Driving Time to Trauma Centers for Children Living in Wisconsin

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ABSTRACT

Introduction: Trauma is the number 1 cause of death among children. Shorter distance to definitive trauma care has been correlated with better clinical outcomes. There are only a small number of pediatric trauma centers (PTC) designated by the American College of Surgeons, and the resources available to treat injured children at non-PTCs are limited. To guide resource allocation and advocacy efforts for pediatric trauma care in Wisconsin, we determined the precise distance to trauma centers for all children living in the state.

Methods: The 2010 US Census data was used to determine ZIP-centroid geolocation. The Wisconsin Department of Health Services trauma classification database was used to identify trauma facilities in Wisconsin. SAS routines invoking the Google Maps application programming interface were used to calculate the driving distance to each of the trauma facilities. We quantified the percentage of children living within 30- and 60-minute driving distances of level I-IV trauma centers.

Results: Just 31.3% of Wisconsin children live within a 30-minute drive of a level I PTC; 32.7% live within 30 minutes of a level II center; 81.3% within 30 minutes of a level III center; and 74.6% within 30 minutes of a level IV center.

Conclusions: Two-thirds of children in Wisconsin live beyond a 30-minute driving distance of a level I PTC, but most children live within 30 minutes of level III and IV trauma centers. As the closest hospitals for most children, smaller trauma centers should be adequately resourced to provide pediatric trauma care.

BACKGROUND

Trauma is the leading cause of death in children in the United States.[1] Distance to definitive trauma care is known to affect outcomes for both adults[2-4] and children.[5] In predominantly rural states, dedicated pediatric trauma centers (PTC) verified by the American College of Surgeons (ACS) are rare, and the time to travel to PTCs is longer.[6] Therefore, local trauma centers—though not specifically certified to care for injured children and with varying levels of mandated equipment, supplies, and training for pediatric patients—may be required to provide emergency care for severely injured children, at least for purposes of stabilization for subsequent transport to a pediatric trauma center. To guide public health policy and resource allocation, it is crucial to know how far the pediatric population is—both in distance and time—from pediatric and adult trauma centers of all levels.

Wisconsin has 2 large trauma centers located in its 2 largest cities, both of which provide ACS-verified level I care to children and adults, and 1 ACS-verified level II PTC. There are an additional 7 ACS-verified level II adult trauma centers that treat pediatric patients but are not ACS-verified for pediatric trauma, as well as 44 state-designated level III hospitals, 53 level IV hospitals, and 15 hospitals that have elected not to seek trauma center designation. Currently, the Wisconsin Department of Health Services does not have specific criteria for level III and IV hospitals regarding the care of pediatric trauma patients; pediatric-specific training and equipment at these centers are not mandated to achieve certification. The current Wisconsin trauma standards for levels

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III and IV centers are based on standards in the 1999 edition of the ACS Resources for the Optimal Care of the Injured Patient.[7] Although studies have investigated the effect of distance to trauma centers on clinical outcomes for injured patients, there is limited data on relative locations of trauma centers and the populations they serve, and few methods exist for combining population and hospital data.[6,8] The availability of the Google Maps application programming interface (API) has made the driving distance and time analysis more dynamic and accessible.[9-11]

The goal of this study was to characterize the precise distance to travel to different levels of trauma care for children in Wisconsin by combining granular census data that identifies pediatric population density in each ZIP code with point-to-point calculators of driving time from ZIP code centroids to specific hospital addresses.

METHODS

Data Source

This study used publicly available data sources. "Turn-by-turn" driving distances and times were developed using a combination of geographical information systems and data-management tools. The US Census Bureau, Census 2010 Summary File 1 served as a source list for Wisconsin ZIP-centroid geolocation (latitude and longitude) for each Wisconsin ZIP code; a total of 774 ZIP codes and the pediatric population of each were identified and used in the analyses.

