How many minutes matter: Association between time saved with air medical transport and survival in trauma patients

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BACKGROUND: Air medical transport (AMT) offers a survival advantage to trauma patients for several reasons, including time-savings over ground transport. Triage guidelines suggest AMT use when there are significant time-savings, but how much time needs to be saved to confer a benefit is unclear. Our objective was to define the time-savings threshold for which AMT has a survival benefit over ground transport.

METHODS: Retrospective cohort of adult trauma patients transported ≤40 miles by ground or air in the Pennsylvania Trauma Outcomes Study 2000 to 2017. Geographic information system network analysis generated the counterfactual transport mode times, and we calculated a time-savings of AMT for each patient. We used restricted cubic splines to allow for non-linear effects of time-saved within multilevel logistic regression to identify a threshold of AMT time-savings associated with survival. Subgroups of patients meeting physiologic or anatomic criteria from the National Field Triage Guidelines (NFTG) and those with a positive Air Medical Prehospital Triage (AMPT) Score were analyzed.

RESULTS: There were 280,271 patients included. The NFTG subgroup had survival advantage starting at 13 minutes of AMT time-saved (adjusted odds ratio, 1.14; 95% confidence interval, 1.01–1.30). The AMPT subgroup had survival advantage starting at 23 minutes with the greatest magnitude of improvement (adjusted odds ratio, 1.22; 95% confidence interval, 1.01–1.48). Among patients that did not meet either NFTG criteria or the AMPT score, no amount of time-saved by AMT was associated with survival ($p > 0.05$). Sensitivity analysis accounting for injury severity in scene time showed the survival benefit starting at 17 minutes of AMT time-saved for the NFTG subgroup and remained 23 minutes in the AMPT subgroup.

CONCLUSION: Among patients meeting physiologic or anatomic NFTG criteria, a ≥ 13- to 17-minute AMT time-savings threshold was associated with improved survival. There is heterogeneity among this threshold among different patient groups that may be due to other benefits of AMT, such as advanced capabilities. These findings can inform AMT triage guidelines. (*J Trauma Acute Care Surg.* 2025;98: 890–898. Copyright © 2025 American Association for the Surgery of Trauma.)

LEVEL OF EVIDENCE: Therapeutic/Care Management; Level IV.

KEY WORDS: Helicopter; emergency medical services; outcome; ambulance; triage.

Trauma is a time sensitive condition. Conceptually, minimizing prehospital time is intuitively beneficial. Air medical transport (AMT) has developed within trauma systems as a key prehospital resource for the timely transport of severely injured trauma patients. Up to a quarter of Americans rely on AMT to reach a trauma center within an hour of injury,[1] and the survival benefit of this mode of transport compared with ground emergency medical services (GEMS) has been demonstrated by multiple groups.[2–8]

The underlying mechanism of this survival benefit is a combination of speed, greater medical capability and experience of AMT crews, and direct access to trauma centers. Most data suggest only specific subgroups of injured patients benefit from minimizing prehospital time,[9,10] and using AMT to reduce time to definitive care over long distances, difficult terrain, or congested areas may be a strategy to improves outcomes in these patients. What has not been established is how much time needs to be saved using AMT over GEMS to benefit injured patients.

The air medical transport of prehospital trauma patients position statement published by Thomas et al.[11] weakly recommended that patients meeting the anatomic and physiologic criteria of the National Guidelines for the Field Triage of Injured Patients (NFTG) published by the American College of Surgeons[12] should be transported by AMT if this offers a "significant time savings." The authors of the position statement, however, found no evidence to guide the duration of time that constitutes "significant." This has left trauma systems to arbitrarily set time standards, or more commonly leave it to the judgment of first responders who must estimate how much time would be saved on their own and decide if it is justifiable to use AMT. Therefore, our objective was to establish whether there is a

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critical time-saving threshold associated with improved survival to guide trauma systems in establishing time-saving criteria for appropriate AMT use and benchmarking. We hypothesize an identifiable survival benefit for a time saved threshold using AMT will be present.

METHODS

Study Population

Our primary data set was the Pennsylvania Trauma Outcomes Study. Pennsylvania Trauma Outcomes Study is a statewide trauma registry comprised of data submitted by all accredited trauma centers in Pennsylvania. This data set was chosen for its large volume, heterogeneous patient population, and the degree of granularity in the variables collected for each patient encounter. This study was deemed exempt from review by the institutional review board.

Adult (age 16 years or older) trauma patients transported by AMT or GEMS from the scene of injury in 2000 to 2017 were included. To evaluate a marginal population where there is some decision making for first responders on scene about whether AMT will save time, we graphically evaluated the proportion of patients undergoing AMT across the distance from the trauma center and excluded patients coming from distances farther than the 75th percentile of AMT utilization proportion. This excludes patients from distances that are nearly always flown to the trauma center with no need to make a transport decision on scene regarding the potential time saved by AMT. In addition, patients with either scene times or transport times exceeding 90 minutes (not representative of typical scene trauma EMS calls), patients who were dead on arrival, and those with unknown transport mode were excluded.

