehospital triage.[27] While others have studied the accuracy of prehospital trauma notification calls and found that emergency medical services (EMS) crews often provide inaccurate information or sometimes no information at all.[28] In reality, it may not be feasible to send a physician on every EMS call. However, training and educating EMS providers on appropriate prehospital triage and using a standardized approach to reporting this assessment is a reasonable objective.

The authors previously investigated the adult UTR in the Commonwealth of Pennsylvania during the same time period and determined the UTR to be 32.2%. The geospatial representation of undertriage in that population is pointedly different. The clustering of undertriage in the adult population was around NTCs where there are no trauma centers in nearby, while that of pediatric patients is the opposite. As Figures 2 and 4 illustrate, there is significant undertriage in the densely populated eastern region of the state, where access to trauma centers is far from limited. This strongly suggests that NTCs are essentially acting as de facto trauma centers, without undergoing the rigorous accreditation process to ensure appropriate management of the pediatric trauma patient.

It must be noted that the existence of a TC does not always eliminate UTR. The presence of pediatric TCs seems to have a slight influence on UTR in the most proximal zip codes; but as evident in Figures 1 and 2, there is a clustering effect that is not always

TABLE 3. Comparison of Pediatric Trauma UTR Zip Code Area Clustering Categories by Study Database: All Patients

	PHC4			PTSF		
	Nonsignificant Clustering	High UTR Clustering	Low UTR Clustering	Nonsignificant Clustering	High UTR Clustering	Low UTR Clustering
N	38,149	20,868	4,937	23,612	9,782	4,213
Median (Q1–Q3) population/mile^2	243 (67–1091)	432 (143–1,625)	162 (60–520)	248 (70–1,115)	440 (147–1,825)	163 (60–520)
Median (Q1–Q3) trauma/1,000 pediatric population per year per zip code	2.1 (1.5–3.1)	2.4 (1.8–3.1)	2.2 (1.5–3.0)	1.4 (0.9–2.1)	1.1 (0.7–1.4)	1.9 (1.4–2.6)
Admitted to pediatric trauma center	71.8%	66.0%	73.7%	87.7%	84.1%	94.4%
Primary payer						
Medicaid	40.6%	46.2%	42.9%	38.2%	45.8%	36.9%
Commercial	53.8%	49.1%	52.8%	46.0%	40.3%	49.8%
Self	4.2%	3.4%	2.2%	5.6%	3.8%	3.5%
In-hospital mortality	0.7%	0.6%	0.7%	1.6%	2.2%	1.0%
ISS						
1–9	77.4%	77.3%	76.5%	70.4%	69.0%	73.3%
10–15	6.5%	5.9%	6.7%	12.1%	12.4%	12.2%
16–25	7.1%	6.0%	8.0%	12.5%	12.6%	10.8%
≥26	9.1%	10.8%	8.8%	4.9%	6.0%	3.6%
AIS head ≥3	10.9%	9.8%	10.6%	20.6%	21.6%	17.5%
AIS chest ≥3	3.1%	2.9%	2.6%	5.4%	6.1%	3.8%
AIS multisystem injury	21.4%	21.8%	22.2%	42.6%	42.1%	48.8%

associated with a TC. This clustering effect is why geospatial representation of the data is so critical to get a more thorough understanding of the still undetermined influences on UTR.

This study is not without its limitations. The trauma criteria are imposed retrospectively on both data sets and may have resulted in some trauma cases being unintentionally excluded. The nature of the data sets, both containing deidentified data void of any patient identifying information, made it impossible to concatenate a patient's record. As the study was of a single state and completed retrospectively in nature, there are inherent threats to generalizability. Alongside the forenamed restrictions, only pediatric patients were evaluated. It should be noted that all pediatric patients were included from the PTSF database, but only those meeting trauma criteria were included from PHC4 using billing codes. As a result, errors in billing coding may also have unintentionally influenced the outcomes of this study. Although the main objective of this study was to evaluate UTR in Pennsylvania, trauma care is an organic process; thus, patients may have been treated at or transferred to TCs beyond the state boundaries and may have influenced the results of our study. Given the limited data available in PHC4, it was not possible to complete a risk adjusted analysis of the population, making it difficult to suggest any correlation between UTR and mortality. Furthermore, the authors acknowledge the importance of highlighting the consequences and effects that UTR have, but given the nature of the data set, they could not be analyzed. Subsequent research should explore the influence that health systems and cultural differences have on UTR across the Commonwealth.

The study used a trauma prediction model (TMPM) as the reporting method because of the significant disadvantage that ISS, which is calculated at discharge, poses.[29] The TMPM estimates a patient's probability of death due to their five worst anatomic injuries exclusively. It has been compared to ISS and found to be a superior measure of injury.[30–32]

CONCLUSION

Almost 50% of pediatric trauma patients in Pennsylvania are being managed at non-PTCs and more than 40% are not managed at either an ATC or PTC, despite the more than 30-year existence of a well-established, mature, statewide trauma system. The shortcomings of this network need to be further evaluated, and interventions must be carried out to ensure that future expansion and agreements help shape a standard within the state that is more appropriately managing the triage of pediatric patients.

AUTHORSHIP

ATR interpreted the data and wrote the manuscript. MAH designed the study; collected, analyzed, and interpreted the data; and wrote the manuscript. TMV interpreted the data and wrote the manuscript and provided editorial oversight. BAG designed the study, interpreted data, and wrote the manuscript. EHB interpreted the data. ADC interpreted data. SJ designed the study and collected the data. FBR designed the study, interpreted the data, and provided editorial oversight.

DISCLOSURE

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