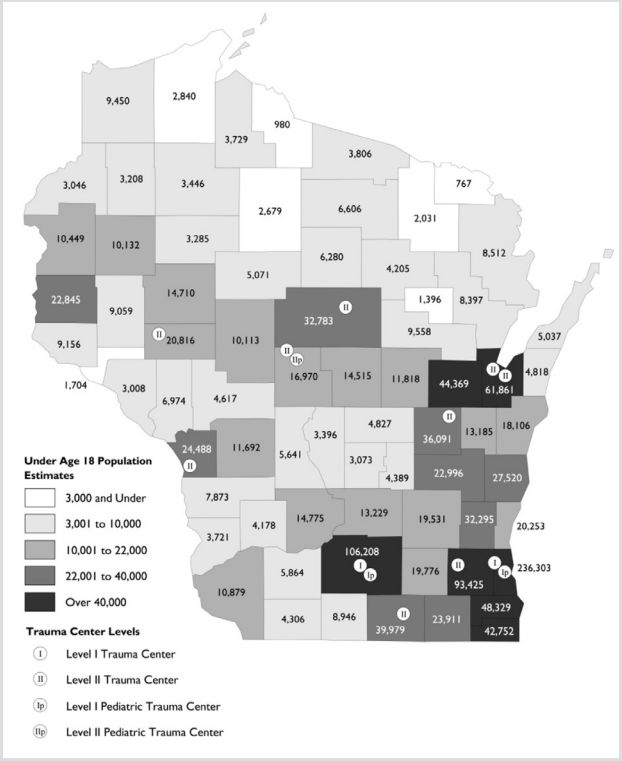
The Wisconsin Department of Health Services Hospital Trauma Classification Database was used to identify hospitals in Wisconsin and key characteristics associated with these facilities, including geolocation (latitude and longitude) of each facility and trauma verification status. The location of each hospital was then linked to Wisconsin ZIP codes and input into a Statistical Analysis System (SAS) macro that contacted the Google Maps API to obtain the driving distance and time from each trauma center to the centroid of each of the 774 Wisconsin ZIP codes.

The American Family Children's Hospital trauma database for 2015-2019 was queried to determine the percentage of pediatric trauma patients that were transferred to level I pediatric trauma centers from the state's levels II-IV trauma centers. This analysis was approved by the University of Wisconsin School of Medicine and Public Health Institutional Review Board.

Data Analysis

SAS v9.4 software was used for managing the datasets and batch-submitting requests to the Google Maps API. A series of routines was developed using SAS to link the Census and American Hospital Association ZIP-level data. Each of the 124 facilities was linked to each of the 774 ZIP codes in Wisconsin, resulting in a total of 95,834 distinct ZIP-facility pairs for which to determine driving distance and time. The SAS routines were then used to invoke the Google Maps API, looping through each of the ZIP-facility pairs in a distinct call to the API. The results were pooled, reformatted, and processed using the SAS routines, and the distances to each of the facilities were ranked for each ZIP code in ascending order. The resulting dataset formed the basis for all subsequent analyses. The driving distances to trauma centers of each level were assessed independently. In other words, if a child lived within 30 minutes of a level I PTC and within 60 minutes of a level II PTC, they were counted once for living within 30 minutes of a level I PTC and again for living within 60 minutes of a level II PTC. The American Family Children's Hospital trauma data was analyzed using R 3.6.1. A comparison of the injury severity score (ISS) was performed using the Wilcoxon rank-sum test.

Figure 1. Wisconsin Population Under Age 18, Estimates by County (2010), and Location of Level I and II Adult and Pediatric Trauma Centers



Darker shading corresponds to a higher density of children.

RESULTS

Two ACS-verified level I pediatric trauma centers, 1 ACS-verified level II pediatric trauma center, 9 ACS-verified level II adult trauma centers, 44 level III trauma centers, 53 level IV trauma centers, and 15 nontrauma hospitals were included in the analysis. Two of the level I adult trauma centers are in the same location as the 2 level I PTCs. There are 39 rural counties (54%) in Wisconsin,[12] and 58 critical access hospitals (35%).[13]

The population of children in Wisconsin and the location of the level I and II trauma centers are shown in Figure 1, and results of our analysis are summarized in Figure 2. Reflecting the predominantly rural population of the state, only 31.3% of Wisconsin children live within a 30-minute driving distance of

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one of the 2 level I PTCs, and 53.9% live within 60 minutes. As there is only 1 level II PTC, which is located in the middle of the state in a predominantly rural area, only 1.04% of children are within 30 minutes and 5.46% are within 60 minutes. Almost one-third (32.7%) of children are within 30 minutes, and 83.6% live within 60 minutes of one of the 9 adult level II centers. As the level III and IV centers are better distributed across the state, 82% of children live within 30 minutes and 93.7% lived within an hour of one of the 44 level III centers. Seventy-five percent of children lived within 30 minutes and 98.4% live within an hour of one of the 53 level IV centers (Table).