Because of the evidence suggesting only certain subgroups of trauma patients benefit from shorter prehospital time,[10] we selected two subgroups based on prior literature that may benefit from AMT. First, we examined patients that satisfied at least one of the anatomic or physiologic criteria in the NFTG as utilized by Thomas et al. in the position paper as the base group to consider AMT in (Supplemental Digital Content, eFig. 1, http://links.lww.com/TA/E264). Secondly, we evaluated patients that met criteria for AMT based on the Air Medical Prehospital Triage (AMPT) score which, when positive, predicts patients that have a survival benefit of AMT over GEMS (Supplemental Digital Content, eFig. 2, http://links.lww.com/TA/E264).[13]

Air Medical Transport Time Saved

To evaluate the time-saved for AMT over GEMS, we calculated the counterfactual prehospital time (i.e., prehospital time for the transport mode *not* used by the patient) for all patients in the study population for the opposite transport mode rather than how they arrived at the trauma center. The counterfactual prehospital time refers to the prehospital time that would have occurred if the patient was transported by the opposite transport mode than they had actually been transported by in the data set, allowing use to assess the exposure of interest (AMT or GEMS transport) that was not observed in the data set. The result was to have a prehospital time for both AMT and GEMS for each individual patient regardless of their actual transport mode.

For patients actually transported by GEMS, we used geographic information system (GIS) software to calculate the straight-line Euclidean distance from the scene of injury to the nearest air medical base location, as well as the straight-line Euclidean distance from the scene of injury to the trauma center. We then calculated the helicopter response time to the scene and transport time to the trauma center using the published average travel speed for US medical helicopters.[14] We then calculated the median scene time for AMT patients within each zip code of Pennsylvania. We calculated the counter-factual AMT total prehospital time as the actual GEMS response time (representing the time for first responders to arrive and call for a helicopter) plus the helicopter response time from the nearest air medical base, plus the median scene time for AMT patients in the zip code the individual patient was injured in, plus the helicopter transport time to the trauma center. The potential AMT time savings was then calculated as the individual patient's recorded total prehospital time as transported by GEMS minus the calculated counter-factual AMT total prehospital time in minutes. Patients with negative values (e.g., GEMS is faster than AMT) were excluded since first responders would rarely utilize AMT under these conditions per state EMS protocols.

For patients actually undergoing AMT, we used GIS software to calculate the network drive time along the road network from the scene of injury to the trauma center. We then calculated the median response and scene time for GEMS patients within each zip code of Pennsylvania. We calculated the counter-factual GEMS total prehospital time as the median response time for GEMS patients in the zip code the individual patient was injured in, plus the median scene time for GEMS patients in the zip code the individual patient was injured in, plus drive time to the trauma center. The potential AMT time savings was then calculated as the individual patient's calculated counter-factual GEMS total prehospital time minus the recorded total prehospital time as transported by AMT in minutes.

Statistical Analysis

Our primary outcome of interest was survival to hospital discharge. Segmented regression was performed for the study population to determine AMT time saved thresholds at which odds of survival significantly changed. Segmented regression is useful for detecting changes or shifts in the relationship between variables (Supplemental Digital Content, Supplemental Methods, http://links.lww.com/TA/E264).[15] These thresholds were used to define the range of time during which AMT time saved potentially presented a survival advantage and to determine the point at which survival was likely confounded by survivorship bias as evidenced where a less steep slope and wider confidence intervals were encountered. Patients with AMT time savings beyond this likely represent patients coming from far enough away that if they survived to the trauma center, they were likely to survive regardless of time saved. Segmented regression was similarly performed on patients meeting the NFTG and AMPT criteria described above.

Restricted cubic spline analysis was then performed to characterize AMT time savings, allowing for non-linear relationships using 3 knots based on the best model fit among 3, 4, and 5 knots using the lowest Akaike Information Criterion. We then used multilevel logistic regression to determine the association between survival and AMT time savings. We performed a purposeful selection of model covariates based on prior literature of confounders of mortality in trauma research and clinical expertise. Covariate included in the model for mortality risk-adjustment included age, sex, injury mechanism (blunt vs. penetrating), multisystem trauma (2 or more body systems injury by Abbreviated Injury Scores), systolic blood pressure (SBP), heart rate, respiratory rate, Glasgow Coma Scale (GCS), Injury Severity Score (ISS), prehospital clinician level of care (basic vs. advanced life support), emergency department transfusion requirements, intubation, crystalloid resuscitation volume, and need for operative intervention for hemorrhage control. We included a random effect for hospitals to account for clustering within centers. The variables included in the regression model were informed by clinical knowledge.

