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RESEARCH METHODS AND STATISTICS

Association of Direct Helicopter Versus Ground Transport and In-hospital Mortality in Trauma Patients: A Propensity Score Analysis

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Abstract

Objectives: Helicopter emergency medical services (HEMS) transport of trauma patients has been used for decades. Its use, however, is still a subject of debate, including issues such as high costs, increasing numbers of crashes, and conflicting results regarding effectiveness in reducing mortality. The aim of this study was to examine whether mode of transport (HEMS vs. ground EMS) is independently associated with mortality among trauma patients transported directly from the scene of injury to definitive care.

Methods: All trauma patients transported directly to a Level I or Level II trauma center by either air or ground EMS over a 4-year period were selected from the Oklahoma State Trauma Registry. Multivariable logistic regression was used to develop propensity scores based on variables measured at the scene of injury. The propensity scores represented the predicted probabilities of a patient being transported by HEMS given a specific set of characteristics and were used as a composite confounding variable in subsequent models of the association of mortality and mode of transport. Along with the propensity scores, Injury Severity Scores (ISS), initial Revised Trauma Score (RTS), and distance from the trauma center were included in a Cox proportional hazards model of the association of mode of transport and 24-hour and 2-week mortality.

Results: Overall, the hazard ratio (HR) for 2-week mortality in patients transported by HEMS was 33% lower (HR = 0.67, 95% confidence interval [CI] = 0.54 to 0.84) than in patients transported by ground EMS from the scene of injury, after adjustment for the propensity score and other covariates. In subanalyses, the apparent association of a reduction in the hazard of early mortality among patients transported by HEMS was most evident for patients with an RTS based on injury scene vital signs of 3 to 7 (HR = 0.61, 95% CI = 0.46 to 0.82). The point estimate of the HR was similar (HR = 0.65 95% CI = 0.34 to 1.2) in the 75% of cases who had normal vital signs at the scene of injury, although it was no longer statistically significant because crude mortality was very low (1.7%) in this group. Among those with a RTS of 3 or less at the scene, crude mortality was 58%, and mode of transport was not associated with mortality (HR = 1.02, 95% CI = 0.68 to 1.6).

Conclusions: Helicopter EMS transport was associated with a decreased hazard of mortality among certain patients transported from the scene of injury directly to definitive care. Refinements in scene triage and transport guidelines are needed to more effectively select patients that may benefit from HEMS transport from those unlikely to benefit.

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The transport of trauma patients to definitive care plays a vital role in any trauma system.[1,2] Emergency medical services (EMS) are often limited, especially in rural areas, and emergency responders must decide how best to use resources to get patients to appropriate levels of care without delay. The decision involves choosing between ground or helicopter ambulances and the choice has many implications. Helicopter emergency medical services (HEMS) can cover greater distances more quickly than ground ambulances[3] and usually are staffed by experienced, expert personnel.[4] However, they are a limited resource, and their use results in a substantially higher financial cost for the patient compared to ground EMS transport.[5–7] Ground ambulances are generally more regionally distributed and can be at the scene of an accident quickly. However, ground personnel vary in their level of expertise and experience, and travel by ground may delay treatment if the scene of injury is far from the appropriate trauma center.

Despite numerous studies of the association of trauma mortality and helicopter transport of trauma patients[6–18] spanning some 25 years, the topic continues to be the subject of debate.[4,19] The settings, patients, training level of HEMS crews, and study methodologies vary considerably among these studies, making it difficult to compare and generalize results. Numerous studies[8–11,14] use Trauma and Injury Severity Score (TRISS)-predicted survival probabilities[20] to calculate the expected number of deaths and compare them with the observed number. Other studies directly compare HEMS-transported with ground-transported patients using multivariable models to adjust for differences between groups.[6,7,17] Some have found a reduction in overall trauma mortality associated with air transport,[8,9,11,17,18] and some[6,7,21] have shown a reduction in mortality for only certain subgroups of patients. Still others[14] have found no reduction in mortality for HEMS-transported patients compared to those transported by ground ambulance.