At our level I PTC, a total of 3,697 patients were admitted for trauma care during 2015-2019. Among these, 1,995 (54.0%) of them were transferred from other regional trauma centers. Out of these transfers, 110 patients were transferred from outside of Wisconsin and were excluded for the subsequent analysis as trauma center leveling criteria are not uniform across states. Out of 1,885 patients who were transferred within Wisconsin, 1 patient (0.05%) was transferred from another level I PTC, 102 patients (5.4%) were transferred from adult level II trauma centers, 714 patients (37.9%) were transferred from level III trauma centers, 811 patients (43.0%) were transferred from level IV trauma centers, and 258 patients (13.7%) were transferred from non-trauma-designated hospitals. The mean ISS for patients who were transferred to our level I PTC and those who presented directly from the scene was 7.09 (SD 8.15) and 6.95 (SD 9.78), respectively ($P = 0.0079$). Among the patients treated at our facility with ISS greater than 15, 57.8% were triaged at another facility before being transferred to a level I PTC.

Figure 2. Percent of Population Younger Than 18 Years Residing Within Specified Driving Time of Nearest Trauma Center, Wisconsin, 2017

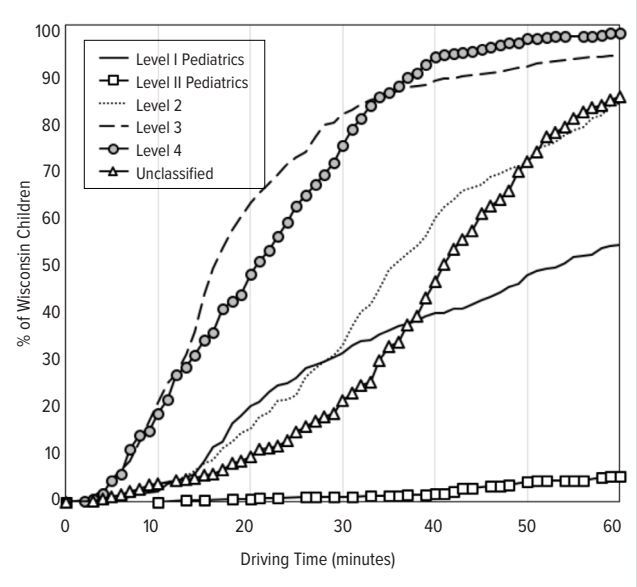

Table. Percentage of Children Within 30- and 60-Minute Driving Time of Adult and Pediatric Trauma Centers

Trauma Center Designation	% Children Within 30-Minute Driving Time	% Children Within 60-Minute Driving Time
Level I (pediatric)	31.3%	53.9%
Level II (pediatric)	1.04%	5.46%
Level II (adult)	32.7%	83.6%
Level III (adult)	81.3%	93.7%
Level IV (adult)	74.6%	98.4%

DISCUSSION

We found that about half of children in Wisconsin live further than a 60-minute drive from a level I PTC, while the vast majority of children live within 30 minutes of a state-designated level III or IV center. We also found that among the pediatric trauma patients treated at our level I PTC, the patients who were transferred from the referring centers had slightly higher ISS than the patients who presented directly from the scene. Lastly, the majority of patients transferred to our level I PTC were triaged at levels III and IV adult trauma centers before being transferred.

Level I PTCs are the highest level of pediatric trauma care and are verified according to ACS standards. ACS-certified level II centers also meet standards for pediatric-specific training and equipment. In Wisconsin, the state designates level III trauma centers as hospitals providing assessment, resuscitation, stabilization, and emergency surgery and arrangement of the transfer to a level I or II facility for definitive surgical and intensive care as necessary. A level IV trauma center is defined by the state as hospitals providing stabilization and advanced trauma life support before transferring patients to a level I or II center. These standards are based on the 1999 edition of the ACS Optimal Care for Injured Patients, and the state is currently in the process of revising the criteria for levels III and IV trauma centers to address pediatric trauma patient-specific resources.[14]

Although there are conflicting results among studies whether pediatric trauma patients have better clinical outcomes when treated at pediatric trauma centers versus adult trauma centers,[15-21] some of these studies showed improved outcomes at pediatric trauma centers with specific equipment and training to care for pediatric patients.[18-20] Our study did not focus on clinical outcomes of patients treated at a different level of trauma center, but it is worth noting that 54% of the trauma patients treated at our facility during 2015-2019 were transferred from non-PTC centers, and the majority were from level III and IV trauma centers. Furthermore, many of the severely injured patients with ISS greater than 15 were triaged at another facility before being transferred to a level I PTC. These findings support the importance of ensuring adequate pediatric trauma equipment and training in level III and IV trauma centers, which are the closest hospitals for most Wisconsin children.