We then plotted the adjusted odds ratio (aOR) and 95% confidence intervals (95% CI) of survival across AMT time-savings to evaluate a critical threshold where the entire 95% CI became greater than 1.0. At the identified threshold, we then evaluated AMT patients that had a time-savings above that threshold and performed a similar model described above with total prehospital time included as a covariate, saving the adjusted predicted probability of survival. For the same patients we performed the same model but using the counter-factual ground prehospital time as a covariate and saved the predicted probabilities of survival. We then compared the probabilities of survival using the observed prehospital time where AMT saved more than the threshold and the predicted prehospital time if they had undergone GEMS transport.

We further used generalized additive models (GAM)[16] to estimate the relationship between AMT time saved and survival. Generalized additive model can also identify non-linear, flexible, and complex relationships between AMT time saved and survival which otherwise could not be captured by more conventional approaches. We estimated the survival probability for each AMT time saved point and its 95% confidence interval using the fitted GAM model. The partial dependence of predicted probability of survival versus AMT time saved was plotted. We defined the significantly advantageous threshold of AMT time saved as the point at which the lower bound of the 95% confidence interval of the estimated survival probability was higher than the upper bound of the 95% confidence interval of the estimated survival probability at 1 minute of AMT time saved, representing essentially no AMT time saving advantage. These GAM models were performed for the entire cohort as well as AMPT and NFTG subgroups.

To determine the impact of applying the time-savings threshold from our findings among patients that benefit, we calculated the net change in patients that would be triaged to AMT as the additional patients that met the AMT time-saving threshold but were transported by GEMS minus that patients that were transported by AMT but did not meet the AMT time-saving threshold. This net change was expressed as the relative percent change in AMT triage from current transport mode triage at a given time-savings threshold.

Continuous data are presented as median (interquartile range [IQR]). Continuous variables were compared using Wilcoxon rank-sum tests, and categorical variables were compared using χ^2 tests. To aid interpretation, we also converted the odds ratios to relative risk using the predicted probability of survival for GEMS patients from our risk-adjusted model as the control event rate and subsequently calculated the absolute risk difference with 95% CI at various time-saving thresholds. Two-sided p-values ≤0.05 were considered significant. Data analysis was conducted using Stata v18MP (StataCorp; College Station, TX), R Statistical Software v4.2.0 (R Foundation for Statistical Computing; Vienna, Austria). Geographic information system analysis was conducted using ArcGIS v10.8 (ESRI; Redlands, CA). The study adheres to the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines (Supplemental Digital Content, http://links.lww.com/TA/E265).

Missing Data

After application of all inclusion and exclusion criteria as well as the results of the AMT utilization by distance and segmented regression analysis, we assess the proportion of missing data among analysis variables. This ranged from 0.02% (sex) to 6.3% for GCS. Given these low rates of missing data, we chose not to impute the data further and performed a complete case analysis.

Sensitivity Analyses

To ensure results from our full cohort analysis were not being driven by either the NFTG subgroup, AMPT subgroup, or both, we separately analyzed patients that did not meet the physiologic or anatomic NFTG criteria, patients with less than 2 points on the AMPT score indicating GEMS transport triage, and patients negative for both NFTG criteria and <2 points on the AMPT score.

In addition, to evaluate the impact of injury severity on our calculated counterfactual prehospital time as more severely injured patients may have differentially longer scene times across transport modes, we examined the difference in median scene time across several subgroups of patient characteristics for each transport mode, including patient with ISS > 15, patients with field hypotension (SBP < 90 mm Hg), and patients with GCS ≤ 8 with potential TBI. For any differences in median scene time of ≥5 minutes, we recalculated the counterfactual prehospital time by recalculating the zip code specific median scene time for AMT for hypotensive patients, patients with GCS ≤ 8, and patients with both hypotension and GCS ≤ 8 and applied this to these specific patient populations that were transported by ground as the counterfactual AMT time.

RESULTS

A total of 358,216 adult trauma patients were eligible for inclusion in the study. On evaluation of AMT utilization by distance, the 75th percentile was represented by 66% of trauma patients flown at a distance of 42 miles from the trauma center, and also corresponded to a plateau in the proportion of AMT utilization (Supplemental Digital Content, eFig. 3, http://links.lww.com/TA/E264). Thus, for the study population, patients at distances >40 miles from the trauma center were excluded resulting in 280,271 patients in the study population.

