Review

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Geospatial Distribution of Hospital Resources in Regional Trauma Systems (Review of Foreign Literature)

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ABSTRACT The review presents the results of foreign studies related to geospatial analysis and modeling of the distribution of trauma centers and helicopter emergency medical services in developed regional trauma systems. The optimal number and geographical location of the trauma centers in the region is determined taking into account the timing of the delivery of victims to the trauma centers of a high level, population density, hospitalization of patients with severe trauma, and the frequency of inter-hospital transfers. The distribution of hospital resources of the trauma system should be based on the needs of the population, and vary depending on the geographical and social characteristics of the region.

Keywords: trauma system, trauma center, major trauma, prehospital time, helicopter transport, geospatial analysis

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RTA – road traffic accident
TS –- trauma system
ACS-COT — American College of Surgeons Committee on Trauma
AIS — Abbreviated Injury Scale
EMS — Emergency Medical Service
GEMSI — Geographic Emergency Medical Service Index
HEMS — Helicopter Emergency Medical Services
ISS — Injury Severity Scale
NBATS — Needs Based Assessment of Trauma Systems

INTRODUCTION

Trauma remains a pressing health problem worldwide and the leading cause of death and disability in patients under 45 [1, 2]. Implementation of trauma care systems *(Trauma Systems)* in developed countries has led to a decrease in mortality among injured patients and an improvement in the results of their treatment [3, 4]. The trauma system (TS) combines services that provide prehospital care and transportation of victims, treatment in a network of trauma centers, rehabilitation, prevention, research and educational activities. Each TS serves a specific geographic area and is integrated into the healthcare system. The development and implementation of TS began in the late 60s and early 70s in the USA by the *American College of Surgeons Committee on Trauma (ACS-COT)* and has been widely distributed in highly developed countries since 2000s. To date, national TSs have been organized in the USA, Canada, Great Britain, Australia and New Zealand, Western Europe, Scandinavia, Israel, Japan [1, 2, 5]. Trauma centers are the most important component of the TS. The effectiveness of the functioning of the entire system largely depends on their number, capabilities and geographical distribution in the region [6]. In Russia, a three-level system of trauma centers is being formed and the experience of its work is being accumulated, which has not yet received a deep scientific analysis in the domestic literature. Meanwhile, the problems of optimal distribution of hospital resources in the TS are widely discussed and studied in detail in foreign literature. International experience in solving them can be useful for the creation and improvement of domestic TSs.

The purpose of the review is to consider the problem of objective assessment and modeling of the optimal geospatial distribution of trauma centers in the context of the functioning of regional TSs.

The search for foreign literary sources in the PubMed database, published in the period from 2014 to 2020, was carried out. The results of studies devoted to the problem of geospatial distribution of hospital resources in developed regional trauma systems, which have the greatest experience in world practice and have proven their effectiveness, are summarized. Developed TS systems are maturity level III / IV systems in accordance with the TS Maturity Index proposed by the World Health Organization [1]. The criterion for severe injury is taken as an indicator of the severity of injuries according the scale *ISS (Injury Severity Scale)* >15 points [2, 5, 7].

LEVELS OF TRAUMA CENTERS

Rational distribution of hospital resources is achieved in inclusive TC models, in which all trauma centers in the region provide trauma care in accordance with their capabilities, depending on which they are divided into levels. Four levels of trauma centers have been identified in the United States, three-level hospital networks have been introduced in Germany, France and Japan, and two-level hospital networks have been introduced in England, Norway and Australia [1, 2, 5].

The Level I Trauma Center has the full range of specialists and the greatest capacity to treat any type of injury, it is usually located in large cities and leads the education, research and prevention activities in the region, often these are university clinics. Megacities may have several Level I centers at the rate of 1 per 1,000,000 population. Large level I trauma centers are designed to treat more than 650 patients with severe injuries per year, medium-capacity centers - more than 400 such patients [8].

Level II trauma centers have most of the resources of a level I center, but are limited in their ability to treat patients with complex and rare injuries, can be located in cities, suburban or rural areas with a high population density. Level II trauma centers complement the clinical activities of a level I center or serve as leading trauma facilities in regions where a level I center does not exist.

Level III and IV trauma centers treat patients with non-severe trauma and are located in rural areas remote from level I or II centers. Level III centers can perform general surgical emergency operations and stabilize the condition of the seriously injured patients before transferring them to level I or II centers. Level IV trauma centers are able to provide advanced vital support for severely injured patients prior to transfer them to level I or II facilities [5].

ROUTING AND INTERHOSPITAL TRANSFERS OF PATIENTS

Prehospital mortality in severely injured patients ranges from 15% to 48%, with 31% to 54% of deaths potentially preventable. From 27 to 58% of preventable deaths are due to delayed specialized care [9]. Transporting severely injured people to a low-level trauma center or to non-core medical facilities (*Undertriage*) can increase preventable mortality or complication rates due to delays in diagnosis and full treatment. On the contrary, the delivery of patients with a non-severe injury to a high-level trauma center (*Overtriage*) does not affect mortality, but leads to unreasonable waste of hospital resources, and in case of mass admissions, it can adversely affect the quality of treatment [10, 11].