Studies that compare outcomes of HEMS-transported patients to those transported by ground are limited by a lack of prehospital data, time and distance data, other missing data, and inadequate control of numerous potentially confounding variables. If between-group differences in the distribution of covariates are sizeable and are not adjusted, estimates of the effect of interest will be biased.[22–24]

Even when multivariable models are used to simultaneously adjust for covariates, the number of covariates that can be included is limited. The use of propensity scores has been proposed as an effective means of accommodating large numbers of covariates.[22–25] Randomized controlled trials assign treatments randomly so groups should be comparable with respect to covariates other than the treatment. In observational research, treatments are not randomly assigned, so patients may differ significantly with respect to other covariates associated with the outcome of interest. A propensity score represents a conditional probability, based on a number of covariates, that a patient will be "treated" or "exposed." In this study, the score reflects the probability that a trauma patient will be transported by helicopter. The propensity score can then be used as a composite confounding variable within a regression analysis or can be used to match patients from each transport group, thereby balancing numerous confounding variables between injured patients transported directly to a trauma center by HEMS versus those transported by ground ambulance. Since a randomized controlled trial will likely never be conducted, the analytic method provides a novel approach to analysis of the ongoing question of the association of HEMS transport and trauma mortality. The objective of this study was to determine the association between modes of transport from the scene of injury to definitive care and 2-week and 24-hour mortality among trauma patients after adjusting for the "propensity" to be flown and numerous hospital covariates.

Two previous studies[6,7] were identified in the HEMS literature that evaluated HEMS transport within an entire statewide trauma system: one in Pennsylvania[6] and the other in North Carolina.[7] At the time these studies were done, these states had 28 and eight accredited trauma centers, respectively. This study was conducted in Oklahoma, which has a large, rural population and only one Level I trauma center, located in Oklahoma City, and two Level II trauma centers, both in Tulsa. The HEMS medical staff in Oklahoma is nearly always composed of a nurse and paramedic. Oklahoma's setting is one for which HEMS transport services may be of particular importance[3] and thus serves as an ideal setting for further examination of the mortality risk in trauma patients transported by helicopter versus ground ambulance.

METHODS

Study Design

A retrospective cohort design was used to assess the association of 2-week mortality with mode of transport from the scene of injury to definitive care, designating helicopter-transported patients as "exposed" and ground-transported patients as "unexposed." Institutional review board approval was obtained from both the Oklahoma State Department of Health and the University of Oklahoma Health Sciences Center.

Study Setting and Population

All trauma patients injured in Oklahoma by a blunt or penetrating mechanism, and transported by EMS directly from the scene of injury to a Level I or Level II trauma center by either ground or helicopter ambulance from January 1, 2005, through December 31, 2008 (n = 10,268), were identified from the Oklahoma Trauma Registry (OTR). Reporting to the OTR is mandatory for all 108 state-licensed, acute-care hospitals. The OTR major inclusion and exclusion criteria are shown in Table 1. The criteria do not prevent hospitals from reporting additional trauma patients, and many lower-severity patients are reported to the OTR. In addition to major trauma patients, the OTR requires all injured patients transferred from one hospital to another be reported. Oklahoma has no statewide air transport criteria. Patients whose primary injury type was burns, who were transferred from another hospital, or who

Table 1
Oklahoma State Trauma Registry Major Trauma Inclusion and Exclusion Criteria

ICD-9 Code Between 800 and 959.9
And at least ONE of the following
Length of stay ≥ 48 hours
ED disposition to surgery or intensive care unit
Transfer from another acute care facility
Dead on arrival or die while in the hospital
AND at least ONE of the following
AIS score of 3 or higher
ISS of 9 or higher
TRISS score of < 0.9
Burn survival probability of < 0.9
Death
Exclusions
Same level falls with isolated orthopedic injury
Poisonings
Submersion injuries
Asphyxiation

AIS = Abbreviated Injury Scale; ICD-9 = International Classification of Diseases, 9th revision; ISS = Injury Severity Score; TRISS = Trauma and Injury Severity Score.

were injured in another state were excluded. Events for which zip code was missing were also excluded from analyses (n = 41). Additionally, patients who had a Glasgow Coma Scale (GCS) score of 3 and a blood pressure, heart rate, and respiratory rate of 0 (traumatic arrest), both at the scene and on arrival at the emergency department (ED), and were pronounced dead on arrival, were excluded (n = 62). Exclusions resulted in a final sample size of 10,184 cases.

Study Protocol

To select covariates for inclusion in constructing the propensity scores, variables were screened for associations with mode of transport. Covariates identified from previous work as being associated with the decision to transport trauma patients by helicopter or ground ambulance were selected first. All of the variables associated with the transport decision were derived from the prehospital setting; no hospital-related variables were included in the construction of the propensity scores since they could not have influenced the transport decision. The prehospital variables considered for inclusion were age, sex, mechanism of injury, scene GCS score, scene systolic blood pressure (sBP), scene respiratory rate, anatomic triage criteria, whether the patient was intubated, whether the patient was injured in an area served by a basic- or intermediate-level ground EMS service versus paramedic, hospital region (i.e., Oklahoma City or Tulsa), whether the patient was injured during daylight hours, and road distance to trauma center. Although scene sBP and anatomic criteria lacked a statistically significant association with mode of transport, both were strongly associated with mortality, and thus they were retained in the propensity score model. Road distances to the trauma center were calculated using the Network Analyst extension of ArcGIS software. The centroids of the 5-digit zip code for the scene of injury location were used as the starting point for distance calculations. The full physical address of the receiving trauma center was used as the end point.

