Helicopter Transport and Blunt Trauma Mortality: A Multicenter Trial

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Background: Despite many studies addressing potential impact of helicopter transport on trauma mortality, debate as to the efficacy of air transport continues.

Methods: This retrospective study combined trauma registry data from five urban Level I adult and pediatric centers. Logistic regression assessed effect of helicopter transport on mortality while adjusting for age, sex, transport year, receiving hospital, prehospital level of care (Advanced Life Support vs. Basic Life Support), ISS, and mission type (scene vs. interfacility).

Results: The study database comprised 16,699 patients. Crude mortality for Air (9.4%) was 3.4 times (95% CI, 2.9–4.0, $p < 0.001$) that of Ground (3.0%) patients. In adjusted analysis, helicopter transport was found to be associated with a significant mortality reduction (odds ratio, 0.76; 95% CI, 0.59–0.98; $p = 0.031$).

Conclusion: The results of this study are consistent with an association between helicopter transport mode and increased survival in blunt trauma patients.

Key Words: Helicopter transport, Helicopter EMS, Blunt trauma.

J Trauma. 2002;52:136–145.

Since their use for evacuation in the Korean and Vietnam wars, helicopters have been increasingly employed for medical transport in the civilian arena. Consistent with the military roots of rotor-wing transport, early descriptions[1] of civilian helicopter Emergency Medical Services (HEMS) focused on the trauma mission. Injured patients comprised the study population in the first paper[2] to objectively assess mortality association between HEMS and a ground control group. Though some papers in the intervening years have addressed utilization of HEMS for nontrauma patients,[3] most of the analytic literature addressing helicopter transport benefits has focused upon use in trauma.

Previous research has yielded conflicting results regarding the impact of HEMS transport on blunt trauma mortality. Many studies[1,2,4–10] have suggested outcome improvement associated with HEMS, but other investigations[11–16] have yielded mixed or negative results, and skepticism persists as to HEMS benefits in blunt trauma transport.[17,18] The purpose of this study was to generate a multicenter database to test for an association between HEMS transport and blunt trauma survival.

MATERIALS AND METHODS

Study Design

This was a retrospective, registry-based cohort study.

Time Frame

Four years (1995 through 1998) of trauma transports were combined to comprise the study database.

Setting

The study was conducted in an urban academic setting in Boston, Massachusetts, with participation from five hospitals. Two hospitals were Level I adult and pediatric trauma centers. Two other institutions were Level I adult trauma centers, and the remaining study hospital was a Level I pediatric trauma center. The study was approved by human studies review committees at all participating hospitals.

Four HEMS services provided transports into the study hospitals. Boston MedFlight based in the study city as a consortium program jointly administered by six hospitals (including the five study centers), was the primary transport service for study patients. Boston MedFlight utilizes two helicopters (BK-117 and an AS-365N2 during the study period) staffed with a nurse/paramedic crew to provide approximately 1500 annual transports. University of Massachusetts LifeFlight is based 30 miles west of the study city. University of Massachusetts LifeFlight utilizes two helicopters (BK-117s during the study period) and a nurse/physician crew, and has an annual transport volume of approximately 1400 patients. Hartford Hospital LifeStar (using two BK-117 helicopters) and Dartmouth-Hitchcock Air Response Team (an Agusta 109), were based in neighboring states and provided

Submitted for publication January 15, 2001.

Accepted for publication June 22, 2001.

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Supported by the Foundation for Air Medical Research.

Presented, in part, at the 12th Annual Meeting of the Society of Academic Emergency Medicine, May 22–25, 2000, San Francisco, California; and Airmed 2000, June 19–22, 2000, Stavanger, Norway.

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occasional transports into the study hospitals. Services Hartford Hospital LifeStar and Dartmouth-Hitchcock Air Response Team utilized nurse/respiratory therapist Hartford Hospital LifeStar and nurse/paramedic Dartmouth-Hitchcock Air Response Team crews to perform approximately 1250 and 650 annual transports, respectively.

Ground transports into the study hospitals were provided by over 30 EMS services. Ground transports were provided by both Basic Life Support (BLS) and Advanced Life Support (ALS) personnel. Trauma stabilization and care provided by BLS personnel was limited to basic maneuvers such as spinal immobilization. ALS personnel had capability for more advanced maneuvers such as endotracheal intubation. During the study period, approximately 90% of the study's geographic area was covered by ground ALS units, none of which administered neuromuscular blockade to facilitate intubation during the study's time frame. ALS and BLS EMS services based in Massachusetts (accounting for all scene transports and nearly all interfacility transports) operated under similar statewide prehospital trauma care protocols.

Patients

Any blunt trauma patient entered into the participating hospitals' trauma registries was entered into the study. Therefore the study included adult and pediatric patients transported by ground or air from trauma scenes or referring community hospitals. Patients included in the study were those sustaining any form of blunt trauma (e.g., vehicular trauma, falls). Patients excluded were those with penetrating trauma, burns, drowning, or other non-blunt trauma injury mechanisms. Since all trauma registries included fields for mechanism of injury, it was possible to reliably limit the study to blunt injuries.