ACS-COT has set targets for *Undertriage* no more than 5%, *Overtriage* - 25–35% of hospitalizations [5]. The geographic distribution of trauma centers can significantly influence the availability of trauma care and *Undertriage* rates [12]. For example, in the states of California and Pennsylvania (USA), *Undertriage* rates in areas without a high-level trauma center are significantly higher (38–58%) than in areas adjacent to trauma centers (26–32%) [11, 13]. In Sweden, for a citizen seriously injured in a road traffic accident (RTA), the chances of being taken a patient to a trauma center are reduced by 5% for each additional kilometer of distance from the scene of an accident to a trauma center [14].

According to some data, the risk of death for patients with severe trauma brought directly to the level I trauma center is less than for patients who initially are admitted to the lower level centers and transferred to the level I center for stabilization [15]. In other studies, no significant difference in mortality among these groups of seriously injured patients was found, which can be explained by the high quality of prehospital care, adequate stabilization of the vital functions of the victims and timely (within 48 hours) their transfer [16–19]. In any case, mortality in patients with severe trauma who received final treatment in level III trauma centers or non-specialized hospitals is significantly higher than in those who were directly transported or transferred for further treatment to high-level centers [12, 20, 21]. Victims with *ISS* scores ⩾25 have the highest survival benefit from treatment at Level I and Level II trauma centers [22].

The opportunity to provide better care in high-level trauma centers justifies the direct delivery and interhospital transfer of severely injured patients to these facilities. Unreasonable transfer of patients who are discharged from the host institution without surgical intervention within 48 hours leads to unnecessary expenditure of TC resources (secondary *Overtriage*) [23]. Development of level III Trauma Centers in rural areas could significantly reduce interhospital transfers [24]. Thus, the presence of a CT scanner, a full-time neurologist, the use of telemedicine with the participation of a traumatologist makes it possible to exclude serious neurological and skeletal injuries and reduce the rate of secondary *Overtriage* [25, 26]. On the contrary, an increase in the number of level I or II trauma centers in the region is accompanied by an increase in the level of secondary *Overtriage* [25].

PRE-HOSPITAL PERIOD DURATION AND MORTALITY

According to the “golden hour” concept, emergency hospital care within 60 minutes significantly reduces trauma mortality. Meanwhile, a number of modern studies have not received evidence to support this concept. Exceeding the pre-hospital time by more than 60 minutes did not significantly increase mortality in patients with severe trauma [27, 28], shock (systolic blood pressure less than 90 mm Hg) and severe traumatic brain injury (*Glasgov Coma Scale* score less than or equal to 8 points) [29, 30]. According to other data, mortality remained associated with the duration of the prehospital period in patients with penetrating wounds of the chest and abdomen, "costal valve", arterial hypotension [31, 32], shock patients who needed transfusion of 6 or more RBC units during the first day, emergency surgical or interventional radiological interventions [30]. Thus, in the state of Maryland (USA), an increase in pre-hospital time for every 5 minutes increased the probability of death in patients with severe blunt trauma or penetrating wounds of the chest and abdomen by 15-17%, in patients with other severe injuries - only by 5% [33]. In Nova Scotia, Canada, patients with penetrating wounds were 3 to 4 times more likely to die when transport times exceeded 30 minutes [34].

A number of studies have even revealed an inverse relationship between the duration of the prehospital period and mortality among victims with severe trauma, arterial hypotension, injuries of the chest and / or abdomen of at least 4 points on a scale *AIS (Abbreviated Injury Scale)* [28, 29, 35]. Mortality was highest among those who were delivered within 30 minutes [36, 37]. In such patients, the first 30 minutes after injury become critical for survival.

The distance from the injury site to the nearest trauma center correlates with the duration of the pre-hospital period and mortality. In Maryland, the chance of death increased by 8% for every 5 miles to the nearest trauma center [33]. In Pennsylvania, for every 10 miles the distance to the nearest trauma center increased, traffic injury deaths increased by 0.141 per 100,000 miles of road traffic [38].

The relationship between the duration of the prehospital period and mortality is ambiguous without taking into account the type of medical institution to which the victim is delivered. The benefit for the critically injured patients of longer distance transport to a high-level trauma center may outweigh the benefit of prompt transport to a level III center or nearest hospital. Studies have shown that the most significant factors of mortality, and, consequently, more objective indicators for assessing the distribution of hospital resources of the TC, are the duration of transportation of victims and the distance to level I or II trauma centers, and not to other medical institutions. Thus, in the state of Kentucky (USA), the mortality rate in patients with severe trauma delivered to the trauma center within 30 minutes was significantly lower (57%) than in patients delivered to a non-specialized hospital within the same time interval (80%). At the same time, mortality did not significantly depend on the distance to the trauma center, but directly correlated statistically significantly with the distance to other hospital [35].

According to accepted protocols and recommendations, the duration of transportation of a victim with a severe injury to a high-level trauma center should not exceed 45 minutes in Michigan (USA), 30 minutes in Germany and Indiana (USA) [2, 35], in the Auvergne– Rhone-Alpes (France) - 15 minutes [3]. If the estimated transport time is above the established threshold, then the victim should be taken to the nearest trauma center or hospital.