In addition to the prehospital covariates, hospital variables were screened for inclusion in the propensity-adjusted regression analyses of mortality outcomes. The hospital variables considered for inclusion were revised trauma score (RTS) at arrival; injury severity score (ISS) grouped as <9, 9 to 14, 16 to 24, or >24; time in minutes from receipt of the first EMS call to arrival at the ED; and time in minutes from receipt of the first EMS call to time of death.

With the exception of respiratory rate, sBP, and anatomic criteria, which were recorded at the scene of injury, data for other covariates were obtained for more than 95% of all incidents. Scene respiratory rate was missing for 10.3% of the patients, and scene sBP was missing for 7.4% of the patients. The anatomic criteria variable (Appendix A) was recorded as "yes" if any one of the anatomic criteria were indicated. However, there is not an explicit "no" recorded by EMS personnel if a criterion is not present, so it was not possible to calculate completeness of this variable. Under the assumption that values were missing at random, multiple imputation using SAS Proc MI with the Markov Chain Monte Carlo method was used to impute all missing prehospital and hospital vital sign measurements.[26,27] Neither missing times nor distances were imputed.

Data Analysis

Differences between helicopter and ground ambulance transports in both prehospital and hospital covariates were tested using chi-square and Cochran-Mantel-Haenszel tests for categorical covariates and the Mann-Whitney U test for continuous covariates. Covariates were tested for associations with 24-hour or 2-week mortality using the same methods. Variables with a $p < 0.20$ in bivariate tests of association with either transport mode or 24-hour or 2-week mortality were selected for entry in the multivariable models used to develop the propensity scores or for inclusion in the propensity-adjusted multivariable outcome model.

Prehospital variables identified from the screening process described above were used in a multivariable logistic regression model to obtain predicted probabilities that a patient would be transported using a helicopter. The probabilities predicted by this model for each patient were then used as that patient's propensity score. SAS Proc RANK grouped the distribution of all propensity scores into quintiles, after which the numbers of helicopter and ground patients represented in each quintile were assessed. Quintiles in which either helicopter or ground patients comprised less than 10% of the total group were deemed too imbalanced with respect to confounding covariates to permit a valid comparison between the modes of transport. These imbalanced quintiles were excluded from the sample used to model the association of 2-week mortality and transport mode.

After excluding patients in the lowest propensity score quintile, SAS Proc PHREG was used to develop multivariable proportional hazards regression models of the association of in-hospital mortality and mode of transport using the propensity score as a composite confounding variable. The time of follow-up was limited to 14 days, since only 58 (7%) of the 814 recorded deaths occurred after this time, and it was considered unlikely that deaths beyond this time would be associated with the mode of transport. Separate models were developed to examine the association of mode of transport with overall 2-week mortality and for 24-hour mortality. The initial model included the propensity score, mode of transport, categorical ISS, and RTS. Time from receipt of first EMS call to arrival at the trauma center and distance from the scene to the trauma center were highly correlated ($r = 0.71$), and thus, it was not appropriate to include both in the mortality model. Distance was retained in the model to adjust for differences in travel distances between HEMS and ground ambulances. A mode-by-time interaction was created as the product of mode and the log of time to death and entered into the model to test the proportional hazards assumption for the analysis of effect of mode of transport. All data analyses were performed using SAS software version 9.1.3 (SAS Institute, Cary, NC).

RESULTS

Selected characteristics of the 10,184 eligible trauma cases reported to the OTR during the 4-year period are shown in Table 2. Crude mortality was higher for the HEMS-transported patients, and HEMS-transported patients were injured farther away from and took longer to arrive at the trauma center. HEMS-transported patients also had slightly lower RTS scores and greater proportions of patients in the higher injury severity categories.

Table 3 summarizes the covariates retained in the regression model that produced the propensity scores. Statistically significant differences between helicopter and ground ambulances were observed for each covariate. After adjusting for the propensity score, however, there were no longer differences between covariates and mode of transport, indicating that using the propensity score was effective in controlling for these confounders.