Data Sources

The sources of data for the study were the trauma registries of the participating trauma centers, with information from these registries combined to form the study's database. Patients who were discharged from the ED were not included in the study hospitals' trauma registries, but the participating registries were all designed to capture patients who died in the study center ED before hospital admission.

Data Collected

Basic patient characteristics collected included sex and age. An a priori decision was made to categorize patients into three age groups: Pediatric ($<$14 years), Adult (14–55), and Over 55 ($>$55). The lower age limit of 14 years was established as defining "pediatric" patients since the inception of the study's primary HEMS program. The upper age limit of 55 was selected based on use in previous literature of this cutoff to delineate an age above which trauma mortality risk is increased.[19]

With regard to transport date, study patients were grouped by year, yielding four groups (years) of transports. Mission type (scene or interfacility) was coded according to whether patients arrived at the receiving trauma center directly from the trauma scene or from a referring hospital.

The main assessment used for acuity adjustment between ground and air transported patients was the Injury Severity Score (ISS). An a priori decision was made to categorize patients' ISS into the following groups: $<$9, 9–15, 16–24, and $>$24.

Transport mode was coded as Air or Ground based on the vehicle transporting the patient to the receiving trauma center. For example, a patient who was ground-transported from a trauma scene to a community hospital, and then flown from the community hospital to a trauma center, would be categorized as an Air transport.

The study could not completely adjust for differences among care capabilities of the various ground EMS units, but transports were coded ALS or BLS to provide a coarse measure of highest prehospital level of care. For example, if BLS personnel were first on-scene, and a patient was subsequently transported from the scene by an ALS level (ground or air) vehicle, the case would be categorized as ALS. All helicopter transports were ALS level.

A covariate for receiving trauma center was also included in the analysis. Different trauma centers have differing case mix, and patients in the study were not distributed equally among study hospitals. Therefore, employment of a Receiving Hospital covariate was intended to provide some degree of adjustment for differing patient characteristics between the five study centers. No implication of differing quality of trauma care at study hospitals is intended by utilization of the Receiving Hospital covariate, and such inference is explicitly discouraged.

Mortality was the study's primary outcome parameter (dependent variable). Patients were coded as dying if they were so coded in the study hospitals' trauma registries. Thus, study mortality reflected deaths occurring during the hospitalization for the incident blunt trauma prompting entry into the registry. There was no attempt to subcategorize mortality (e.g., by time or proximate cause of death).

Analysis

Air and Ground patient characteristics, as well as mortality outcome, were assessed with univariate and multivariate analysis. For univariate analysis, categorical data were assessed with Pearson χ^2.

Multivariate logistic regression was performed using a stepwise method as described by Hosmer and Lemeshow.[20] A univariate p value of 0.15 was used as cutoff for further investigation of a variable in multivariate modeling. Variables which were initially found to be statistically nonsignificant were checked in the final model for both significance and possible confounding. All odds ratio (OR) estimates are reported with a 95% confidence interval (CI). Statistical significance for terms in multivariate models was determined by Wald and likelihood ratio testing. Model performance was

Table 1 Patient Characteristics

Characteristic	All Patients (n = 16,699)	Air (n = 2292)	Ground (n = 14,407)	p Value, Air vs. Ground
Injury year (%)				0.20
1995	4112 (24.6)	554 (24.2)	3558 (24.7)	
1996	4136 (24.8)	536 (23.4)	3600 (25.0)	
1997	4222 (25.3)	613 (26.8)	3609 (25.1)	
1998	4229 (25.3)	589 (25.7)	3640 (25.3)	
Receiving trauma center (%)				<0.001
A	5892 (35.3)	722 (31.5)	5170 (35.9)	
B	4046 (24.2)	723 (31.5)	3323 (23.1)	
C	3099 (18.6)	442 (19.3)	2657 (18.4)	
D	1908 (11.4)	328 (14.3)	1580 (11.0)	
E	1754 (10.5)	77 (3.4)	1677 (11.6)	
Male (%)	10,478 (62.8)	1609 (70.2)	8869 (61.6)	<0.001
Age group (%)				<0.001
Pediatric	2344 (14.0)	231 (10.1)	2113 (14.7)	
Adult	9677 (58.0)	1660 (72.4)	8017 (55.7)	
Over 55	4678 (28.0)	401 (17.5)	4277 (29.7)	
Mission type (%)				<0.001
Interfacility	5443 (32.6)	1142 (49.8)	4301 (29.9)	
Scene	11,256 (67.4)	1150 (50.2)	10,106 (70.2)	
Pre-trauma center care (%)				
ALS	5537 (33.2)	2292 (100)	3245 (22.5)	
BLS	7723 (46.3)	0	7723 (53.6)	
Missing	3439 (20.6)	0	3439 (23.9)	
ISS (%)				<0.001
<9	8457 (50.6)	599 (26.1)	7858 (54.5)	
9–15	5346 (32.0)	722 (31.5)	4624 (32.1)	
16–24	1376 (8.2)	396 (17.3)	980 (6.8)	
>24	1385 (8.3)	573 (25.0)	812 (5.6)	
Missing	135 (0.8)	2 (0.1)	133 (0.9)	
Died (%)	640 (3.8)	215 (9.4)	425 (3.0)	<0.001