AVAILABILITY OF EARLY AID AT TRAUMA CENTERS

Ground and air traffic conditions (weather, time of day, day of the week, type and congestion of the road) can significantly affect the duration of the transportation of victims. In this regard, a more objective indicator for assessing the availability of early specialized care is not the remoteness of high-level trauma centers, but the percentage of residents or victims in the region who can potentially be delivered to these centers within a threshold time. Delivery time to a high-level trauma center of ⩽30 min may be unrealistic, especially in rural and hard-to-reach areas, so 45 [8, 39] or 60 minutes is taken as the threshold time [6, 40–42].

Software *ArcGIS, GeoDa* allows you to estimate the percentage of recipients and victims who can be delivered by land or air within 45 or 60 minutes from the place of residence or possible accident sites to all trauma centers and hospitals in the region [13, 39, 40, 42–44]. The availability of early hospital care based on the calculation of the potential time of delivery of victims to the trauma center from the places of injury is more objectively assessed, but not the postal addresses of residents of the region. Injury analysis showed that 73% of patients were injured within 5 minutes of driving time from their place of residence, 11% within 5–20 minutes, and 16% over 20 minutes. With an increase in the average distance between places of residence and places of injury, the error in assessing the availability of hospital care for addressees in the region increases [45].

Calculations using *ArcGIS* found that in the United States, delivery to level I and II trauma centers within 60 minutes is available for 90% of residents [46]. In Nova Scotia, 43% of the province's population can be transported within 60 minutes to a Level I trauma center and 88% of residents to a Level III trauma center [41]. The population of rural areas [46] and road accident victims [41] have significantly lower access to TC hospital resources. For example, in the states of Oregon and Washington (USA), 89% of urban and only 29% of rural patients requiring emergency surgical interventions are taken to high-level trauma centers [47].

Recently, the method of geospatial analysis (mapping) and mathematical modeling has been actively used to objectively assess the geographical distribution of resources of a regional TS and determine its optimal configuration. The method allows you to create models with a rational number and location of trauma centers of different levels and bed capacity, providing the specified parameters of the vehicle (the average time of delivery of victims to trauma centers by land and air, the required number of helicopter flights, the number of hospitalizations and interhospital transfers) [8, 42]. For example, geospatial analysis has shown that with the optimal placement of 27 trauma centers in Pennsylvania, the percentage of victims delivered to trauma centers within 60 minutes would increase from 91 to 97%, and only 16-22 rationally placed trauma centers are enough to ensure the current level of hospital care availability [48].

Helicopter Emergency Medical Services (*HEMS*) is an important vehicle resource. Level I trauma center requires the presence of two or more helicopters, level II trauma center - at least one helicopter [3]. Rational placement and use of *HEMS* can increase the availability of care in trauma centers and reduce mortality [49, 50]. In New South Wales (Australia), 86% of the state's residents can be taken to the trauma center by ground transport within 60 minutes, the use of *HEMS* increases this figure to 99% [51]. A geospatial analysis of the TC of Pennsylvania found that redeploying two helicopters to areas with the highest road traffic deaths ("hot spots") would reduce the average time to get victims from the accident site to trauma centers and reduce the predicted death rate from road accidents in seven counties of the state by 12% [38].

J.B. Brown et al. (2019) proposed a *"Geographic Emergency Medical Service Index - GEMSI)*. The *GEMSI* index is directly proportional to the number of emergency ambulances per 100 sq. miles, the coefficient of geographic dispersion of *EMS* (*Emergency Medical Service*) agencies and inversely proportional to the average distance from *EMS* agencies to the nearest trauma centers and *HEMS* bases. An increase in the index value correlates with a lower level of mortality from road traffic accidents in the region. Geospatial modeling using the *GEMSI* index showed that the predicted death rate from traffic accidents in Pennsylvania could be reduced by 6% with the addition of one optimally placed *EMS* agency, and by 22% with the relocation of the helicopter base [52].

The geographical concentration of level I and II trauma centers in the region correlates with injury mortality, which is associated with an increase in the availability of trauma care. In the United States, the clustered (concentrated) distribution of level I and II trauma centers in districts with high population density correlates with lower mortality rates, with an increase in the coefficient of dispersion of trauma centers per unit, mortality from injuries increases by 0.02 per 100,000 people [43].

ACS-COT recommends planning and regularly reviewing the number and distribution of trauma centers in accordance with the needs of the population of the region [6]. Inadequate access to TC resources can adversely affect the quality of care, often leading to severe social and financial consequences that go far beyond medical issues. For example, in California, the closure of a number of level I and II trauma centers due to financial problems led to a 29% increase in mortality among victims who had to be transported over longer distances to trauma centers remaining in the region [53].

An increase in the number of trauma centers without taking into account the needs of the region does not guarantee an increase in the availability of specialized care and the effectiveness of prehospital triage. Thus, the creation of 5 additional level II trauma centers in the state of Florida (USA) did not affect the *Undertriage* indicator and only led to an increase in the *Overtriage* level. [54].