Table 2
Total Patients, Crude Mortality, Mean Distance From Scene to Trauma Center, Mean Time From First Call Received to Arrival At Trauma Center, RTS, and ISS by Mode of Transport

	Helicopter	Ground
Total patients	2,717	7,467
Number of deaths	274	540
Mortality proportion, %	10.1	7.2
Mean distance from trauma center, miles (SD)	53 (±31)	11 (±12)
Mean time from call received to arrival at trauma center, minutes	74 (±28)	45 (±28)
Initial ED RTS, mean (±SD)	6.4 (±2.3)	7.3 (±1.5)
Injury Severity Score, %		
ISS < 9	11	21
ISS 9 to 14	32	43
ISS 16 to 24	24	19
ISS > 24	33	17

ISS = Injury Severity Score; RTS = revised trauma score.

HEMS-transported patients constituted only 8% of the lowest quintile of propensity scores. This lowest quintile was therefore excluded from the mortality analysis because of inadequate representation of HEMS-transported patients. Exclusion of this quintile removed 1,884 ground patients and 149 HEMS patients, leaving a sample size of 8,151 for the outcome analysis. For the other four quintiles, the proportion of patients from the smaller group was at least 15%.

Overall, the multivariable-adjusted hazard for 2-week, in-hospital mortality among HEMS-transported patients was 33% lower (hazard ratio [HR] = 0.67, 95% confidence interval [CI] = 0.54 to 0.84) than the hazard among ground transported patients (Table 4). The reduction in the hazard of death for HEMS transport was essentially the same for patients who died in the first 24 hours (HR = 0.66, 95% CI = 0.5 to 0.87; Table 5). Plots of the cumulative hazard functions for 2-week mortality and for 24-hour mortality are shown in Figures 1 and 2, respectively.

In post hoc subanalyses using all 10,184 patients, the apparent reduction in the risk of mortality for HEMS transport was most evident for patients with an RTS value between 3 and 7 based on their vital signs at the scene (HR = 0.61, 95% CI = 0.46 to 0.82). Crude mortality was 20% among these patients ($n = 2,011$), who had some abnormality in their vital signs as evidenced by their RTS values. The majority of patients ($n = 7,612$) had normal vital signs at the scene as indicated by a prehospital RTS above 7, and crude mortality was very low in this group (1.7%). Among patients with RTS scores above 7 based on vital signs at the scene, the point estimate of the HR for mortality associated with HEMS transport was similar to that of the group with a prehospital RTS between 3 and 7, although it was no longer statistically significant (HR = 0.65, 95% CI = 0.34 to 1.2) because of the small number of deaths. Patients with a prehospital RTS below 3 constituted the smallest group and had a crude mortality of 58%. For these patients, mode of transport was not significantly associated with risk of death (HR = 1.02, 95% CI = 0.68 to 1.6).

DISCUSSION

There have been many studies to evaluate whether there is a difference in in-hospital mortality among trauma patients transported by HEMS versus those transported by ground ambulance.[6–18] Some of the primary limitations of previous studies are a lack of prehospital data, time and distance data, and adequate balancing of the HEMS- and ground-transported patients with respect to numerous variables related to both the likelihood of HEMS transport and the increased risk of death. Our study tried to address each of these limitations by incorporating time and distance measures and using a propensity score approach, which combined many confounding covariates into a

Table 3
Unadjusted and Propensity Score–adjusted Comparison of Covariates Included in the Propensity Score for Patients Transported by Helicopter or Ground Ambulance

Covariates	Helicopter	Ground	Unadjusted p-value	Propensity-adjusted p-value
Mean age, years (SD)	36 (±19)	40 (±22)	<0.0001	0.53
Sex (female)	30	32	0.07	0.80
Hospital region Oklahoma City	45	37	<0.0001	0.57
Scene GCS < 14	37	22	<0.0001	0.77
Scene sBP <100 mm Hg	10	10	0.98	0.82
Scene RR <10 or >29 breaths/min	11	15	<0.0001	0.42
Anatomic criteria	14	13	0.17	0.82
Intubated	33	14	<0.0001	0.53
Etiology			<0.0001	0.12
Motor vehicle crash—rollover, ejected, extrication	43	17		
Motor vehicle crash—without rollover, ejected, extrication	18	18		
Motorcycle or pedestrian	14	14		
Firearm or stabbing or other	18	31		
Fall	7	20		
Dark when transported	40	50	<0.0001	0.58
Injury type penetrating	8	18	<0.0001	0.19

Data are reported as % unless otherwise noted.
GCS = Glasgow Coma Scale score; RR = respiratory rate; sBP = systolic blood pressure.