The median age of patients was 54 (IQR, 33–76) and 59% were male sex. Eighty-six percent resided in an urban region and the median ISS was 9 (IQR, 5–16) as seen in Table 1. Segmented

TABLE 1. Population Characteristics by Transport Mode

	Ground	Helicopter	*p*
N	250,791	29,416	
Median age (IQR), y	53 (31–76)	39 (23–55)	<0.001
Sex, male	144,339 (57.5%)	20,514 (69.7%)	<0.001
Survival	236,172 (94.2%)	26,665 (90.6%)	<0.001
ISS > 15	60,698 (24.2%)	13,815 (47.0%)	<0.001
Multisystem injury	5,587 (2.2%)	2,767 (9.4%)	<0.001
Penetrating mechanism	20,103 (8.0%)	1,777 (6.0%)	<0.001
Median prehospital duration (IQR), min	41 (31–53)	46 (37–55)	<0.001
Median SBP (IQR)	136 (120–153)	133 (118–149)	<0.001
Median HR (IQR)	88 (76–100)	91 (79–106)	<0.001
Median RR (IQR)	18 (16–20)	18 (16–20)	<0.001
Median GCS (IQR)	15 (14–15)	15 (10–15)	<0.001
ED blood transfusion	8,797 (3.5%)	2,552 (8.7%)	<0.001
Prehospital crystalloid volume			<0.001
None	111,850 (60.7%)	1,828 (8.2%)	<0.001
<500 mL	52,036 (28.2%)	12,093 (53.9%)	<0.001
500–1000 mL	20,159 (10.9%)	8,143 (36.3%)	<0.001
>2000 mL	328 (0.2%)	365 (1.6%)	<0.001
Intubated	3,492 (11.5%)	971 (10.2%)	<0.001
Urgent thoracic surgery	1,961 (0.8%)	324 (1.1%)	<0.001
Urgent abdominal surgery	8,202 (3.3%)	1,626 (5.5%)	<0.001
Urgent vascular surgery	1,942 (0.8%)	322 (1.1%)	<0.001
Urgent craniotomy	4,156 (1.7%)	903 (3.1%)	<0.001
Urgent interventional radiology	993 (0.4%)	157 (0.5%)	<0.001
AMPT criteria met	19,104 (10.3%)	6,186 (26.9%)	<0.001
NFTG criteria met	9,834 (3.9%)	2,667 (9.1%)	<0.001

HR, heart rate; RR, respiratory rate; ED, emergency department.

regression analysis determined the presence of inflection points at approximately 30 minutes, where the slope (representing odds of survival) became significantly less positive (Fig. 1). Similar inflection points were found in the NFTG and AMPT subgroups (Supplemental Digital Content, eFigs. 4, 5, http://links.lww.com/TA/E264). Following 30 minutes, odds of survival steadily increased, approaching 100%. This suggests that survivorship bias may confound patients who stood to gain approximately 30 or more minutes of AMT time saved, as these patients were already more likely to survive their injury than those who were more sensitive to the timeliness of their transport to a trauma center. To minimize the impact of this bias, we limited our analyses to AMT time saved of 30 minutes or less.

Spline analysis of the entire cohort demonstrated a significant increase in adjusted odds of survival starting at 17 minutes of AMT time saved (aOR, 1.13; 95% CI, 1.01–1.28, Fig. 2). The NFTG subgroup demonstrated greater sensitivity to the amount of AMT time saved, with a survival advantage being detected starting at just 13 minutes of AMT time saved (aOR, 1.14; 95% CI, 1.01–1.30, Fig. 3). The AMPT subgroup demonstrated a significant change in odds of survival at a longer threshold of 23 minutes, but with the greatest magnitude of survival odds improvement (aOR, 1.22; 95% CI, 1.01–1.48, Fig. 4). When we examined patients that did not meet NFTG criteria and/or the AMPT score, no amount of time saved by AMT was associated with survival ($p > 0.05$, Fig. 5A–C), suggesting the association between AMT time-savings and survival was primarily driven by patients with physiologic or anatomic NFTG criteria and/or a positive AMPT score for AMT.

Using the GEMS control survival rate of 89.7% in the NFTG subgroup, a 13-minute threshold of AMT time-savings is associated with a 1.1% absolute increase in survival (risk different, 0.011; 95% CI, 0.001–0.022). Using the GEMS control survival rate of 77.5% in the AMPT subgroup, a 23-minute threshold of AMT time-savings is associated with a 3.3% absolute increase in survival (risk difference, 0.033; 95% CI, 0.002–0.061).

The GAM analysis demonstrated similar findings for both subgroups. The whole cohort had a shorter interval, requiring approximately 13 minutes of AMT time saved before a survival advantage was statistically significant (Supplemental Digital Content, eFig. 6, http://links.lww.com/TA/E264). The NFTG subgroup required approximately 11 minutes (Supplemental Digital Content, eFig. 7, http://links.lww.com/TA/E264), and the AMPT subgroup required approximately 27 minutes to demonstrate a survival advantage (Supplemental Digital Content, eFig. 8, http://links.lww.com/TA/E264). GAM analysis of patients who met neither NFTG nor AMPT criteria found no survival benefit at any time interval (Supplemental Digital Content, eFig. 9, http://links.lww.com/TA/E264).