assessed with Receiver Operating Characteristic (ROC) curve analysis.[21] For all statistical tests, significance was set at the 0.05 level. Analysis was performed with STATA software (version 7.0, Stata Corp., College Station, TX).

RESULTS

During the study period, a total of 16,699 blunt trauma patients were entered into the five participating trauma registries, with an overall mortality rate of 640 (3.8%). Patient characteristics of the entire study population, as well as Air and Ground patients, are shown in Table 1. Table 1 also demonstrates univariate comparisons between Air and Ground patients.

The first step in analysis was to assess which covariates were associated with mortality in univariate analysis. Covariates with an alpha level of association of stronger than (i.e., below) $p = 0.15$ were identified for incorporation into multivariate analysis. Results for the univariate analysis revealed that many covariates were significantly associated with mortality. Patients receiving pre-trauma center ALS, as well as those with increasing age and higher ISS, were significantly ($p < 0.001$) more likely to die. These three variables were thus selected for inclusion in multivariate regression. The variables Sex ($p = 0.48$) and Transport Year ($p = 0.44$) were not significantly associated with mortality, and thus were not included in multivariate regression. Scene versus interfacility Mission Type was not initially significant ($p = 0.32$) in univariate mortality analysis. However, in the model-generating stage at which previously discarded variables were rechecked, Mission Type was the sole discarded variable which was significant ($p < 0.001$) in the multivariate model. Therefore, despite its lack of statistical significance in univariate modeling, Mission Type was included in the multivariate model. Notably, crude analysis yielded an increased mortality in Air as compared with Ground patients (OR, 3.4; 95% CI, 2.9–4.0; $p < 0.001$).

In generating the multivariate model, therefore, the following covariates were assessed along with the primary independent variable Air vs. Ground transport mode: Age, ISS, Mission Type, Prehospital Level of Care, and Receiving Hospital. Incorporation of these covariates into the logistic model was straightforward, except in the case of the two variables—ISS and Prehospital Level of Care—which had missing data as noted in Table 1. As seen in Table 1, the Missing category n for ISS was 135 (0.8% of 16,699) and the Missing category n for Prehospital Level of Care was 3439 (20.6% of 16,699).

As it had been suspected that some data would be missing, the study design included an a priori plan for analysis of variables with missing data. Since cases with missing data

Table 2 **Multivariate Mortality Results**

Variable	OR	Standard Error	Wald p Value	95% Confidence Interval, OR
Air transport	0.756	0.098	0.031	0.586–0.975
Increasing age group	2.71	0.259	<0.001	2.25–3.27
Scene mission type	1.49	0.160	<0.001	1.21–1.84
Prehospital level of care				
ALS	Baseline			
BLS	0.423	0.060	<0.001	0.320–0.560
Missing	0.554	0.129	0.011	0.351–0.874
ISS				
<9	Baseline			
9–15	4.08	1.02	<0.001	2.50–6.66
16–24	19.5	4.88	<0.001	12.0–31.9
>24	163	37.2	<0.001	104–255
Missing	22.1	10.0	<0.001	9.11–53.7

could have been in some way different from other cases, simply discarding cases with missing data was judged inadvisable. Similarly unappealing was the subjective assignation of likely values to cases with missing data. Therefore, the following conservative approach was taken. Since both of the variables (ISS and Prehospital Level of Care) were analyzed categorically, an extra category "Missing" was added to each variable's possible value. As noted below (see Discussion section) treatment of missing ISS and Prehospital Level of Care data differently from the a priori plan did not alter the results of the multivariate model with respect to HEMS and mortality improvement.

Pertinent results from the adjusted analysis are shown in Table 2. In this multivariate analysis, HEMS transport was associated with a significant decrement in mortality as compared with ground transport (OR, 0.76; 95% CI, 0.59–0.98; $p = 0.037$ by likelihood ratio testing). The area under the ROC curve was 0.933, indicating that the model had "outstanding" discriminating performance.[21]

DISCUSSION

The subject of helicopter trauma transport cost and benefit has provoked significant debate, evidenced in a body of literature that is of significant quantity if inconsistent quality. Justification for yet another study requires placement of the project in the context of the extant HEMS literature, with explanation of how the current study may enhance the state of knowledge. The first step in such a process is a brief overview of the HEMS trauma literature. This literature is characterized by a few general study designs, as discussed below.