Table 4
HR for Two-week Mortality (Helicopter vs. Ground), from Multivariable, Propensity-adjusted Proportional Hazards Model

Parameter	Parameter Estimate	Standard Error	Chi-square	Pr > chi-square	HR	95% HR CL
Mode of transport	−0.397	0.115	11.93	0.001	0.672	0.537–0.842
Propensity score	−0.800	0.228	12.29	0.001	0.449	0.287–0.703
ISS > 24	0.584	0.201	8.43	0.004	1.793	1.209–2.658
ISS 16 to 24	−0.039	0.221	0.03	0.860	0.962	0.624–1.483
ISS 9 to 14	−0.304	0.240	1.60	0.206	0.738	0.461–1.182
RTS	−0.747	0.021	1,273.44	<0.0001	0.474	0.455–0.493
Distance (miles)	−0.008	0.002	15.11	0.000	0.992	0.988–0.996

CL = confidence limits; HR = hazard ratio; ISS = Injury Severity Score; Pr = probability; RTS = Revised Trauma Score.

Table 5
HR for 24-Hour Mortality (Helicopter vs. Ground), from Multivariable, Propensity-Adjusted Proportional Hazards Model

Parameter	Parameter Estimate	Standard Error	Chi-Square	Pr > Chi-Square	HR	95% HR CL
Mode of transport	−0.416	0.143	8.45	0.004	0.660	0.498–0.873
Propensity score	−0.806	0.281	8.21	0.004	0.447	0.257–0.775
ISS > 24	0.232	0.214	1.18	0.277	1.262	0.830–1.919
ISS 16 to 24	−0.141	0.238	0.35	0.553	0.868	0.544–1.385
ISS 9 to 14	−0.198	0.259	0.58	0.446	0.821	0.493–1.364
RTS	−0.856	0.026	1,097.57	<0.0001	0.425	0.404–0.447
Distance (miles)	−0.008	0.003	10.09	0.002	0.992	0.987–0.997

CL = confidence limits; HR = hazard ratio; ISS = Injury Severity Score; Pr = probability; RTS = Revised Trauma Score.

single composite confounder value. Using this technique reduces bias in the estimate of the association of HEMS transport on 2-week mortality by balancing between-group differences among covariates other than mode of transport that might otherwise influence the risk of mortality.

As we noted, several previous studies of HEMS transport and trauma mortality used the TRISS methodology. One of the first studies examining HEMS transport used this method to compare observed versus expected deaths among 150 HEMS-transported patients and 150 ground-transported patients.[8] The authors found a 52% reduction in the predicted mortality in HEMS patients, and no significant difference in the observed and expected number of deaths in the ground-transported patients. The HEMS crews in that