The availability of publicly available application programming

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interfaces such as Google Maps has increased the accessibility of using turn-by-turn analysis to calculate more accurate driving distances. We used this approach to calculate the distance between where children live and the nearest trauma center based on the longitude and latitude associated with ZIP codes. Using the ZIP code of individual children provides more precise calculations compared to ZIP code blocks that were used in a previous study.[22]

One of the limitations of this study is that the driving time calculated is the average driving time for nonemergency vehicles and does not account for weather. The study also does not take into account cases where patients are transferred via air. Therefore, the percentage of children living within 30 or 60 minutes of a level I or II trauma center may be higher in cases of severe trauma. However, as air transport may not always be an option and the road conditions are not always predictable, the findings of our study still highlight the need for pediatric trauma care capability in nonpediatric trauma centers.

Another limitation of this study is the use of ZIP codes instead of census tracts as a surrogate for where Wisconsin children lived. Although the census tract is more granular than the ZIP code for patient location,[23] census tracts do not allow for centroid geolocation. And ZIP code has been widely used in studies of health care access, which allows ready comparison between studies. Lastly, as pointed out by a recent study,[24] there is potential discordance between the children's residence and the location of trauma. Although injuries do not always occur near the place of residence, prior research suggests that 88% of major traumatic injuries occur within 10 miles of home.[25] In our cohort, 75% of the patients were injured within 10 miles of their home.

CONCLUSION

Granular geolocation data demonstrate that two-thirds of children in Wisconsin live beyond a 30-minute driving distance to a level I PTC, but most children live within 30 minutes of levels III and IV trauma centers. As states and hospitals balance the need to provide trauma care to children at the hospitals close to their homes with the expense of pediatric-specific resources and training, our findings highlight the need for maintaining consistent and clear standards for pediatric trauma care at local trauma centers.

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REFERENCES

1. Kochanek KD, Murphy SL, Xu J, Arias E. Deaths: final data for 2017. *Natl Vital Stat Rep*. 2019;68(9):1-77.

2. Brown JB, Rosengart MR, Billiar TR, Peitzman AB, Sperry JL. Distance matters: effect of geographic trauma system resource organization on fatal motor vehicle collisions. *J Trauma Acute Care Surg*. 2017;83(1):111-118. doi:10.1097/TA.0000000000001508

3. Karrison TG, Philip Schumm L, Kocherginsky M, Thisted R, Dirschl DR, Rogers S. Effects of driving distance and transport time on mortality among Level I and II traumas occurring in a metropolitan area. *J Trauma Acute Care Surg.* 2018;85(4):756-765. doi:10.1097/TA.0000000000002041

4. Jarman MP, Curriero FC, Haut ER, Pollack Porter K, Castillo RC. Associations of distance to trauma care, community income, and neighborhood median age with rates of injury mortality. *JAMA Surg*. 2018;153(6):535-543. doi:10.1001/jamasurg.2017.6133

5. Amram O, Schuurman N, Pike I, Friger M, Yanchar NL. Assessing access to paediatric trauma centres in Canada, and the impact of the golden hour on length of stay at the hospital: an observational study. *BMJ Open*. 2016;6(1):e010274. doi:10.1136/bmjopen-2015-010274

6. US Government Accountability Office. *Pediatric Trauma Centers: Availability, Outcomes, and Federal Support Related to Pediatric Trauma Care*; 2017. GAO-17-334. Accessed June 30, 2019. https://www.gao.gov/assets/gao-17-334.pdf

7. Wis. Admin. Code § DHS 118 (2021). Accessed December 11, 2019. https://docs.legis.wisconsin.gov/code/admin_code/dhs/110/118

8. Report Card Task Force Members; ACEP Staff. America's emergency care environment, a state-by-state report card: 2014 edition. A*nn Emerg Med*. 2014;63(2):97-242. doi:10.1016/j.annemergmed.2013.11.024