Within our cohort, 10.5% of patients were transported by AMT. The percent change in AMT proportion varied by time-

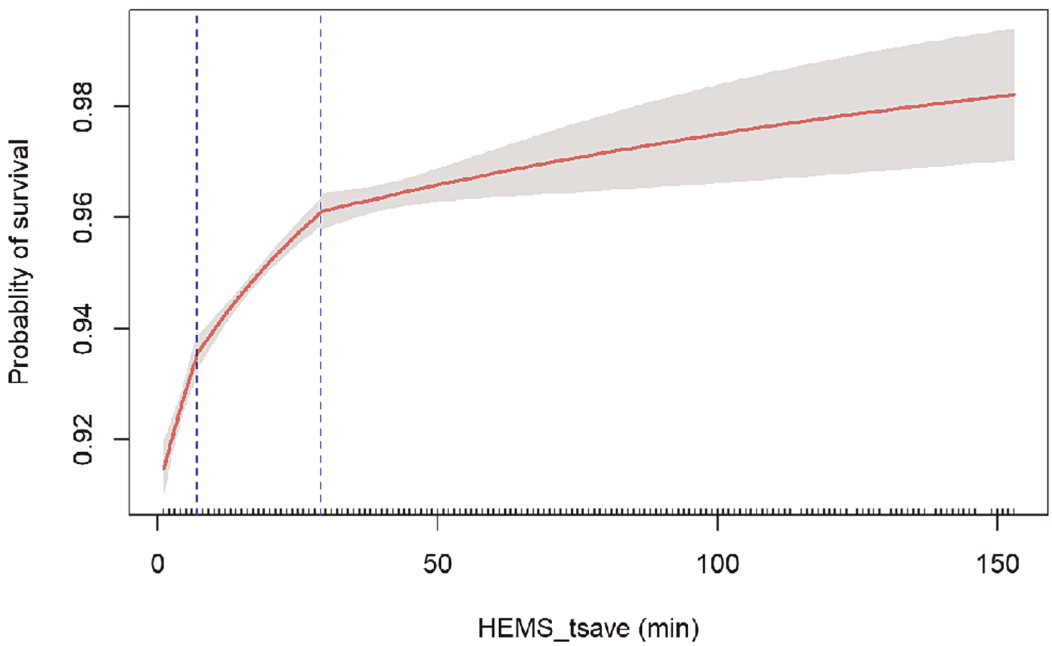

Figure 1. Segmented regression analysis demonstrating a plateau of the odds of survival at a threshold of 30 minutes in the entire study population.

savings threshold and selection criteria. Using a time-savings threshold of 13 or more minutes with the NFTG selection criteria, a relative increase of 26.4% patients would be triaged to AMT transport. However, at a threshold of 18 minutes with the NFTG selection criteria, the net increase in AMT triage was 0.1% representing the "break-even" threshold in this study population. Thus, time-saving thresholds greater than 18 minutes with the NFTG selection criteria resulted in a net reduction of AMT triage. For example, using a 20-minute threshold resulted in an 8.7% relative reduction in patients triaged to AMT. Using the AMPT score selection criteria at the identified time-savings threshold of 23 minutes resulted in a 55.1% relative reduction in AMT triage.

In our sensitivity analysis exploring differences in median scene time across injury severity characteristics, among GEMS transport patients, the difference in median scene time was only 2 minutes between patients with and without ISS > 15, hypotension, or GCS ≤ 8. We similarly found a 2-minute difference in median scene time among AMT patients for ISS > 15, thus we