SCOPE OF HOSPITALS IN TRAUMA CENTERS AND QUALITY OF TREATMENT

The unregulated opening of trauma centers, especially level II ones, increases systemic costs, leads to a decrease in the volume of hospitalizations in a level I trauma center, which reduces the experience of medical staff, especially in the treatment of rare complex injuries, and jeopardizes educational and research activities [55, 56]. Competition between level I and II trauma centers in the region reduces the efficiency of both ones.

Many studies have found that an increase in the average annual volume of hospitalizations in a trauma center increases the survival of patients [57-59]. According to the *Resuscitation Outcomes Consortium*, an increase in the number of admissions to the trauma center correlates with a decrease in indicators such as the number of days of mechanical ventilation, the severity of multiple organ dysfunction, reduces the predicted mortality rate by 7% for every additional 500 hospitalizations per year [59]. A number of studies have shown that the total number of admissions to a level I trauma center is not a predictor of mortality [60]. The relationship of mortality with the volume of hospitalizations was revealed only for some categories of patients [58]. According to the *TraumaRegister DGU®* (Germany), the number of patients admitted to the trauma center with an *ISS* injury severity of at least 16 points is an independent predictor of their survival. Observed mortality was significantly lower than predicted when at least 40 patients with severe trauma were admitted to the trauma center per year [7]. An analysis of data from the *National Trauma Databank* (USA) showed that an increase in the volume of hospitalizations of patients with severe trauma in trauma centers of level I or II by 1% reduced the ratio of observed to predicted mortality by 73%. Conversely, a 1% decrease in hospital admissions over 3 years was associated with a two-fold increase in this indicator [61].

According to the *ACS-COT* recommendations, a level I trauma center should concentrate rare complex trauma cases, accept at least 1200 patients with trauma per year, including at least 240 patients with an injury severity over 15 points on the *ISS* scale, which will provide the necessary experience of medical staff, the decision educational and research tasks [5]. In France, a level I trauma center must treat at least 100 patients with severe trauma annually, a level II center - at least 50 such patients [3].

The opening of new trauma centers not only reduces the flow of patients to existing centers, but changes the composition of their payers, reduces the number of patients with private insurance and self-payment cases, which can worsen the financial support of the trauma center and reduce the quality of treatment [39, 54].

On the other hand, exceeding the volume of hospitalizations beyond the capacity of the trauma center will lead to a lack of resources to provide quality care. Therefore, there is an optimal range for this indicator that provides the best treatment results and may vary in each TC.

PLANNING FOR OPENING ADDITIONAL TRAUMA CENTERS IN THE REGION

In 2015, *ACS-COT* launched the *Needs Based Assessment of Trauma Systems (NBATS)* to address the need for additional trauma centers in the region. The optimal number of trauma centers is determined on the basis of the following indicators: the total population of the region, the average time of transportation of victims, the degree of support for the region by the authorities, the number of patients with severe trauma discharged per year from level I and II trauma centers and non-specialized institutions, the number of already existing centers of I, II and III levels. The *NBATS* tool underestimated the number of urban trauma centers and overestimated their number in rural areas [62].

The *NBATS-2* tool, developed by *ACS-COT* in 2018, uses a geospatial analysis and modeling methodology that predicts how the opening of additional trauma centers will affect the availability of care for the population, calculates the average transportation time, the volume of hospitalizations in existing centers, and based on this helps to choose the optimal location of new centers [44]. For example, the *NBATS-2* tool showed that adding one urban level II trauma center in Tennessee would only increase the number of casualties delivered to high-level trauma centers within 45 minutes by only 2%, but would reduce admissions to a level I center by 40%. The opening of two trauma centers in rural areas will increase the number of victims and recipients entering the 45-minute delivery zone by 22% and 29%, respectively, and the volume of hospitalizations at the level I center will decrease by only 25% [39].

Geospatial analysis can be used to select candidates for level II trauma centers from large hospitals (more than 200 beds). In Pennsylvania, those identified for this are located more than 15 to 30 minutes away from existing urban and suburban trauma centers. Models with the addition of 1-6 new trauma centers from selected hospitals significantly increased the number of victims and recipients that could be delivered to the trauma center within 60 minutes [40]. Geospatial analysis also reveals the clustering of *Undertriage* indicators by region and, based on this data, determines areas for the location of new trauma centers. The highest *Undertriage* rates (38-39%) were in areas with large hospitals that were treating patients with severe trauma and could be considered candidates for trauma centers [13].

CONCLUSION

The experience of the organization and functioning of developed regional trauma systems allows us to draw the following conclusions.

1. The main indicators for assessing the distribution of hospital resources in the regional trauma system are the availability of assistance to victims in level I and II trauma centers, the volume of hospitalizations of patients with an injury severity score of more than 15 points on the *ISS* scale, the number of interhospital transfers.

2. The distribution of hospital resources in the regional trauma system should ensure the direct delivery of patients with severe trauma to level I or II trauma centers as soon as possible, which improves treatment outcomes, reduces the number of interhospital transfers and reduces the financial costs of the system.

