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ORIGINAL ARTICLE

A seven-center examination of the relationship between monthly volume and mortality in trauma: a hypothesis-generating study

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Abstract

Introduction The relationship between trauma volumes and patient outcomes continues to be controversial, with limited data available regarding the effect of month-to-month trauma volume variability on clinical results. This study examines the relationship between monthly trauma volume variations and patient mortality at seven Level I Trauma Centers located in the Eastern United States. We hypothesized that higher monthly trauma volumes may be associated with lower corresponding mortality.

Methods Monthly patient volume data were collected from seven Level I Trauma Centers. Additional information retrieved included monthly mortality, demographics, mean monthly injury severity (ISS), and trauma mechanism (blunt versus penetrating). Mortality was utilized as the primary study outcome. Statistical corrections for mean age, gender distribution, ISS, and mechanism of injury were made using analysis of co-variance (ANCOVA). Center-specific, annually-adjusted median monthly volumes (CSAA-MMV) were calculated to standardize patient volume differences across participating institutions. Statistical significance was set at $\alpha < 0.05$.

Results A total of 604 months of trauma admissions, encompassing 122,197 patients, were analyzed. Controlling for patient age, gender, ISS, and mechanism of injury, aggregate data suggested that monthly trauma volumes < 100 were associated with significantly greater mortality (3.9%) than months with volumes > 400 (mortality 2.9%, $p < 0.01$). To account for differences in monthly volumes between centers, as well as for temporal bias associated with potential differences over the entire study duration period, data were normalized using CSAA-MMV as a standardized reference point. Monthly volumes ≤ 33% of the CSAA-MMV were associated with adjusted mortality of 5.0% whereas monthly volumes ≥ 134% CSAA-MMV were associated with adjusted mortality of 2.7% ($p < 0.01$).

Conclusions This hypothesis-generating study suggests that greater monthly trauma volumes appear to be associated with lower mortality. In addition, our data also suggest that across all participating centers mortality may be a function of relative month-to-month volume variation. When normalized to institution-specific, annually-adjusted "median" monthly trauma contacts, we show that months with patient volumes ≤ 33% median may be associated with subtly but not negligibly (1.4–2.3%) higher mortality than months with patient volumes ≥ 134% median.

Keywords Care optimization · Mortality · Multi-center study · Population study · Trauma networks · Trauma outcomes · Trauma volumes

Introduction

The relationship between trauma volumes and patient outcomes continues to be controversial, with little available information regarding the effect of month-to-month trauma volume variability on clinical results. Evidence suggests that trauma center (TC) volumes may indeed be associated with outcomes, and that multiply-injured patients with

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life-threatening injuries benefit most from being treated at high-volume TCs [1]. However, this is not universally supported. For example, some authors have suggested that "Level I" versus "Level II" TC designation may be a more important determinant of outcomes than actual volumes [2]. Others emphasize that institutional outcomes, as opposed to volumes, should be used as primary determinants of TC care quality [3]. The latter approach was supported by an analysis of the National Trauma Databank looking at the relationship between TC volume and outcomes, which failed to demonstrate improved survival among higher volume TCs [4]. The aim of the current project was to investigate the relationship between monthly TC volumes and mortality across seven regional Level I trauma centers, and to determine whether center-specific volume fluctuations influence patient mortality. We hypothesized that higher monthly trauma volumes will be associated with lower observed monthly mortality.

Methods

Monthly trauma volume data were collected from seven Level I Trauma Centers between Jan 1998 and July 2016 (Fig. 1). Each participating TC utilized a similar three-tiered system of trauma alerts (a.k.a., trauma team activations, trauma responses, trauma "codes", or trauma notifications). Although the exact nomenclature regarding specific trauma activation/acuity levels may vary between institutions, fundamental principles were common across all participating TCs. Within this paradigm, highest level activations (16% of total patient contacts in this study) involved major trauma with evidence of life threatening injury and/or physiological compromise; intermediate level activations (46% of patient contacts) featured the presence of injury without significant physiologic compromise; and trauma consultations/notifications (38% of patient contacts) were characterized by the presence of injury requiring specialty trauma evaluation/follow-up in a stable patient.