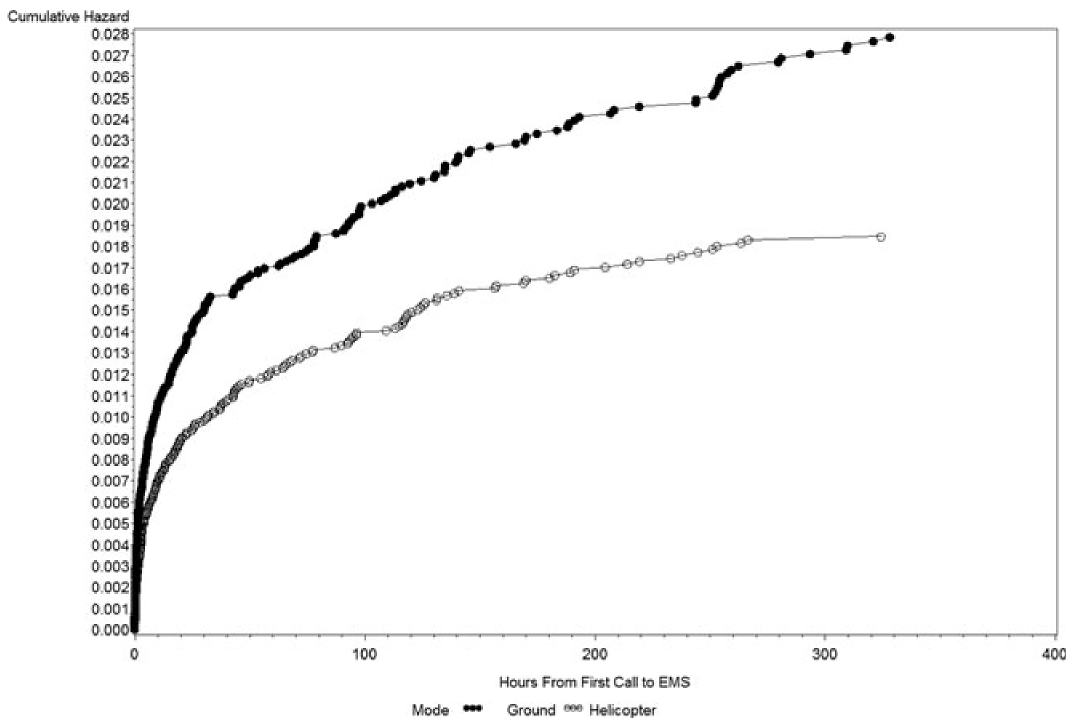

Figure 1. Plot of cumulative hazard by hours from first call to EMS: 2-week mortality.

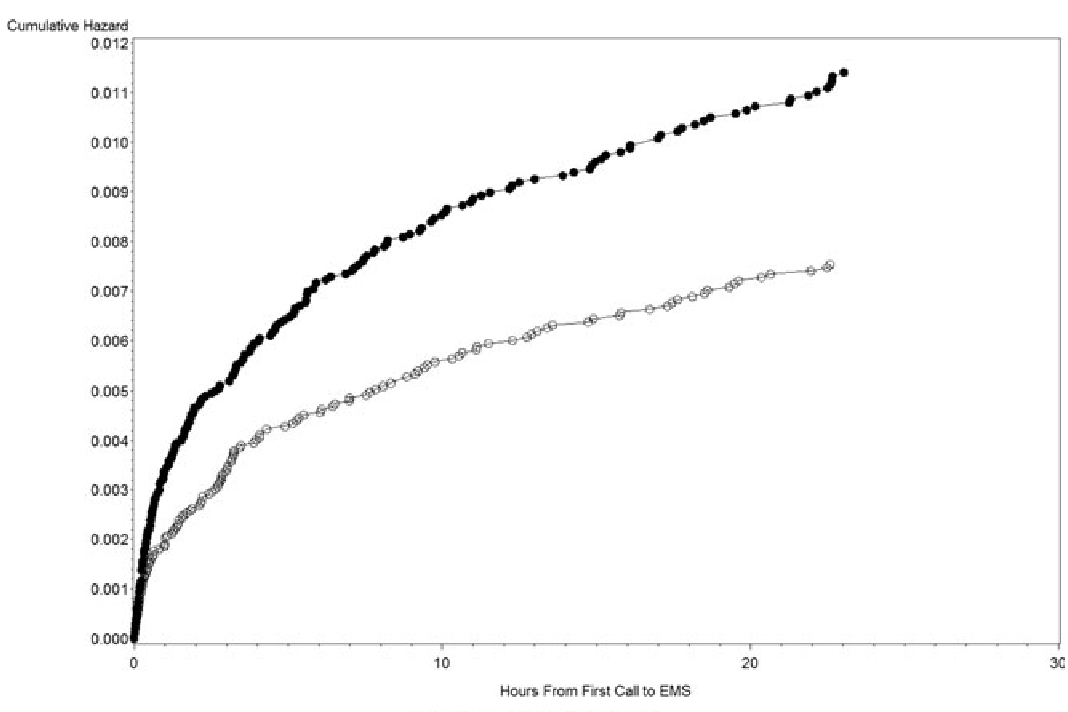

Figure 2. Plot of cumulative hazard by hours from first call to EMS: 24-hour mortality.

study were composed of "acute care" physicians and nurses, whereas the land ambulance crews were made up of EMTs and two "intensive care" units that used paramedics. The same authors conducted a multicenter TRISS study of 1,273 trauma patients transported by seven different HEMS services and found significant reductions in expected mortality ranging from 14% to 39% for five services and nonsignificant reductions of 4% for the other two.[9] In this multicenter study, HEMS staffing varied, with four services using a physician/nurse combination, two using only nurses, and one using a nurse/paramedic crew. Although the first aforementioned study presented average times from injury to hospital arrival of 35 minutes for ground and

58 minutes for helicopter transports,[8] neither of these TRISS studies could incorporate time or distance measures into their analyses. Another issue with using the TRISS methodology to evaluate the effect of mode of transport on mortality is that the patient population and trauma system being studied must be of similar composition to the major trauma outcome study from which the coefficients for calculating survival probabilities were derived.[20,28] Moreover, both studies were conducted more than 25 years ago, making it likely that advances in both prehospital and hospital care of trauma patients have occurred.