3. An objective indicator of the availability of early specialized care in the trauma system is not the remoteness of trauma centers, but the proportion of residents or victims in the region who can potentially be delivered by ground or helicopter transport to a high-level trauma center in 45 or 60 minutes. Exceeding the duration of transportation for more than 30 minutes is critical for the survival of patients with severe blunt

trauma and penetrating wounds of the chest or abdomen with unstable hemodynamics, requiring emergency surgical interventions. If it is impossible to transport patients with severe trauma to a high-level trauma center within the specified timeframe, they may be admitted to a level III trauma center with subsequent early (within 48 hours) interhospital transfer.

4. A high concentration of trauma centers in the region reduces the time of delivery of patients, but leads to a decrease in the volume of hospitalizations. There is a minimum volume of hospitalizations in the level I trauma center of patients with severe trauma (at least 100-240 patients per year), which ensures the clinical excellence of the medical staff, the financial stability of the trauma center and correlates with the results of treatment.

5. Geospatial analysis (mapping) is the most effective method for objectively assessing the distribution of hospital resources and choosing the optimal configuration of the regional trauma system. The method allows to determine the rational number, location and bed capacity of trauma centers of different levels, taking into account the given time of transportation of victims by land and air transport and the potential number of interhospital transfers.

Further development and application of information technologies and methods of mathematical modeling is promising for solving the problem of creating a trauma system with an optimal concentration of trauma centers in the region, which ensures the minimum transportation time and the required amount of hospitalizations for severely injured patients.

REFERENCES

1. Dijkink S, Nederpelt CJ, Krijnen P, Velmahos GC, Schipper IB. Trauma systems around the world: A systematic overview. *J Trauma Acute Care Surg*. 2017;83(5):917–925. PMID: 28715361 https://doi.org/10.1097/TA.0000000000001633
2. *Weißbuch Schwerverletztenversorgung. Deutsche Gesellschaft für Orthopädie und Unfallchirurgie e.V. (DGOV)*. Berlin; 2012. Available at: http://www.dgu-online.de/qualitaet-sicherheit/schwerverletzte/weissbuch-schwerverletztenversorgung.html [Accessed 18 Nov 2021]
3. David JS, Bouzat P, Raux M. Evolution and organisation of trauma systems. *Anaesth Crit Care Pain Med*. 2019;38(2):161–167. PMID: 29476943 https://doi.org/10.1016/j.accpm.2018.01.006
4. Vali Y, Rashidian A, Jalili M, Omidvari AH, Jeddian A. Effectiveness of regionalization of trauma care services: a systematic review. *Public Health*. 2017;146:92–107. PMID: 28404479 https://doi.org/10.1016/j.puhe.2016.12.006
5. *American College of Surgeons Committee on Trauma. Resources for Optimal Care of the Injured Patient*. 6th ed. Chicago, IL: American College of Surgeons Committee on Trauma; 2014. Available at: https://www.facs.org/-/media/files/quality-programs/trauma/vrc-resources/resources-for-optimal-care.ashx [Accessed 19 Nov 2021]
6. American College of Surgeons Committee on Trauma. Statement on trauma center designation based upon system need. *Bull Am Coll Surg*. 2015;100(1):51–52. PMID: 25626271
7. Zacher MT, Kanz KG, Hanschen M, Häberle S, van Griensven M, Lefering R, et al. Association between volume of severely injured patients and mortality in German trauma hospitals. *Br J Surg*. 2015;102(10):1213–1219. PMID: 26148791 https://doi.org/10.1002/bjs.9866
8. Jansen JO, Moore EE, Wang H, Morrison JJ, Hutchison JD, Campbell MK, et al. Maximizing geographical efficiency: An analysis of the configuration of Colorado's trauma system. *J Trauma Acute Care Surg*. 2018;84(5):762–770. PMID: 29370062 https://doi.org/10.1097/TA.0000000000001802
9. Pfeifer R, Halvachizadeh S, Schick S, Sprengel K, Jensen KO, Teuben M, et al. Are Pre-hospital Trauma Deaths Preventable? A Systematic Literature Review. *World J Surg*. 2019;43(10):2438–2446. PMID: 31214829 https://doi.org/10.1007/s00268-019-05056-1
10. Polites SF, Leonard JM, Glasgow AE, Zielinski MD, Jenkins DH, Habermann EB. Undertriage after severe injury among United States trauma centers and the impact on mortality. *Am J Surg*. 2018;216(4):813–818. PMID: 30241769 https://doi.org/10.1016/j.amjsurg.2018.07.061
11. 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. PMID: 24662870 https://doi.org/10.1097/TA.0000000000000197
12. van Rein EAJ, van der Sluijs R, Houwert RM, Gunning AC, Lichtveld RA, Leenen LPH, et al. Effectiveness of prehospital trauma triage systems in selecting severely injured patients: Is comparative analysis possible? *Am J Emerg Med*. 2018;36(6):1060–1069. PMID: 29395772 https://doi.org/10.1016/j.ajem.2018.01.055
13. Horst MA, Jammula S, Gross BW, Cook AD, Bradburn EH, Altenburg J, et al. Undertriage in trauma: Does an organized trauma network capture the major trauma victim? A statewide analysis. *J Trauma Acute Care Surg*. 2018;84(3):497–504. PMID: 29283966 https://doi.org/10.1097/TA.0000000000001781
14. Fagerlind H, Harvey L, Candefjord S, Davidsson J, Brown J. Does injury pattern among major road trauma patients influence prehospital transport decisions regardless of the distance to the nearest trauma centre? – a retrospective study. *Scand J Trauma Resusc Emerg Med*. 2019;27(1):18. PMID: 30760302 https://doi.org/10.1186/s13049-019-0593-7
15. Mans S, Reinders Folmer E, de Jongh MA, Lansink KW. Direct transport versus inter hospital transfer of severely injured trauma patients. *Injury*. 2016;47(1):26–31. PMID: 26510409 https://doi.org/10.1016/j.injury.2015.09.020
16. Hamada SR, Delhaye N, Degoul S, Gauss T, Raux M, Devaud ML, et al. Direct transport vs secondary transfer to level I trauma centers in a French exclusive trauma system: Impact on mortality and determinants of triage on road-traffic victims. *PLoS One*. 2019;14(11):e0223809. PMID: 31751349 https://doi.org/10.1371/journal.pone.0223809
17. Rozenberg A, Danish T, Dombrovskiy VY, Vogel TR. Outcomes After Motor Vehicle Trauma: Transfers to Level I Trauma Centers Compared With Direct Admissions. *J Emerg Med*. 2017;53(3):295–301. PMID: 28528722 https://doi.org/10.1016/j.jemermed.2017.04.001