In addition to monthly trauma volumes, abstracted registry information included monthly mortality, demographics, mean monthly injury severity (ISS), and mechanism of injury (blunt versus penetrating). Mortality was utilized as the primary study outcome. Statistical corrections for mean age, ISS, mechanism of injury, and patient gender were made to determine adjusted mortality rate. For the purposes of end-point determination, mortality was defined as death documented and defined within each institution's trauma registry.

Each TC's reported monthly volumes were standardized to the corresponding median volume for the available data during the respective study interval. Furthermore, to avoid temporal bias over the study duration, the baseline "median" monthly volume was re-set on annual basis for each reporting institution (e.g., for TC A in Fig. 1, "median" volume was calculated as "baseline" value for each of the reporting years from 1998 to 2015). This was termed "center-specific, annually-adjusted median monthly volume" (CSAA-MMV). Mortality determinations were then stratified according to the corresponding "standardized volume" categories. Analysis of co-variance (ANCOVA) was performed, controlling for mean age, gender distribution, ISS, and mechanism of injury. Statistical significance was set at $\alpha < 0.05$. At all participating institutions, IRB approval was obtained prior to conducting study-related activities.

	Years Reported																		
Institution	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
A	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	
B											x	x	x	x	x	x	x		
C															x	x	x	x	x
D																x	x	x	x
E													x	x	x	x	x	x	
F													x	x	x	x	x	x	
G													x	x	x	x	x	x	

Fig. 1 Data reporting grid for each participating institution. Within the grid, black boxes marked with "x" indicate the presence of data from each respective institution for the corresponding year. Green background areas indicate absence of data

Results

A total of 604 months of trauma admissions, reported variably by all seven contributing institutions (Fig. 1) and encompassing 122,197 patient encounters, were analyzed. Mean patient age was 47.3 ± 5.24 years, with 37.2% of the sample being female. Blunt injury mechanism was present in 89.7% of cases, with a mean ISS of 9.01 ± 1.64, mean initial GCS of 14.1 ± 1.58, and average monthly mortality of 3.27% for all reported study periods. Trauma center-specific data, injury mechanism, patient demographics, and outcome characteristics are shown in Table 1.

In terms of seasonal differences, we noted that winter months were associated with lower volumes and greater mortality, while summer months were characterized by higher volumes and mortality levels closer to "baseline" values (Fig. 2a, b). Average patient age fluctuated seasonally (Fig. 2c) with winter months being associated with significantly older mean patient ages compared to summer months. The percentage of male patients was greater during summer and early fall months (Fig. 2d). No significant differences were seen within the yearly cycle in terms of composite ISS or blunt versus penetrating trauma (Fig. 2e, f).

Controlling for patient age, ISS, gender, and mechanism of injury, we found that months with < 100 trauma encounters were associated with significantly greater adjusted mortality (3.9%) than months with volumes > 400

Table 1 Characteristics of reported data, grouped by participating center

Institution	Months reported (n)	Average monthly volume	Male patients (%)	Blunt mechanism (%)	Average monthly ISS	Raw mortality (%)	Adjusted mortality (%)	Average age (years)
A	208	153.1	60.4	94.40	8.91	3.22	3.20	46.2
B	84	199.6	60.5	85.80	7.38	2.82	3.60	44.2
C	56	150.0	55.2	93.40	10.04	3.22	2.00	56.6
D	39	166.1	66.3	89.95	6.95	2.13	2.90	47.5
E	72	430.4	67.0	91.05	9.50	3.17	4.30	46.2
F	72	204.6	69.8	77.94	8.81	4.59	4.50	44.6
G	72	180.2	64.9	88.20	11.25	4.37	3.00	50.6