The most straightforward study design is that of reviewing a collection of rotor-wing transports and retrospectively assessing whether patient outcome was affected by helicopter use. This descriptive approach has been used to suggest possible HEMS utility in vehicular trauma[1,4,12] and also in the setting of nonvehicular blunt trauma occurring in difficult terrain.[22,23] Unfortunately, the simplicity which makes this approach appealing belies an inevitable subjectivity. Studies utilizing this general approach are thus useful, but provide insufficient evidence to confirm or refute benefit from air transport.

Realization that descriptive methodologies would not provide conclusive assessment of HEMS benefits prompted investigators to move toward analytic techniques. Given the fact that practical limitations virtually precluded execution of a randomized clinical trial, other tools for comparing air versus ground transport were developed. The best-known of these tools, TRISS, has been used in a multitude of HEMS papers. As described by Boyd et al. in 1987,[19] TRISS incorporates physiologic (Trauma Score), anatomic (Injury Severity Score), and age (55 years as cutoff) independent variables into a logistic regression model with dependent variable mortality. Predicted mortality, calculated using the multivariate logistic regression model (with β coefficients from a large trauma database), can then be compared with actual mortality. Studies assessing HEMS patients' survival versus that predicted by TRISS can incorporate a ground "control" group by simultaneously evaluating whether ground-transported patients' survival was equivalent to that predicted by TRISS.

When assessed as a group, studies utilizing TRISS methods provide argument for at least some mortality benefit associated with HEMS blunt trauma transport, but there have been at least three investigations with contrary findings. In the first, an analysis of scene transports in London,[14] both air and ground patients died at rates higher than TRISS-predicted and the authors concluded that any possible benefit accrued by HEMS was limited to severely injured patients. Another negative study,[24] from San Antonio, demonstrated that both air and ground transported patients died at rates predicted by TRISS. A third study, performed in Australia, analyzed air transports and found a nonsignificant difference between predicted (17%) and actual (14%) mortality in a group in which 42% of patients with severe head injuries (GCS < 8) were not intubated.[25] In contradistinction to the findings of the three negative studies, eight other TRISS studies have identified at least some mortality reduction associated with helicopter transport.[2,5–7,9,10,26–28]

The first TRISS study, reported in 1983 by Baxt and Moody of UCSD,[2] analyzed scene trauma transports and found a 52% reduction in mortality associated with HEMS transport. A control cohort of ground-transported patients died at the predicted rate. Baxt et al. followed the initial study with a multicenter analysis[7] which found a more modest 21% reduction in expected mortality when HEMS was utilized; no ground transport cohort was analyzed. In a third (Baxt and Moody) UCSD study,[10] a 9% mortality reduction was identified in a subset of severely brain-injured (GCS < 9) blunt trauma patients transported by HEMS as compared with ground ambulance controls. While Baxt et al. were analyzing the efficacy of scene helicopter transport in an urban setting, Boyd et al. published the first TRISS analysis[5] of mortality impact of HEMS on rural setting patients undergoing interfacility transports; as compared with a ground control group, a 25.4% reduction in mortality was associated with air transport. Bartolacci et al.[9] used TRISS to analyze HEMS-related survival benefit for scene transports in an Australian system, concluding that helicopter use resulted in 12 lives saved per 100 transports. With the exception of the Boyd paper, the preceding TRISS studies assessed both adult and pediatric patients. In a paper focusing on pediatric transports (scene and interfacility), Moront et al.[6] found that 11 lives were saved for every 1000 patients transported by air as compared with a ground control group.

Two other TRISS papers focused on crew configuration, but shed light on overall mortality benefit. Baxt and Moody[26] found a 35% mortality reduction associated with transport by a physician-staffed helicopter, as compared with an insignificant mortality reduction when the same service flew with a nurse/paramedic staff. Hamman et al.[27] found statistically significant mortality reductions, compared with TRISS predicted, for both physician (30% fewer deaths) and nonphysician (45%) crews.

A final type of TRISS study design is worth mention because it combines TRISS with a standardization measure allowing adjustment for differing regional case mix. Though it is cited much less frequently than the earlier *British Medical Journal* TRISS paper[14] by Nicholl et al., the *Journal of Trauma* paper by Younge et al.[28] describing a standardized W statistic is arguably better designed and provides more meaningful results. The paper by Younge et al. assesses the same London HEMS service as that reported by Nicholl et al., and encompasses more patients by including transports from the years before and after the study set of Nicholl et al. More importantly, Younge et al. assessed outcome only in patients transported to the specialized trauma center, whereas patients in Nicholl et al.'s study were transported to the London trauma center as well as 19 regional hospitals without trauma center facilities. Furthermore, Nicholl et al. did not calculate an M statistic (which assesses similarity between a study population and the Major Trauma Outcome Study [MTOS] cohort from which TRISS coefficients are derived) and Younge et al. demonstrated that the M statistic for London patients precluded "standard" TRISS calculations. Therefore, Younge et al. report a standardized W statistic of 4.2 lives saved per 100 HEMS flights; this is translated to signify that there would be 4 excess survivors per 100 transports to the study center if that study center's trauma patients had an injury distribution similar to that of the MTOS cohort.