Some HEMS studies have focused on the use of helicopters in an urban setting.[13,15,16,29,30] They found no overall benefit of HEMS transport for patients injured in areas close to a trauma center. However, they did point out special circumstances where HEMS transport in these areas may be justified, such as events requiring prolonged extrication of the patient or multicasualty events that overwhelm available ground EMS units. Both Oklahoma City and Tulsa have defined ''no-fly'' zones around their respective Level I and Level II trauma centers in which HEMS transport is used only in special circumstances. Furthermore, any HEMS transport occurring in these areas triggers a mandatory utilization review by a medical control board to determine whether the flight was justified. Recent work on the same population as our study revealed that only 211 HEMS transports occurred from these no-fly zones over a 4-year period, suggesting the no-fly designation is effective in avoiding unnecessary flights.

Three large studies,[6,7,17] two of which were statewide analyses,[6,7] found evidence of decreased mortality among HEMS-transported patients compared to ground-transported patients. One of the studies[17] found a reduction in the odds of mortality (odds ratio = 0.76, 95% CI = 0.59 to 0.98) for HEMS-transported patients slightly smaller in magnitude to that found in the present study. The two statewide analyses[6,7] did not find significant reductions in mortality for HEMS transports overall, but did note some indication of reduced mortality among patients with moderate to severe injury severity scores. These studies did not have data available for time or distance and little or no data available on prehospital vital signs.

In a previous analysis of factors in the prehospital setting associated with HEMS transport, distance was the primary factor in determining whether a patient would be flown to the trauma center. The association of HEMS and distance was so strong that distance strata were formed to prevent the influence of distance from overwhelming associations with other patient-related variables such as scene vital signs. With regard to reducing time to care and the effect of distance, the short-term benefit of HEMS transport seems less clear. The mean time for ground-transported patients was 45 minutes and for HEMS transports 74 minutes. In work prior to the current study we found that at a distance of 16 to 35 miles from the trauma center, the time from call being received to arrival at the trauma center did not differ significantly (difference in means = 1.3 minutes [95% confidence limits {CL} = –0.5 to 3.1 minutes]) between HEMS- and ground-transported patients. However, from 36 miles to 60 miles (difference in means = 11 minutes [95% CL = 8 to 14 minutes]) and from 60 to 100 miles (difference in means = 16 minutes [95% CL = 6 to 26]) HEMS was faster than ground transport. Data available regarding the relationship of the time that ground EMS was called and the time HEMS was called indicated the vast majority of the HEMS dispatches in this study were nonsimultaneous, with a mean of 9.3 minutes (standard deviation [SD] ± 6.4 minutes) between the call to ground EMS and the call for HEMS transport. Nonsimultaneous dispatch is another factor that can change the distance at which HEMS is faster than ground transport.[31] It appears that time differences for HEMS-transported patients, at least of the magnitude seen in this study, may not be as important as early care and stabilization of severely injured patients so that they arrive in a more treatable condition at the trauma center.

As Brathwaite et al.[6] pointed out, a helicopter is a means of transportation, not a method of treatment. Therefore, any benefit noted with HEMS transport must logically be related to other plausible explanations, such as decreased time from injury to definitive care or stabilizing treatment rendered by more experienced, expert personnel.[4,6,11] In this study, both increasing time and distance were associated with lower mortality, even in the fully adjusted models. For time, we theorize that this somewhat unexpected finding may be due to the overall recognition by EMS personnel of the critical condition of patients who ultimately die after arrival at the trauma center, which motivates more rapid transport to the trauma center. This is not to say that delays in transport do not contribute to the death of some patients, but this is a more difficult conclusion to make when studying patients in aggregate. The ''protective'' effect of distance is even more puzzling, but higher mortality associated with penetrating injuries, virtually all of which occurred in areas close to the trauma center, may partially explain this phenomenon. However, injury type (blunt or penetrating) was included in the propensity score.

Experience among HEMS crews with prehospital airway management has been suggested as a possible explanation for any reduction in trauma mortality seen in HEMS-transported patients.[4,17,21,32] HEMS providers generally have more experience with advanced airway management as well as other advanced procedures. An improperly placed endotracheal airway will likely be more detrimental to the patient than not attempting intubation and moving quickly to the trauma center. One study found a beneficial effect on mortality of intubation for head-injured patients intubated by HEMS, but an increase in the odds of mortality for head-injured patients intubated by ground EMS.[32] Another study found better outcomes among patients with severe head injuries who were intubated in the field by HEMS compared to patients not intubated until hospital arrival.[21] One proposed explanation is that the HEMS crews are more experienced with establishing and confirming placement of an endotracheal airway than ground EMS crews.[4,19,21] However, another explanation might be that HEMS crews are more comfortable intubating patients who were likely to have survived without it, whereas ground EMS crews may only attempt to intubate patients in the direst condition, thereby resulting in the apparent association of mortality. We did not have the data necessary to sort out these two possible explanations, and thus, this is a question that warrants further research.