9. Wang F, Xu Y. Estimating O–D travel time matrix by Google Maps API: implementation, advantages, and implications. *Ann GIS*. 2011;17(4):199-209. doi:10.1080/19475683.2011.625977

10. Fenton SJ, Lee JH, Stevens AM, et al. Preventable transfers in pediatric trauma: a 10-year experience at a level I pediatric trauma center. *J Pediatr Surg*. 2016;51(4):645-8. doi:10.1016/j.jpedsurg.2015.09.020

11. McEvoy CS, Ross-Li D, Held JM, et al. Geographic distance to pediatric surgical care within the continental United States. *J Pediatr Surg*. 2019;54(6):1112-1117. doi:10.1016/j.jpedsurg.2019.02.048

12. Department of Natural Resources. Urban and rural counties under E-Cycle Wisconsin. November 2017. Accessed January 13, 2020. https://dnr.wi.gov/topic/Ecycle/documents/countiesmap.pdf

13. Wisconsin Office of Rural Health. List of critical access hospitals in Wisconsin. Updated May 15, 2018. Accessed January 13, 2020. http://www.worh.org/library/list-critical-access-hospitals-wisconsin

14. Department of Health Services. Proposed order of Department of Health Services To Adopt Permanent Rules. In: Services WDoH, ed. Wisconsin 2019. Accessed August 8, 2019. http://docs.legis.wisconsin.gov/code/register/2019/763A1/register/submit_proposed/cr_19_086/cr_19_086_rule_text

15. Rogers AT, Gross BW, Cook AD, et al. Outcome differences in adolescent blunt severe polytrauma patients managed at pediatric versus adult trauma centers. *J Trauma Acute Care Surg*. 2017;83(6):1082-1087. doi:10.1097/TA.0000000000001642

16. Mitchell RJ, Curtis K, Testa L, Holland AJ, Sv Soundappan S, Adams S. Differences in survival outcome for severely injured paediatric trauma by type of trauma centre. *J Paediatr Child Health*. 2017;53(8):808-813. doi:10.1111/jpc.13514

17. Miyata S, Cho J, Lebedevskiy O, Matsushima K, Bae E, Bliss DW. Trauma experts versus pediatric experts: comparison of outcomes in pediatric penetrating injuries. *J Surg Res*. 2017;208:173-179. doi:10.1016/j.jss.2016.09.040

18. Webman RB, Carter EA, Mittal S, et al. Association between trauma center type and mortality among injured adolescent patients. *JAMA Pediatr.* 2016;170(8):780-786. doi:10.1001/jamapediatrics.2016.0805

19. Walther AE, Falcone RA, Pritts TA, Hanseman DJ, Robinson BR. Pediatric and adult trauma centers differ in evaluation, treatment, and outcomes for severely injured adolescents. *J Pediatr Surg.* 2016;51(8):1346-1350. doi:10.1016/j.jpedsurg.2016.03.016

20. Sathya C, Alali AS, Wales PW, et al. Mortality among injured children treated at different trauma center types. *JAMA Surg*. 2015;150(9):874-881. doi:10.1001/jamasurg.2015.1121

21. Walther AE, Pritts TA, Falcone RA, Hanseman DJ, Robinson BR. Teen trauma without the drama: outcomes of adolescents treated at Ohio adult versus pediatric trauma centers. *J Trauma Acute Care Surg*. 2014;77(1):109-116. doi:10.1097/TA.0000000000000277

22. Nance ML, Carr BG, Branas CC. Access to pediatric trauma care in the United States. *Arch Pediatr Adolesc Med*. 2009;163(6):512-518. doi:10.1001/archpediatrics.2009.65

23. Rossiter K. Understanding geographic relationships: counties, places, tracts and more. United States Census Bureau. July 31, 2014. Accessed May 19, 2020. https://www.census.gov/newsroom/blogs/random-samplings/2014/07/understanding-geographic-relationships-counties-places-tracts-and-more.html

24. Wei R, Clay Mann N, Dai M, Hsia RY. Injury-based geographic access to trauma centers. *Acad Emerg Med*. 2019;26(2):192-204. doi:10.1111/acem.13518

25. Haas B, Doumouras AG, Gomez D, et al. Close to home: an analysis of the relationship between location of residence and location of injury. *J Trauma Acute Care Surg*. 2015;78(4):860-865. doi:10.1097/TA.0000000000000595

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