Adjusted mortality results are controlled for patient's age, gender, ISS, injury mechanism (blunt versus penetrating) and monthly volume characteristics

patients (mortality 2.9%, $p<0.01$, Fig. 3). However, due to differences between contributing TCs in terms of average monthly volume ranges, we normalized data using CSAA-MMV as a standardized point of reference. The intent of CSAA-MMV was to offset the effect of volume differences between participating TCs and to reduce any temporal or other purely volume-related biases within each reporting TC. Using CSAA-MMV, monthly volumes ≤ 33% of the "median center-specific, annually-adjusted volume" were associated with adjusted mortality of 5.0% while monthly volumes ≥ 134% of the "median" were associated with adjusted mortality of 2.7% ($p<0.01$, Fig. 4). There was also a weak, but significant negative correlation between CSAA-MMV and monthy mortality quantized in 0.5% increments ($r = -0.16$, $p < 0.01$).

Finally, in an attempt to further reduce the effect of temporal bias and changes in therapeutic approaches over time, all pre-2008 data from institution A were excluded and repeat subset analyses were performed using the truncated dataset. Utilizing the previously employed statistical procedure, our data once again showed that monthly volumes correlated with mortality, mirroring the original results (Table 2).

Discussion

This hypothesis-generating study suggests that monthly trauma volume variations may correlate with mortality. These findings have not been described in the past, neither within a similar context nor with the same level of granularity. More specifically, regardless of how busy a given TC was at baseline, periods of relatively slower activity were associated with higher mortality and increased activity was associated with lower mortality across all participating institutions. Standardized to CSAA-MMV, mortality was significantly higher for normalized volumes of ≤ 33% of median when compared to normalized volumes of ≥ 134% of median (Fig. 4). These results become even more profound when one considers that most significant differences between reporting centers, up to and including monthly volume characteristics, as well as adjustments for median volume differences between consecutive years, were taken into consideration during final analyses. It is not certain whether the relative lack of published evidence in this area may have been a consequence of "lack of interest" in the topic, the potentially "political" nature of the subject, or whether studies on the topic simply have not been published in sufficiently large numbers to provide a meaningful "baseline understanding" of the issue.

Literature in this general area is inconsistent, showing conflicting results. In a study by Smith, et al. [5], TC volume of "significantly injured" patients did correlate with outcomes, with low-volume centers being considered to see < 140 such patients per year while high-volume TCs treating > 200 "significantly injured" trauma contacts per year. Although important differences exist between our trauma sample and the population described by Smith and colleagues [5], certain generalizations can be made. For example, our data show that the average monthly volume for each individual TC did not necessarily correlate with patient outcomes. Rather, we noted that "slower" months (e.g., < 200 traumas) had higher mortality than "busier" months (e.g., > 200) largely independent of the reporting institution. It is interesting to note that although monthly trauma volumes of < 200 may be associated with higher mortality, no currently available evidence points to an "upper" inflection point, at which mortality could theoretically increase due to limited availability of resources and logistics at "extremely high" TC volumes. In fact, neither of our two models (e.g., those based on absolute or median volumes) demonstrated any substantial evidence of such an "upper" inflection point. It is possible that the current study, looking at aggregate numbers from