18. Gale SC, Peters J, Hansen A, Dombrovskiy VY, Detwiler PW. Impact of Transfer Distance and Time on Rural Brain Injury Outcomes. *Brain Inj*. 2016;30(4):437–440. PMID: 26963433 https://doi.org/10.3109/02699052.2016.1140808
19. Pickering A, Cooper K, Harnan S, Sutton A, Mason S, Nicholl J. Impact of prehospital transfer strategies in major trauma and head injury: systematic review, meta-analysis, and recommendations for study design. *J Trauma Acute Care Surg*. 2015;78(1):164–177. PMID: 25539218 https://doi.org/10.1097/TA.0000000000000483
20. Renson A, Schubert FD, Gabbe LJ, Bjurlin MA. Interfacility Transfer is Associated with Lower Mortality in Undertriaged Gunshot Wound Patients. *J Surg Res*. 2019;236:74–82. PMID: 30694782 https://doi.org/10.1016/j.jss.2018.11.011
21. Gomez D, Alali AS, Xiong W, Zarzaur BL, Mann NC, Nathens AB. Definitive care in level 3 trauma centres after severe injury: A comparison of clinical characteristics and outcomes. *Injury*. 2015;46(9):1790–1795. PMID: 26071325 https://doi.org/10.1016/j.injury.2015.05.047
22. Vickers BP, Shi J, Lu B, Wheeler KK, Peng J, Groner JI, et al. Comparative study of ED mortality risk of US trauma patients treated at level I and level II vs nontrauma centers. *Am J Emerg Med*. 2015;33(9):1158–1165. PMID: 26066772 https://doi.org/ 10.1016/j.ajem.2015.05.010
23. Bukur M, Teurel C, Catino J, Kurek S. The Price of Always Saying Yes: A Cost Analysis of Secondary Overtriage to an Urban Level I Trauma Center. *Am Surg*. 2018;84(8):1368–1375. PMID: 30185318
24. Galanis DJ, Steinemann S, Rosen L, Bronstein AC, Biffl WL. Rural Level III centers in an inclusive trauma system reduce the need for interfacility transfer. *J Trauma Acute Care Surg*. 2018;85(4):747–751. PMID: 30036262 https://doi.org/10.1097/TA.0000000000002033
25. Parikh PP, Parikh P, Mamer L, McCarthy MC, Sakran JV. Association of System-Level Factors with Secondary Overtriage in Trauma Patients. *JAMA Surg*. 2019;154(1):19–25. PMID: 30325989 https://doi.org/10.1001/jamasurg.2018.3209
26. Lynch KT, Essig RM, Long DM, Wilson A, Con J. Nationwide secondary overtriage in level 3 and level 4 trauma centers: are these transfers necessary? *J Surg Res*. 2016;204(2):460–466. PMID: 27565083 https://doi.org/10.1016/j.jss.2016.05.035
27. Brown E, Tohira H, Bailey P, Fatovich D, Pereira G, Finn J. Longer Prehospital Time was not Associated with Mortality in Major Trauma: A Retrospective Cohort Study. *Prehosp Emerg Care*. 2019;23(4):527–537. PMID: 30462550 https://doi.org/10.1080/10903127.2018.1551451
28. Byrne JP, Mann NC, Hoeft CJ, Buick J, Karanicolas P, Rizoli S, et al. The impact of short prehospital times on trauma center performance benchmarking: An ecologic study. *J Trauma Acute Care Surg*. 2016;80(4):586–596. PMID: 26808027 https://doi.org/ 10.1097/TA.0000000000000974
29. Kim J, Song KJ, Shin SD, Ro YS, Hong KJ, Holmes JF. Does Prehospital Time Influence Clinical Outcomes in Severe Trauma Patients?: A Cross Sectional Study. *Prehosp Emerg Care*. 2017;21(4):466–475. PMID: 28489503 https://doi.org/10.1080/10903127.2017.1294223
30. Newgard CD, Meier EN, Bulger EM, Buick J, Sheehan K, Lin S, et al. Revisiting the "Golden Hour": An Evaluation of Out-of-Hospital Time in Shock and Traumatic Brain Injury. *Ann Emerg Med*. 2015;66(1):30–41. PMID: 25596960 https://doi.org/10.1016/j.annemergmed.2014.12.004