Both trauma triage guidelines and compliance with those guidelines have been shown to vary by region,[33–36] and most previous studies of HEMS transport noted a significant number of patients transported by helicopter with minor to moderate injuries.[5] We too identified a large number of HEMS-transported patients who would seem at low risk of dying. Among all the HEMS-transported patients, 43% had an ISS of less than or equal to 14, and of these, 83% had normal prehospital and initial hospital RTS values. This information alone is insufficient to deem all of these HEMS transports inappropriate since loss of digits, limbs, or vision, for example, are certainly important outcomes in addition to mortality. Closer evaluation of the specific injury diagnoses for these patients should be done to help determine the reason HEMS transport was used. Refinement of field trauma triage and ongoing evaluation of compliance with triage guidelines are still important areas of research for trauma systems.[4,33,34]

LIMITATIONS

Since our study was limited to direct transports of trauma patients, we cannot evaluate the effect of HEMS transport for interfacility transport or transport of patients with medical conditions. Distance calculations using zip code centroids are not ideal, since some zip code areas in rural areas may be large, but full addresses were too often missing or may not be available at all for rural trauma incidents. Another limitation is that two of the HEMS services that transported patients in this study were hospital-based, while the remaining HEMS transports were by regional air ambulance service groups. We did not evaluate whether differences in outcome were present between these two types of HEMS services. It is possible that differences exist between hospital-based and regional HEMS services with regard to experience of personnel, equipment, and relationships with trauma center staff. Weather conditions are a common reason for canceled HEMS transports; this was not measured. If the data had been available, our study may also have benefited from the inclusion of additional prehospital procedures and the times these procedures were performed, as this may have aided further evaluation of the reasons for the reduction in mortality.

Better information concerning the timing of certain procedures such as intubation, sedation, and paralytics would also help determine the validity of vital signs measured at arrival at the trauma center. Although these GCS modifiers are recorded in the trauma registries, it became apparent that they may be recorded inconsistently. Some vital signs measured at the hospital may have been obtained from patients who had already received treatments that influence those measurements. This could be a concern if these modified vital signs occur more frequently in one group or the other, so that actual vital signs are being frequently compared to modified vital signs. For example, if HEMS-transported patients more frequently received treatments that interfere with vital sign measures such as GCS prior to arrival at the trauma center, they may have somewhat artificially lower vital signs recorded. This would bias comparisons with potentially unaltered vital signs among ground-transported patients. In this study, data regarding intubation in the prehospital setting was incomplete, so it was combined with intubation status at the initial ED assessment, which is supposed to represent intubation prior to arrival as well. However, in discussions with trauma registrars, they indicated that intubations recorded here typically took place prior to arrival, but not always. Thus, it was not possible to accurately identify all patients who had been intubated in the prehospital setting. In the face of uncertainty regarding either the validity of vital signs because of interventions or the timing of important procedures such as intubation, one might use proxies for neurologic status such as high Abbreviated Injury Score (AIS) values for the head region. Correlations between severe head injury (AIS $\geq$ 4) and both prehospital and ED GCS measurements suggest, however, that this approach may not provide a particularly good proxy for GCS even at high AIS values.

CONCLUSIONS

This study found a 33% lower hazard of mortality within 14 days following an injury event associated with helicopter emergency medical services transport from the scene of injury, after adjusting for numerous covariates including a distance measure. However, the sizable proportion of helicopter EMS-transported patients with normal vital signs and moderate injury severity scores suggests that further improvements in trauma triage and HEMS utilization protocols are needed. Among patients with normal vital signs at the scene of injury, the survival benefit with HEMS transport was not significant. Additional studies are also needed to address the question of why and for what type of patient the reduction in mortality is seen with HEMS transport. Studies of the reason for mortality reduction may identify areas on which to focus training of both HEMS and ground EMS personnel with regard to triage and stabilizing treatment. The use of statewide data in the setting of a large rural state with only one Level I and two Level II trauma centers makes the results applicable to other states with a similar population and resource distribution.

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Appendix A: Anatomical Triage Criteria

1. Amputation, proximal to wrist or ankle
2. Two or more long bone fractures
3. Unstable pelvic fracture
4. Open or depressed skull fracture
5. Penetrating injury, head/neck/torso/groin