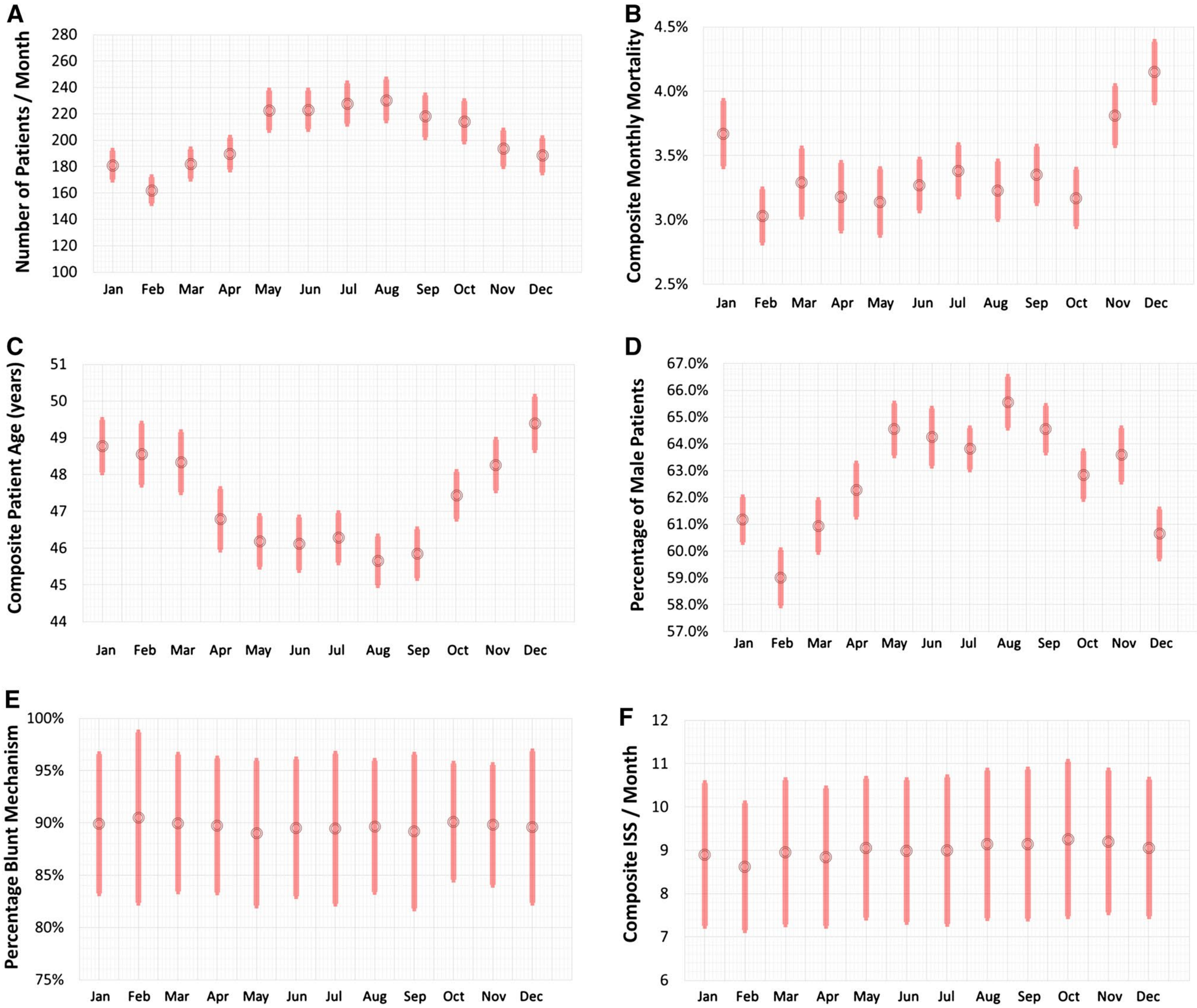

Fig. 2 **a** Mean composite monthly volumes for all seven participating centers (*x*-axis shows month of the year; y-axis shows average number of trauma contacts; vertical bars represent standard error). **b** Mean composite monthly mortality for all seven reporting centers (*x*-axis shows month of the year; *y*-axis shows average trauma mortality; vertical bars represent standard error). **c** Mean composite monthly patient age for all seven reporting centers (*x*-axis shows month of the year; y-axis shows average patient age; vertical bars represent standard error). **d** Mean composite monthly percentage of male patients for all seven reporting centers (x-axis shows month of the year; *y*-axis shows average percentage of male patients; vertical bars represent standard error). **e** Mean composite monthly percentage of blunt injuries for all seven reporting centers (*x*-axis shows month of the year; *y*-axis shows average percentage of blunt injuries; vertical bars represent standard error). **f** Mean composite monthly injury severity score (ISS) for all seven reporting centers (*x*-axis shows month of the year; *y*-axis shows average ISS; vertical bars represent standard error)