TRISS studies provided very useful insight into the question of HEMS transport and mortality benefit, but both HEMS proponents and detractors can identify weaknesses in the TRISS papers which make their results less than definitive. While discussion of these issues is beyond the scope of this paper, it is fair to posit that the TRISS studies have failed to provide an irrefutable answer to the HEMS benefit question. At least one nonappealing aspect of the TRISS papers, their relative analytic complexity, is addressed by the final type of general study design—stratified analysis.

Stratified analyses of one sort or another have comprised an important portion of HEMS literature, though the need for large numbers probably accounts for the fact that this study design is seen less frequently than others. The appeal of the stratified design is that it performs direct outcome comparison between air and ground patients who have been acuity-stratified by severity markers (e.g., RTS, ISS). For meaningful analysis, sufficiently large numbers must be accrued in each stratification "bin" to afford a study of sufficient power to detect as statistically significant any mortality differences exhibited by the data.

The initial HEMS outcome studies performing stratified analysis were published in the late 1980s. In perhaps the first such paper, published in 1987, Baxt and Moody[10] assessed ground and air transported patients with severe brain injuries and reported that HEMS use was associated with increased survival when patients were stratified by GCS. A year later, Moylan et al.[8] studied air and ground blunt trauma scene transports matched for Trauma Score, age, mechanism of injury, and injured organ systems and found a significant mortality reduction associated with HEMS use. In the same year, however, Schiller et al.[13] failed to identify mortality benefit in an analysis of patients matched by ISS (but not GCS, which was lower in the HEMS group). In a 1989 study employing a stratified approach to compare air and ground transport of both scene and interfacility patients, Schwartz et al.[29] identified significant mortality benefit associated with HEMS transport of both scene and interfacility patients.

In the latter half of the 1990s, other stratified analyses were performed. In 1997, Cunningham et al.[15] reported an investigation of scene transports, identifying minimal HEMS mortality benefit in a multivariate logistic regression model controlling for Trauma Score (TS), age, ISS, and mortality risk as calculated by a TRISS-like score. The study design created a 20-bin table stratifying patients by ISS and RTS. For the eight bins with TS of 5–12 and ISS < 41, HEMS patients had survival advantages ranging from 3.4 to 23.9%, but the improvements were statistically significant only in the two bins for TS between 5 and 12 and ISS between 21 and 30;

no confidence intervals or power analysis were reported. Bartolacci et al.,[9] whose TRISS-based analysis was previously mentioned, also failed to demonstrate a substantial benefit associated with HEMS. In their ISS-stratified analysis of 48-hour mortality in helicopter versus ground patients, the point estimate suggesting a 43% increased mortality risk associated with ground transport was not statistically significant, possibly due to insufficient power as indicated by the width of the 95% confidence interval (0.74–2.78).

Brathwaite et al.[16] performed a large-sample study which was similar in many ways to the current study. The primary acuity measure in their study was ISS, which was categorized into five groups: $<$16, 16–30, 31–45, and 46–60. Overall, the β coefficient for HEMS was not statistically significant, but the investigators found a statistically significant interaction (epidemiologically speaking, an effect modification) between HEMS transport and mortality for patients in the middle three ISS groups, thus demonstrating survival improvement for patients with moderate injury severity.

The current study possesses some characteristics which suggest it may add to the overall understanding of the ability of HEMS to impact blunt trauma mortality. The study also suffers from certain shortcomings, which for the most part are identifiable if unavoidable. On balance, the advantages of examining a large unbiased data sample with multivariate techniques appear to outweigh the study's disadvantages, but characterization of the investigation's strengths and weaknesses will help put it in proper perspective.

First, this study was not TRISS-based. This could fairly be judged an advantage or disadvantage. On the one hand, TRISS methodology has proven invaluable to many previous investigators and TRISS-based literature has gone far to address the issue of HEMS and blunt trauma mortality. On the other hand, as would be any mechanism allowing comparison of a population's actual mortality to that predicted from analysis of a different group, TRISS is necessarily complex. In the end, the fact that most TRISS studies demonstrate HEMS-associated mortality improvement has clearly not ended debate on the subject. Therefore, it could be said that although TRISS is "tried and true," another such study may be less additive to the literature than an investigation using a more straightforward multivariate methodology. The current study does not compare actual to TRISS-predicted mortality, but does incorporate some (e.g., ISS, age) TRISS covariates. One difference is that this study lacks incorporation of a physiologic severity marker such as trauma score. Though reasonable argument could be made that the GCS component of trauma score is difficult to standardize (i.e., given different means of scoring intubated, sedated, and/or paralyzed patients), the lack of incorporation of a physiologic severity marker has to be considered a shortcoming of this study's methodology as compared with TRISS. There is little reason to believe that the absence of physiologic scores would bias the results toward one transport mode. The authors believe that the advantages of the current study design—including a direct comparison between ground and air transport modes—offset its deficiencies as compared with TRISS analysis.