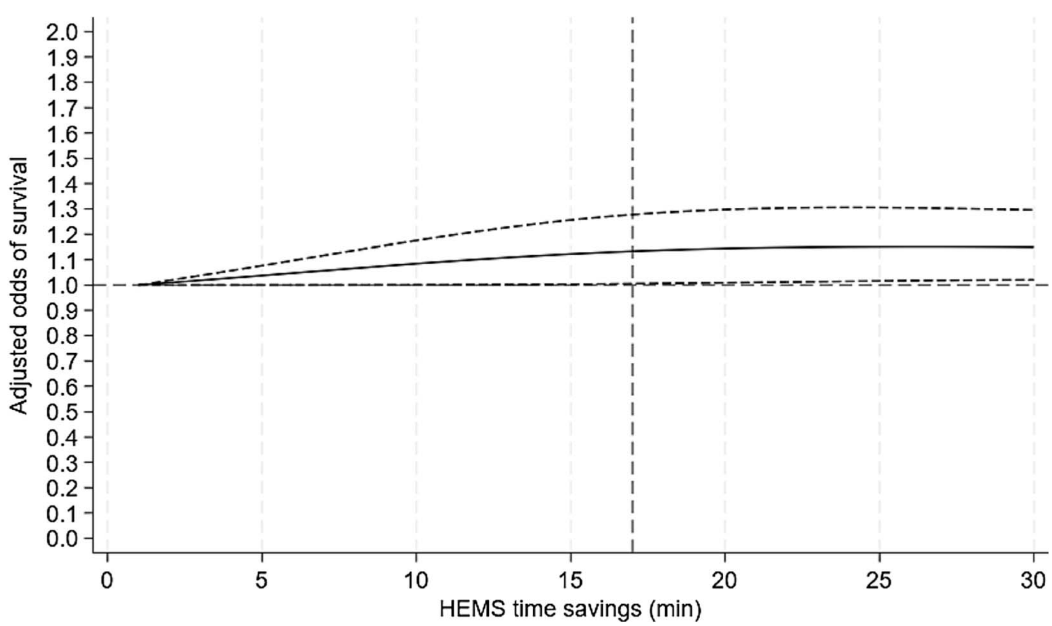

Figure 2. Adjusted odds of survival and 95% confidence interval (dotted lines) plotted over air medical transport time saving over ground transport in the entire study population. Vertical dashed line represents threshold where the entire 95% confidence interval is above 1.0 indicating a significant association between the odds of survival and time saved by AMT.

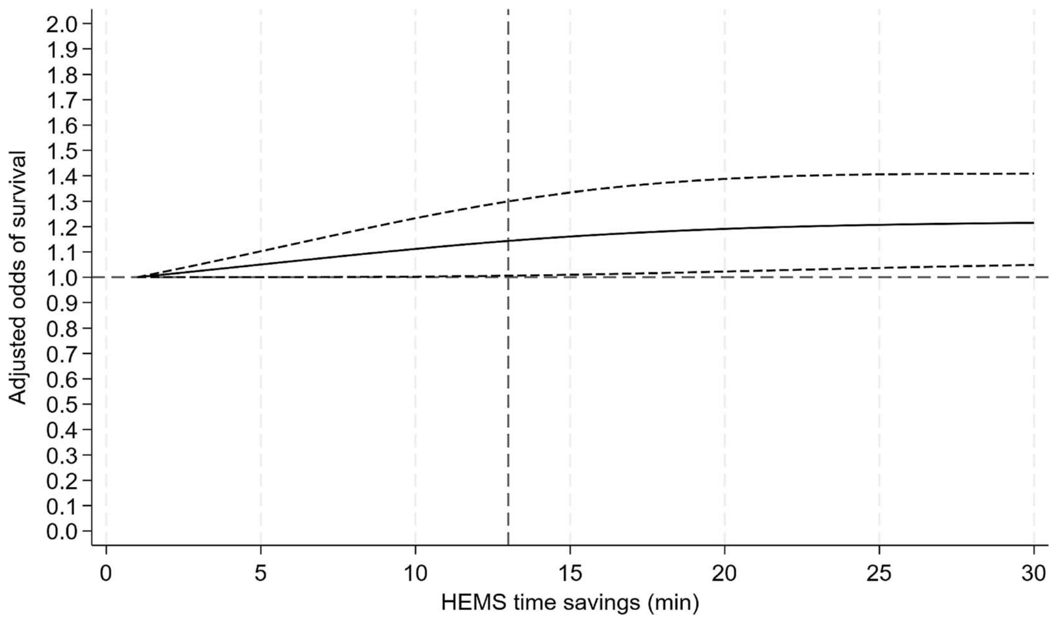

Figure 3. Adjusted odds of survival and 95% confidence interval (dotted lines) plotted over air medical transport time saving over ground transport in patients meeting at least one physiologic or anatomic criterion of the National Field Triage Guidelines. Vertical dashed line represents threshold where the entire 95% confidence interval is above 1.0 indicating a significant association between the odds of survival and time saved by AMT.

did not alter the counterfactual prehospital time calculations for these patients. We did, however, find for AMT patients, those with hypotension had a 5 minute longer median scene time compared with those without hypotension, and a 9 minute longer median scene time for those with GCS ≤ 8 compared with those without GCS ≤ 8. When recalculating the counterfactual scene time for patients with hypotension and/or GCS ≤ 8, we found in the whole cohort no threshold of time-savings was associated with a survival benefit for AMT (Supplemental Digital Content, eFig. 10, http://links.lww.com/TA/E264). Among the NFTG subgroup the survival advantage for AMT over ground transport emerged at 17 minutes of AMT time saved (aOR, 1.16; 95% CI, 1.01–1.35, Supplemental Digital Content, eFig. 11, http://links.lww.com/TA/E264). The AMPT subgroup demonstrated the same threshold of