seven institutions, is insufficient to detect subtle differences or effectively illustrate resource-specific patient care demands that may indeed be associated with clinical outcomes (e.g., emergency room or intensive care understaffing, competing systemic priorities such as concurrent acute care surgery responsibilities, weekday versus weekend occurrences, the effect of trauma transfers on diagnostic and therapeutic delays, etc.) [6–10]. Beyond our stated findings that higher monthly volumes may be associated with lower mortality, we are unable to determine whether increases in trauma volumes beyond the highest monthly volume range in this study would continue to be associated with lower mortality or whether an increase in mortality would eventually be seen at the so-called "resource saturation" point. Until appropriate multivariate analyses with sufficient data granularity can be conducted, it will be impossible to identify any points of "resource saturation" with certainty. Also, given the aggregate nature of our data, based on monthly reporting (and thus relatively poor granularity), it is impossible to make any conclusive

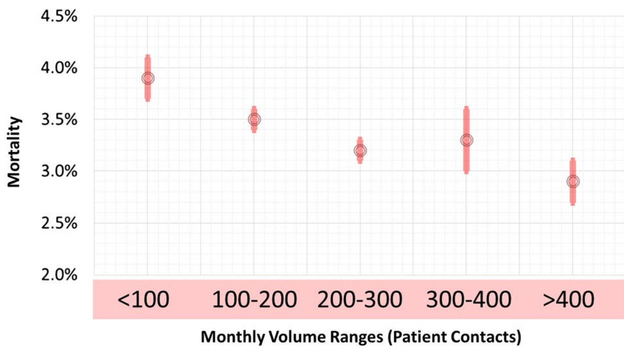

Fig. 3 Relationship between corrected raw monthly trauma volumes and corresponding monthly mortality. The *x*-axis shows absolute monthly trauma volumes while the *y*-axis represents adjusted mortality. Statistical corrections included ISS, mechanism of injury, patient age and gender

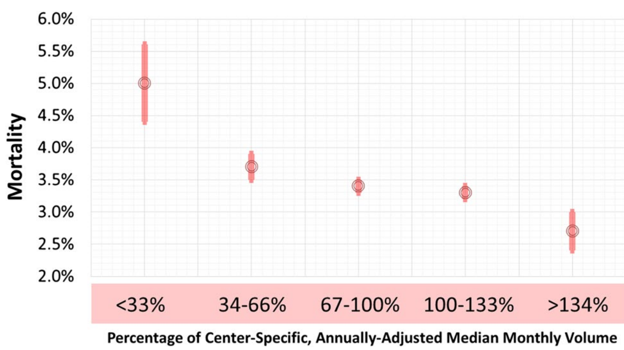

Fig. 4 Relationship between corrected center-specific, annually-adjusted median monthly volumes (CSAA-MMV) and corresponding monthly mortality corrected for ISS, mechanism of injury, patient gender, and age. The *x*-axis shows CSAA-MMV ranges while the *y*-axis represents adjusted mortality

statements regarding our observations until independent verification of these results is performed.

Based on the current analysis of multi-center data, our research indicates that larger absolute monthly volumes do correlate with better patient outcomes. Although the observed absolute 1% difference in mortality between months with < 100 trauma contacts and > 400 trauma contacts does not appear to be clinically profound, when translated to a national or global level, it could potentially translate into many thousands of lives saved each year. Borrowing from a high prevalence example in cardiology, both 30-day and one-year mortality differences of 1% between patients with coronary artery occlusion receiving accelerated tissue plasminogen activator and those treated with other regimens translate into roughly 10 lives saved per 1,000 patients treated [11].