If TRISS is less than optimal, one reason for the relative paucity of studies such as the current one is the large number of patients required. The fact that this study analyzed outcomes in 16,699 patients represents a major strength, if for no other reason than that of more robust analysis and minimization of type II error risk. One tradeoff of including such a large number of patients is that a substantial number with very low or very high ISS will be included even though HEMS transport will not have any mortality effect on a patient with an ISS on either extreme of the scale. The a priori plan of the authors, which was to include all blunt trauma patients, maximized study numbers and prevented need for arbitrary (and inherently flawed) assignation of ISS cutoffs defining inevitable survival or mortality. Since inclusion of patients who were clearly destined to live (or die) would bias the main effect finding toward the null, and therefore underestimate any mortality benefit associated with HEMS, the inclusion of all ISS groups for statistical analysis was not considered a major study drawback. This inclusion of all blunt trauma patients in the statistical analysis should not, however, be translated into an endorsement of HEMS use for patients with obviously survivable (or lethal) injuries; further research is indicated to improve identification of these subgroups so that transport resources can be optimally utilized.

The study's methodology allowed adjustment for at least one factor–prehospital level of care—previously underemphasized in the literature. There are two reasons that such adjustment, even in the imperfect sense used in the current paper, may be useful. First, it may be unfair to compare outcomes in patients transported by advanced-practice HEMS personnel with survival in a cohort undergoing transport by ground EMTs with limited capabilities. While there was inevitable residual heterogeneity within the ground ALS group, and between ground ALS and HEMS ALS providers, the distinction between ALS and BLS is much greater and subgrouping by ALS/BLS allowed the current study to coarsely adjust for prehospital level of care. Additionally, prehospital level of care is a surrogate for injury severity, rendering inclusion of this covariate a means for improving the study's ability to adjust for acuity and remove a potential confounder of the HEMS-mortality relationship.

The prehospital level of care issue can be logically extended to include discussion about whether ground EMS providers can and/or should be trained to provide the advanced care offered by HEMS crews. Such a debate could, for example, take the form of the following question: "If a major prehospital care difference between HEMS and ground providers is the ability to provide neuromuscular blockade-facilitated intubation, then why not simply train ground EMS providers to use paralytic agents, thus obviating the need for expensive helicopters?" As with many seemingly straightforward clinical questions, this issue is convoluted. In fact, while debate along the lines of "augmented ground EMS" training should be vigorously encouraged, there are at least three reasons that such discussions should not distract from attempts by HEMS researchers to determine whether there is any mortality benefit associated with helicopter transport.

First, absent demonstration of HEMS-associated mortality reduction it is arguably moot to speculate as to which HEMS aspects should be incorporated into ground EMS practice as interventions which improve survival. Second, assuming that specific life-saving aspects of HEMS can be identified, it is not a given that they can be adapted to ground EMS. Regardless of increased training, no EMS supervisory authority can fiat the experience and expertise gained by the fact that a limited number of HEMS crew cover a large area and therefore have frequent exposure to patients of high acuity and need for procedural interventions. For example, the medical crew in the primary study service has reported a 6-year airway establishment success rate of nearly 98% in 722 patients, with these high numbers attributed in part to concentrated training of a limited crew cadre performing frequent airway interventions.[30] Third, even if ground EMS personnel perform at HEMS crew levels, health care economics researchers have suggested that replacement of a HEMS program with multiple ground units of HEMS-comparable training and response times actually increases cost.[31] One trauma surgeon commentator[32] has stated that it is "fallacious to compare the expense of one helicopter to that of one ATLS ambulance," noting that 22 ambulances would be required to cover the same territory as a single helicopter in his system. Other economics researchers, confirming the cost-effectiveness of HEMS as being comparable or superior to that of other frequently utilized medical interventions, have also noted the difficulties of assessing cost-effectiveness of HEMS as compared with augmented-capability ground EMS.[33]

Overall, experts have presented strong argument that if HEMS is associated with mortality reduction along the lines found in the current paper, then helicopter transport is cost-effective as defined by current standards.[33] Detailed discussion of cost-effectiveness issues is beyond the intended scope of this paper, as preliminary economic assessment has proven the issue complex. For purposes of this paper, the points previously mentioned do not mean HEMS-associated benefit cannot be accrued with augmented ground EMS capability; they do, though, demonstrate as fallacy the contention that such increased ground EMS training would be easy or inherently cost-effective. While these issues are being sorted out, it appears reasonable to focus efforts on the primary question of HEMS-associated survival benefit.