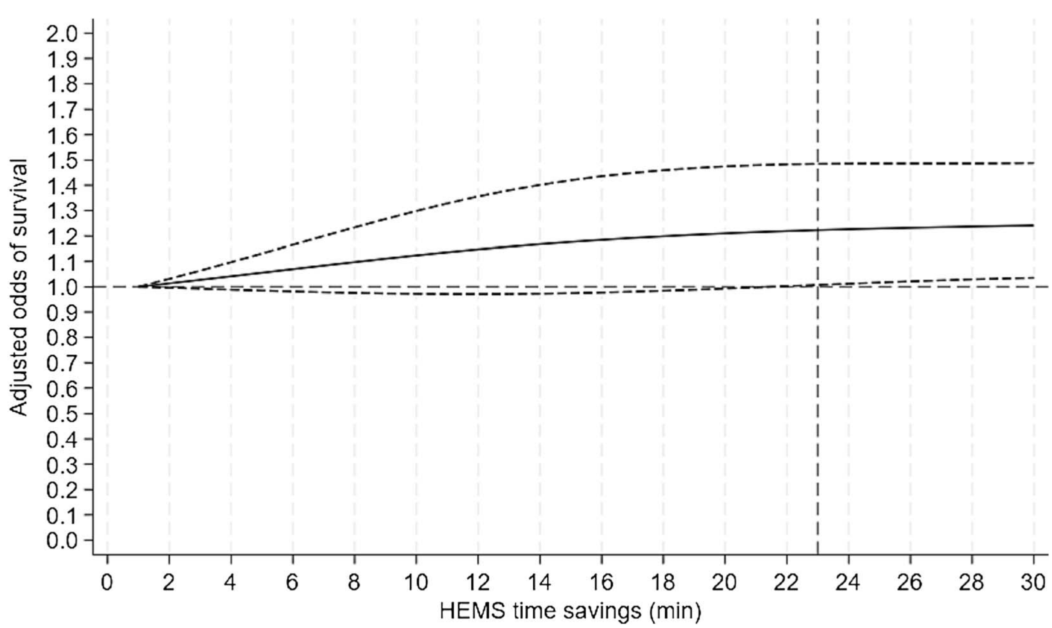

Figure 4. Adjusted odds of survival and 95% confidence interval (dotted lines) plotted over air medical transport time saving over ground transport in patients with 2 or more points on the Air Medical Prehospital Triage score. Vertical dashed line represents threshold where the entire 95% confidence interval is above 1.0 indicating a significant association between the odds of survival and time saved by AMT.