Similar to Smith, et al. [5], we postulate that the relationship between TC volume and mortality provides strong support for configuring our trauma systems in a fashion that supports trauma patient volume optimization, careful review of existing trauma networks in this context, and ensuring that the most seriously injured individuals are treated at the busiest regional centers. Most importantly, our current data also suggest that within each TC studied, there is a slight but noticeable difference in mortality between "low-volume" and "high-volume" periods. If independently confirmed, our results would potentially lend support for initiatives aimed at trauma volume flow optimization and/or maintenance of readiness among TCs, regardless of baseline volume characteristics, similar to the way firefighting or military organizations perform "readiness drills" during periods of relative calm. Such maintenance of readiness may be facilitated by modern, high fidelity virtual reality simulation models [12–14]. In the era of electronic patient tracking, hypothetically speaking, real-time volume dashboards could be used to trigger a simulation.

We also observed important seasonal differences in a number of key trauma outcome parameters. For example, the proportion of male patients as the subset of overall study sample was substantially greater between May and September (63.8–65.6%) than it was between December and March (59.0–61.2%). The mean age of patients demonstrated an inverse behavior during the corresponding periods (45.6–46.3 versus 48.3–49.4 years). Of interest, no significant differences were seen in blunt versus penetrating mechanism of injury or in overall trauma severity across the seasonal progression.

Looking at seasonal differences in trauma volume and mortality, we noted that mortality tended to be higher during the winter months, which also corresponded to periods of

Table 2 Key study analyses using the truncated dataset (Institution A's pre-2008 data were removed)

Volume range (non-normalized)	< 100	100–200	200–300	300–400	400
Monthly mortality, $p < 0.01$ (mean ± std. error)	5.30 ± 1.30%	3.50 ± 0.80%	3.20 ± 0.10%	3.10 ± 0.10%	2.70 ± 0.30%
CSAA-MMV ranges	< 33%	34–66%	67–100%	101–133%	> 134%
Monthly mortality, $p < 0.04$ (mean ± std. error)	3.77 ± 0.81%	3.65 ± 0.41%	3.33 ± 0.13%	3.08 ± 0.10%	2.34 ± 0.21%

Note that the observed trends, both for normalized and non-normalized volume data, are similar to those reported for the complete original data-set (again controlling for age, gender, ISS, and mechanism in both cases)

CSAA-MMV Center-specific, annually-adjusted median monthly volume significantly lower volumes. The exact nature of the relationship remains difficult to define. However, the two phenomena may well be linked, especially when one considers that the average age of patients during the winter months was significantly greater as compared to summer months. A number of important characteristics associated with seasonal trauma patterns and outcomes have been proposed, including geographic, gender-based, anatomic considerations, as well as injury mechanism and severity [15–19]. Our attempt at correcting for these subtle—yet potentially significant seasonal differences—involved the inclusion of gender, age, blunt versus penetrating trauma mechanism, and ISS as covariates in our overall model.

The number of isolated time periods when trauma volume drops below a certain critical threshold warrants evaluation as a potential metric of care quality, especially for high volume TCs that see large volumes of patients on seasonal or episodic basis. In theory, this is not much different from "readiness assessment" or "practice drills" that firefighters or the military personnel conduct in order to ensure continued competency, both in terms of cognitive and physical skills [20–22]. Lack of readiness can be a major source of stress among emergency providers [22, 23]. It is also well documented that stress can adversely affect both mental and skills-based tasks [22, 24]. More information is required to "connect the dots" in our current, very limited understanding of operational readiness in the context of fluctuating clinical, cognitive, and physical demands. Experiences with formalized video reviews of trauma resuscitations and virtual reality simulations suggest that individual performance can improve in a number of domains pertaining to readiness and maintenance of both cognitive and non-cognitive skills [25–28].