31. Brown JB, Rosengart MR, Forsythe RM, Reynolds BR, Gestring ML, Hallinan WM, et al. Not all prehospital time is equal: Influence of scene time on mortality. *J Trauma Acute Care Surg*. 2016;81(1):93–100. PMID: 26886000 https://doi.org/10.1097/TA.0000000000000999
32. Harmsen AM, Giannakopoulos GF, Moerbeek PR, Jansma EP, Bonjer HJ, Bloemers FW. The influence of prehospital time on trauma patients outcome: a systematic review. *Injury*. 2015;46(4):602–609. PMID: 25627482 https://doi.org/10.1016/j.injury.2015.01.008
33. 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. PMID: 29417146 https://doi.org/10.1001/jamasurg.2017.6133
34. Tansley G, Schuurman N, Bowes M, Erdogan M, Green R, Asbridge M, et al. Effect of predicted travel time to trauma care on mortality in major trauma patients in Nova Scotia. *Can J Surg*. 2019;62(2):123–130. PMID: 30907993 https://doi.org/10.1503/cjs.004218.
35. Hu W, Dong Q, Huang B. Effects of distance and rescue time to medical facilities on traffic mortality utilizing GIS. *Int J Inj Contr Saf Promot*. 2018;25(3):329–335. PMID: 29460672 https://doi.org/10.1080/17457300.2018.1431931
36. Clements TW, Vogt K, Hameed SM, Parry N, Kirkpatrick AW, Grondin SC, et al. Does increased prehospital time lead to a "trial of life" effect for patients with blunt trauma? *J Surg Res*. 2017;216:103–108. PMID: 28807193 https://doi.org/10.1016/j.jss.2017.04.027
37. Alarhayem AQ, Myers JG, Dent D, Liao L, Muir M, Mueller D, et al. Time Is the Enemy: Mortality in Trauma Patients With Hemorrhage From Torso Injury Occurs Long Before the "Golden Hour". *Am J Surg*. 2016;212(6):1101–1105. PMID: 27832843 https://doi.org/10.1016/j.amjsurg.2016.08.018
38. 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. PMID: 28422905 https://doi.org/10.1097/TA.0000000000001508
39. Dooley JH, Ozdenerol E, Sharpe JP, Magnotti LJ, Croce MA, Fischer PE. Location, Location, Location: Utilizing Needs-Based Assessment of Trauma Systems-2 in Trauma System Planning. *J Trauma Acute Care Surg*. 2020;88(1):94–100. PMID: 31856019 https://doi.org/10.1097/TA.0000000000002463
40. Horst MA, Gross BW, Cook AD, Osler TM, Bradburn EH, Rogers FB. 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. PMID: 28590351 https://doi.org/10.1097/TA.0000000000001582
41. Tansley G, Schuurman N, Erdogan M, Bowes M, Green R, Asbridge M, et al. Development of a model to quantify the accessibility of a Canadian trauma system. *CJEM*. 2017;19(4):285–292. PMID: 28343457 https://doi.org/ 10.1017/cem.2017.9
42. Jansen JO, Morrison JJ, Wang H, He S, Lawrenson R, Hutchison JD, et al. Access to specialist care: Optimizing the geographic configuration of trauma systems. *J Trauma Acute Care Surg*. 2015;79(5):756–765. PMID: 26335775 https://doi.org/ 10.1097/TA.0000000000000827
43. Brown JB, Rosengart MR, Billiar TR, Peitzman AB, Sperry JL. Geographic distribution of trauma centers and injury-related mortality in the United States. *J Trauma Acute Care Surg*. 2016;80(1):42–49. PMID: 26517780 https://doi.org/ 10.1097/TA.0000000000000902
44. Winchell RJ, Xu P, Mount LE, Huegerich R. Development of a Geospatial Approach for the Quantitative Analysis of Trauma Center Access. *J Trauma Acute Care Surg*. 2019;86(3):397–405. PMID: 30531336 https://doi.org/10.1097/TA.0000000000002156
45. Amram O, Schuurman N, Yanchar NL, Pike I, Friger M, Griesdale D. Use of geographic information systems to assess the error associated with the use of place of residence in injury research. *Inj Epidemiol*. 2015;2(1):29. PMID: 26550555 https://doi.org/10.1186/s40621-015-0059-y.