A separate issue, central to the interpretation of the study's results, is the fact that the study is trauma registry-based and used data from five hospitals. This approach incurs both advantages and disadvantages. On the negative side, registry information is not collected for purposes of a study such as this one, and thus may be missing data of potential relevance to the assessment of the HEMS survival hypothesis. As an example, though Baxt and Moody's seminal HEMS mortality study[2] was characterized by longer prehospital times for HEMS (58 minutes) as compared with ground EMS (35 minutes), it remains possible that some benefit is accrued by faster transport speeds of helicopters as compared with ground ambulances. Unfortunately, the current study was not able to adjust for time issues because the pertinent data were simply not available for the ground-transported patients. For the data which are present in the trauma registries, it is not possible to systematically confirm data accuracy, and patient capture and data coding methods and reliability may be different at varying institutions. On the other hand, trauma registries at each of the participating hospitals were well-established and administered by professionals who would have no interest in biasing data toward or against HEMS mortality demonstration. Since any misclassification would be expected to be random, the expected result would be to bias the study results toward the null rather than in favor of either air or ground transport.[34] Given the study's positive result, such misclassification seems unlikely to have clouded the association between transport mode and survival.

One problem inherent in retrospective assessment of trauma registry data—the question of complete patient capture—warranted further exploration. Trauma registrars at all centers confirmed that their registries were designed to capture all trauma patients other than those discharged alive from the ED, but capture may not have been 100%. Based on the relatively low likelihood of registries' failing to capture admitted trauma patients, it was postulated that cases most likely to be missed would be those dying in the ED. Though there was no reliable method to check the capture rate for the hospitals' trauma registries during the study years, an informal analysis was performed to check the ED death capture rate at one center. After human studies committee approval, 1 year (1999) of one study center's handwritten ED logs were reviewed to assess the frequency and air/ground transport breakdown of any ED deaths "missed" by the trauma registry. This review revealed a total of 11 trauma-related ED deaths which were not included in the trauma registry; all 11 of these patients were brought in to the ED "in arrest" by ground EMS. The results of this review thus supported the common-sense notion that ED deaths in general would be more likely to be transported by ground, since any patients in arrest at the scene are transported by ground in the study's area. Importantly, then, any bias introduced by trauma registry exclusion of ED deaths would be (1) expected to be of small magnitude, since registries are designed to capture such patients, and more importantly, 2) expected to bias the study *against* HEMS transport by removing ground-transported death cases from analysis. Therefore, any results effects due to missing of ED deaths would be expected to be manifest as underestimation of the HEMS association with improved survival.

Since the receiving trauma center was accounted for in multivariate analysis, the problem of confounding by differing case mix is avoided. The use of multiple trauma centers' data also had the advantage of maximizing the external validity of the study results by including a wide variety of blunt trauma patients.

With Boston MedFlight transports constituting over 80% of HEMS study patients, and unreliable differentiation between HEMS programs in trauma registries, there was no attempt to control for HEMS program in the analysis. Likewise, the large number of ground EMS agencies involved precluded adjustment for this factor. On a related note, one of the study's strengths is that patients were transported during an era in which prehospital care was reasonably advanced. To wit, while the seminal work of Baxt and Moody[2] remains relevant today, it is noteworthy that the esophageal obturator airway was the maximum airway intervention afforded ground transported patients in that study. Similarly, other frequently cited papers in the air transport literature are over a decade old, and thus correlation of these authors' findings with a more up-to-date study has some value.

If this study is strengthened by assessment of outcomes during a period of contemporary out-of-hospital care, the inability to identify EMS interventions is a significant barrier to efforts toward explaining the HEMS-associated mortality benefit. Though information on procedures was reliably available for air-transported patients, obtaining such data on ground-transported patients did not prove feasible. Initial attempts to review medical records demonstrated that well under half of the hospital records contained EMS "run sheets." Follow-up plans to obtain run sheets from ambulance companies proved impractical due to the fact that over 30 ground services were involved, with many companies involved in corporate mergers or other reorganizations rendering access to 4 years of run sheets virtually impossible. A major direction for further investigation will be performance of subset analysis to try and explain any putative mortality benefit associated with HEMS use.

To maximize the size of the study population, scene and interfacility mission types were both included in the study database. Such combination of mission types has been performed in at least three previous HEMS papers.[4,6,35] Precedent for assessing both scene and interfacility patients while simultaneously controlling for mission type is found in at least one previous *Journal of Trauma* study.[35] The inclusion of a separate mission type term in our model represents a potential improvement upon one TRISS study[6] which analyzed combined scene and interfacility pediatric patients but which did not appear to include a mission type term in their model. It was felt that for the current study, inclusion of such a mission type variable would be of critical importance: since mission type was included as an independent variable in the current study's model, the main effect (i.e., HEMS) odds ratio point estimate of 0.756 is adjusted for (i.e., takes into account) mission type.