There are important limitations of this study, making it largely a preliminary, hypothesis-generating exercise. First, its retrospective nature predisposes our data to biases. Second, our data reflect aggregate monthly reporting and lack sufficient granularity to warrant any conclusions until independently confirmed. Further assessment of the relationship between period-specific trauma volume variations and mortality (as well as other outcomes) will require much more sophisticated statistical methodology, including risk adjustment at the level of individual cases or closer scrutiny of time scales using much greater data granularity (e.g., daily or weekly intervals). Third, the current results do not reflect the full spectrum of TCs (e.g., only Level I centers were included) and volume ranges. In fact, many centers see volumes both lower and higher than our reported volume ranges. Consequently, it is still possible that extremely high trauma volumes may be associated with an upward inflection in mortality beyond the range described in this report. It is also possible that unforeseen biases within the current data preclude generalizability of our results. Also within this context, Institution A contributed significantly more data than others. While this could potentially introduce temporal bias, mortality data normalization for institution-specific, annually-adjusted volume characteristics provides some degree of assurance that our final results are not disproportionately skewed by undue biases. Moreover, data analyses using a truncated dataset from Institution A produced results generally consistent with analyses using global dataset. Fourth, although our data were standardized and corrections were made for key differences in trauma volume, injury severity score and patient characteristics, it is possible that additional considerations in this complex overall model could further modify our final results. Finally, we do not know the exact resources available at each trauma center on daily basis (e.g., the number of attending trauma surgeons, fellows, residents, advance practitioners, nurses). Emergency department volumes, intensive care bed availability, and staffing levels were not available for analysis, either. All of the above variables may have additionally contributed to trauma outcomes.

Conclusion

In addition to demonstrating a subtle inverse association between trauma volumes and mortality, this hypothesis-generating study provides preliminary evidence that across all participating centers mortality may also be a function of relative month-to-month volume variations. When normalized to CSAA-MMV, our data suggest that monthly volumes $\leq 33\%$ may be associated with subtle increase in mortality when compared to monthly volumes $\geq 134\%$. This finding, in turn, lends support to the hypothesis that month-to-month TC efficiency may increase with greater period-specific patient volumes. However, lack of data granularity precludes any definitive conclusions based on the current investigation and further studies are warranted to independently validate our observations, assess whether the negative effect of monthly volumes below 33% of center-specific "median" can be overcome with case-based simulation or other forms of ongoing preparedness training, and whether volumes in excess of 134% are associated with an institutional "saturation point" beyond which the volume-mortality relationship results in less favorable outcomes. The trauma community must continue to carefully, systematically, and critically review its performance and any factors potentially associated with patient outcomes. This is especially important in the era where an impasse in further improvement of already excellent outcomes requires a more global examination of "when, where, and how we do things".

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Compliance with ethical standards

Conflict of interest Drs. Stanislaw P. Stawicki, Keith Habeeb, Niels D. Martin, M. Shay O'Mara, James Cipolla, David C. Evans, Creagh Boulger, Babak Sarani, Charles H. Cook, Alok Gupta, William S. Hoff, Peter G. Thomas, Jeffrey M. Jordan, Weidun Alan Guo, and Mark J. Seamon declare no conflicts of interest related to this scholarly work.

Ethical standards The conduct of this study was approved by Institutional Review Boards at each participating institution. Research procedures have been performed in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki and its later amendments.