46. Carr BG, Bowman AJ, Wolff CS, Mullen MT, Holena DN, Branas CC, et al. Disparities in access to trauma care in the United States: A population-based analysis. *Injury*. 2017;48(2):332–338. PMID: 28069138 https://doi.org/10.1016/j.injury.2017.01.008
47. Newgard CD, Fu R, Bulger E, Hedges JR, Mann NC, Wright DA, et al. Evaluation of Rural vs Urban Trauma Patients Served by 9-1-1 Emergency Medical Services. *JAMA Surg*. 2017;152(1):11–18. PMID: 27732713 https://doi.org/10.1001/jamasurg.2016.3329
48. Horst MA, Jammula S, Gross BW, Bradburn EH, Cook AD, Altenburg J, et al. Development of a trauma system and optimal placement of trauma centers using geospatial mapping. *J Trauma Acute Care Surg*. 2018;84(3):441–448. PMID: 29283969 https://doi.org/10.1097/TA.0000000000001782
49. Smedley WA, Stone KL, Killian J, Brown A, Farley P, Griffin RL, et al. Population Coverage of Trauma Systems: What Do Helicopters Add? *Am Surg*. 2019;85(9):1073–1078. PMID: 31638527
50. Brown JB, Gestring ML, Stassen NA, Forsythe RM, Billiar TR, Peitzman AB, et al. Geographic Variation in Outcome Benefits of Helicopter Transport for Trauma in the United States: A Retrospective Cohort Study. *Ann Surg*. 2016;263(2):406–412. PMID: 26479214 https://doi.org/10.1097/SLA.0000000000001047
51. Gomez D, Larsen K, Burns BJ, Dinh M, Hsu J. Optimizing access and configuration of trauma centre care in New South Wales. *Injury*. 2019;50(5):1105–1110. PMID: 30846283 https://doi.org/10.1016/j.injury.2019.02.018
52. Brown JB, Rosengart MR, Peitzman AB, Billiar TR, Sperry JL. Defining geographic emergency medical services coverage in trauma systems. *J Trauma Acute Care Surg*. 2019;87(1):92–99. PMID: 31260425 https://doi.org/10.1097/TA.0000000000002296
53. Hsia RY, Srebotnjak T, Maselli J, Crandall M, McCulloch C, Kellermann AL. The association of trauma center closures with increased inpatient mortality for injured patients. *J Trauma Acute Care Surg*. 2014;76(4):1048–1054. PMID: 24625549 https://doi.org/10.1097/TA.0000000000000166
54. Ciesla DJ, Pracht EE, Leitz PT, Spain DA, Staudenmayer KL, Tepas JJ 3rd. The trauma ecosystem: The impact and economics of new trauma centers on a mature statewide trauma system. *J Trauma Acute Care Surg*. 2017;82(6):1014–1022. PMID: 28328670 https://doi.org/10.1097/TA.0000000000001442
55. Pigneri DA, Beldowicz B, Jurkovich GJ. Trauma Systems: Origins, Evolution, and Current Challenges. *Surg Clin North Am*. 2017;97(5):947–959. PMID: 28958366 https://doi.org/10.1016/j.suc.2017.06.011
56. 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):576–579. PMID: 24553522 https://doi.org/10.1097/TA.0000000000000125
57. Bell TM, Boustany KC, Jenkins PC, Zarzaur BL. The relationship between trauma center volume and in-hospital outcomes. *J Surg Res*. 2015;196(2):350–357. PMID: 25840485 https://doi.org/10.1016/j.jss.2015.02.009
58. Caputo LM, Salottolo KM, Slone DS, Mains CW, Bar-Or D. The relationship between patient volume and mortality in American trauma centres: a systematic review of the evidence. *Injury*. 2014;45(3):478–486. PMID: 24129325 https://doi.org/10.1016/j.injury.2013.09.038
59. Minei JP, Fabian TC, Guffey DM, Newgard CD, Bulger EM, Brasel KJ, et al. Increased trauma center volume is associated with improved survival after severe injury: results of a Resuscitation Outcomes Consortium study. *Ann Surg*. 2014;260(3):456–465. PMID: 25115421 https://doi.org/10.1097/SLA.0000000000000873
60. Calland JF, Stukenborg GJ. Trauma centre patient volume and inpatient mortality risk reconsidered. *Injury*. 2016;47(5):1072–1077. PMID: 26654874 https://doi.org/10.1016/j.injury.2015.11.017
61. Brown JB, Rosengart MR, Kahn JM, Mohan D, Zuckerbraun BS, Billiar TR, et al. Impact of Volume Change Over Time on Trauma Mortality in the United States. *Ann Surg*. 2017;266(1):173–178. PMID: 27308736 https://doi.org/10.1097/SLA.0000000000001838
62. Ashley DW, Pracht EE, Garlow LE, Medeiros RS, Atkins EV, Johns TJ, et al. Evaluation of the Georgia trauma system using the American College of Surgeons Needs Based Assessment of Trauma Systems tool. *Trauma Surg Acute Care Open*. 2018;3(1):e000188. PMID: 30402557 https://doi.org/10.1136/tsaco-2018-000188

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