Subgroup analysis was performed for scene and interfacility patients, and is reported with the caveat that this a posteriori testing was not part of the initial study plan. For the 5443 interfacility transports, the point estimate for HEMS mortality reduction was 0.91 but the smaller n resulted in a wide 95% confidence interval (0.59–1.40) which included the null. For the scene transports (n = 11,256), suggestion of mortality benefit associated with HEMS transport remained (OR 0.62) and though the confidence intervals were wide (0.45–0.86) they did not cross the null and the p for HEMS was 0.004 by likelihood ratio testing. These data are suggestive but should be confirmed by prospective analysis designed to specifically address the question.

Few patients (135, 0.81% of 16,699) had missing ISS. To account for these patients, a fifth ISS group comprised of those with "missing" ISS was included in the main multivariate results reported above. In an a posteriori check to ensure that inclusion of these 135 patients did not skew the analysis, a multivariate assessment of HEMS and mortality was performed, which excluded the 135 patients with no ISS. The results of this analysis (n = 16,564) were nearly identical to the main model results: HEMS reduced mortality with OR 0.76 and 95% CI 0.59–0.98 (p = 0.04 by likelihood ratio testing). In another a posteriori check to ensure that ISS grouping had no effect on the study's results, assessment of HEMS' association with mortality reduction in a multivariate model incorporating analysis of ISS as a continuous variable found results similar to the main model (HEMS OR, 0.70; 95% CI, 0.53–0.93; p = 0.01 by likelihood ratio testing).

In checking for effects of treatment of missing data, Prehospital Level of Care was a concern. Whereas ISS information was infrequently missing, the variable for maximum Prehospital Level of Care (ALS vs. BLS) was commonly unavailable (n = 3439, 20.6% of 16,699). Furthermore, since all HEMS transports were by definition ALS, all cases with missing Prehospital Level of Care status were in the Ground transport group. The lack of ability to obtain EMS run sheets, described earlier in the discussion on EMS interventions, also translated into an inability to assign ALS/BLS status to some patients. As has been described in the Results section, these 3439 patients were separately grouped as "Missing" and included in analysis. In an a posteriori check to ensure that inclusion of the 3439 patients with missing Prehospital Level of Care status did not skew the analysis, a multivariate assessment of HEMS and mortality was performed, which excluded the 3439 patients with no ALS/BLS status. The results of this analysis (n = 13,260) remained similar to the main model results, with the association between HEMS and mortality falling just within the 0.05 level for statistical significance (HEMS OR, 0.77; 95% CI, 0.60–0.997; p = 0.046 by likelihood ratio testing).

In conclusion, though this multicenter trial contained flaws it makes a strong case for mortality reduction associated with HEMS transport of blunt trauma patients in the study setting. The magnitude of mortality reduction—approximately 24%—is in a range supported by previous literature. Furthermore, though the p values for HEMS transport were not as low as corresponding results for other model covariates (e.g., ISS), the HEMS term was statistically significant when evaluated by confidence interval analysis as well as both Wald and likelihood ratio testing. The reliability of the current study's identification of a HEMS-associated mortality improvement is enhanced by the study's adjustment for factors known to influence survival, and by the fact that the magnitude and significance of HEMS-associated mortality improvement remained relatively constant in a posteriori analyses employing different treatment of certain variables. The study's conclusions are limited to the contention that survival was enhanced with utilization of HEMS in the study population, over the study period. The analysis was not able to identify which aspects of HEMS practice accounted for the survival benefit, though it is clear that the helicopter itself was less responsible than some uncharacterized combination of a myriad of other HEMS-related advantages (e.g., rapid response, highly trained crews, improved communication with receiving trauma centers, capability of transporting patients directly to operating rooms at receiving centers).

The next steps for investigators will be to attempt to explain the mechanism for HEMS-associated mortality benefit and assess nonmortality endpoints. These steps, as well as performance of subset analyses to further characterize which patients benefit from HEMS, will aid in refining HEMS triage criteria to maximize appropriate utilization of helicopters in trauma care.

ACKNOWLEDGMENTS

For longstanding support and assistance with planning and executing this study, the authors express special appreciation to Dr. Erwin Hirsch of the Department of Surgery at Boston Medical Center and Boston University School of Medicine, and to Dr. Alasdair Conn of the Department of Emergency Services at Massachusetts General Hospital and Harvard Medical School.

The study could never have been contemplated but for the ongoing collection and selfless sharing of trauma registry data from participating centers. The authors gratefully acknowledge the invaluable assistance of the study hospitals' trauma registry coordinators and trauma directors: Dianne Danis, RN, and Geoff Silver, MD (Beth Israel Deaconness Medical Center), Joseph Blansfield, RN, and Erwin Hirsch, MD (Boston Medical Center), Mary Kennedy, RN and Jonathan Gates, MD (Brigham and Women's Hospital), Carole Atkinson, RN, and Dennis Lund, MD (Children's Hospital), and Grace P. McDonald-Smith and Ronald Tompkins, MD ScD (Massachusetts General Hospital).

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