References

1. Nathens AB, et al. Relationship between trauma center volume and outcomes. JAMA. 2001;285(9):p. 1164–71.
2. Demetriades D, et al. The effect of trauma center designation and trauma volume on outcome in specific severe injuries. Ann Surg. 2005;242(4):512–9.
3. London JA, Battistella FD. Is there a relationship between trauma center volume and mortality? J Trauma Acute Care Surg. 2003;54(1):16–25.
4. Glance LG, et al. The relation between trauma center outcome and volume in the National Trauma Databank. J Trauma Acute Care Surg. 2004;56(3):682–90.
5. SMITH RF, et al. The impact of volume on outcome in seriously injured trauma patients: two years' experience of the Chicago Trauma System. J Trauma Acute Care Surg. 1990;30(9):1066–76.
6. Di Bartolomeo S, et al. A population based study on the night-time effect in trauma care. Emerg Med J. 2014;31(10):808–12.
7. Kiekkas P, et al. Association between nursing workload and mortality of intensive care unit patients. J Nurs Scholarsh. 2008;40(4):385–90.
8. Zare MM, et al. Mortality after nonemergent major surgery performed on Friday versus Monday through Wednesday. Ann Surg. 2007;246(5):866–74.
9. de Alencar C. Preventable trauma deaths. Rev Saúde Pública, 2012. 46(2):1–8.
10. Egol KA, et al. Mortality rates following trauma: the difference is night and day. J Emerg Trauma Shock. 2011;4(2):178.
11. Califf RM, et al. One-year results from the Global Utilization of Streptokinase and TPA for Occluded Coronary Arteries (GUSTO-I) trial. GUSTO-I Investig Circ. 1996;94(6):1233–8.
12. Eppich WJ, et al. The role of high-fidelity simulation in training pediatric emergency medicine fellows in the United States and Canada. Pediatr Emerg Care. 2013;29(1):1–7.
13. Freeman KM, et al. A virtual reality patient simulation system for teaching emergency response skills to US Navy medical providers. Prehospital Disaster Med. 2001;16(01):3–8.
14. Alexander AL, et al. From gaming to training: A review of studies on fidelity, immersion, presence, and buy-in and their effects on transfer in pc-based simulations and games. DARWARS Train Impact Group. 2005;5:1–14.
15. Emaus N, et al. Hip fractures in a city in Northern Norway over 15 years: time trends, seasonal variation and mortality. Osteoporosis Int. 2011;22(10):2603–10.
16. Crawford JR, Parker MJ. Seasonal variation of proximal femoral fractures in the United Kingdom. Injury. 2003;34(3):223–5.
17. Robertson A, et al. Spinal injury patterns resulting from car and motorcycle accidents. Spine. 2002;27(24):2825–30.
18. Brown B, Baass K. Seasonal variation in frequencies and rates of highway accidents as function of severity. Transp Res Rec J Transp Res Board. 1997;1581:p. 59–65.
19. Klauber MR et al. The epidemiology of head injury a prospective study of an entire community—San Diego County, California, 1978. Am J Epidemiol. 1981;113(5):500–9.
20. Smith DL, Manning T, Petruzzello SJ. Effect of strenuous live-fire drills on cardiovascular and psychological responses of recruit firefighters. Ergonomics. 2001;44(3):244–54.
21. Bolstad CA, Endsley MR, Cuevas HM. A theoretically based approach to cognitive readiness and situation awareness assessment, in teaching and measuring cognitive readiness. Berlin: Springer; 2014. pp. 161–77.
22. von Lubitz D, et al. Medical readiness in the context of operations other than war: Development of first responder readiness using OODA-Loop thinking and advanced distributed interactive simulation technology. In Proceedings EMISPHERE 2004 symposium on European-Mediterranean Virtual Hospital, Istanbul (Turkey). 2004.
23. Farkašovská D, Ferenc J, Training program to increase. The resistance of members of fire and rescue services at the airport. Acta Avionica. 2013;15(27).
24. Stawicki S, et al. Fundamentals of patient safety in medicine and surgery. New Delhi: Wolters Kluwer Health (India) Pvt Ltd.; 2014.
25. Scherer LA, et al. Videotape review leads to rapid and sustained learning. Am J Surg. 2003;185(6):p. 516–20.
26. Seymour NE, et al. Virtual reality training improves operating room performance: results of a randomized, double-blinded study. Ann Surg. 2002;236(4):458–64.
27. Difede J, et al. Virtual reality exposure therapy for the treatment of posttraumatic stress disorder following September 11, 2001. J Clin Psychiatry. 2007;68(11):1639.
28. Reznek M, Harter P, Krummel T. Virtual reality and simulation: training the future emergency physician. Acad Emerg Med. 2002;9(1):78–87.

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