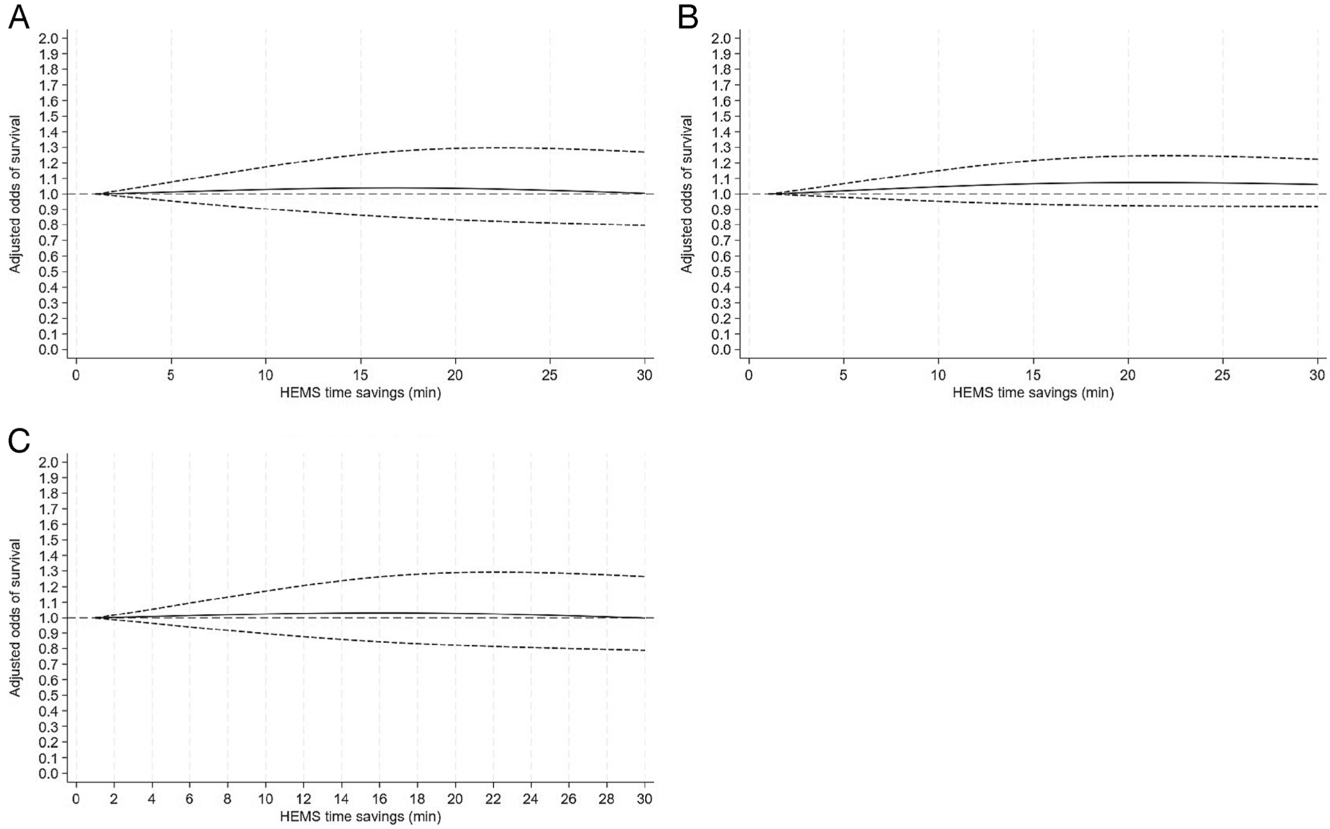

Figure 5. Adjusted odds of survival and 95% confidence interval (dotted lines) plotted over air medical transport time saving over ground transport in patients not meeting physiologic or anatomic NFTG criteria (A); with less than 2 points on the AMPT score (B); not meeting NFTG criteria and less than 2 points on the AMPT score (C). The entire 95% confidence interval is never above 1.0 indicating no association between the odds of survival and time saved by AMT.

23 minutes, again with a greater magnitude of survival odds improvement (aOR, 1.21; 95% CI, 1.01–1.47, Supplemental Digital Content, eFig. 12, http://links.lww.com/TA/E264). As expected, for patients that did not meet NFTG criteria and/or the AMPT score, no amount of time saved by AMT was associated with survival in our sensitivity analysis ($p > 0.05$, Supplemental Digital Content, eFig. 13 A-C, http://links.lww.com/TA/E264).

DISCUSSION

In this study, we demonstrate an increase in the odds of survival was associated with an AMT prehospital time savings of 13 minutes or greater among patients meeting any one of the physiologic or anatomic NFTG criteria, and an AMT prehospital time savings of 23 minutes or greater among patients positive (2 or more points) on the AMPT score. Patients that do not meet one of these selection criteria did not demonstrate a survival benefit associated with any amount of prehospital time-savings from AMT. In sensitivity analysis accounting for longer AMT scene time among patients with hypotension or GCS ≤ 8 that may be undergoing additional interventions such as blood transfusion or advanced airway management, the threshold among the NFTG subgroup increased to 17 minutes, while the threshold of time-saving AMT survival benefit remained 23 minutes in the AMPT subgroup.

This is the first study to our knowledge to identify a specific time threshold of prehospital time reduction for AMT associated with a survival benefit, using novel counter-factual prehospital time calculations in GIS.[11] We did not find a survival benefit for AMT time-savings in unselected trauma patients, which we might expect based on prior work that finds no association between prehospital time and outcomes in the general trauma population.[17,18] The cohort of patients meeting at least one physiologic or anatomic NFTG criteria as initially outlined by Thomas et al. as the initial selection criteria demonstrates a modest improvement in survival, while the group meeting AMT triage criteria from the AMPT score has a larger magnitude in the improvement in survival odds, but at a longer time threshold.

This longer time threshold for patients positive on the AMPT score may be due to the types of patients identified by the AMPT score which was initially developed to identify patients that have a survival benefit from AMT over GEMS transport. Nearly all the AMPT score positive patients would also fall in the NFTG cohort. Further, three of the seven criteria are GCS <14, unstable chest wall fractures, and suspected hemothorax or pneumothorax representing both head and chest injuries that are likely to benefit from the skill, experience, and advanced procedures of AMT crew (e.g., advanced airway management, hemodynamic management, chest decompression)[3,19] rather than purely from rapid transport to a hospital alone.

This study has several implications. First, these time-saving thresholds can be used as a starting point for AMT triage protocols and guidelines. We acknowledge that a single threshold value is difficult to operationalize in modern EMS and trauma systems. We propose that a time-savings of at least 15 minutes to 20 minutes be considered as a starting point for considering AMT in patients that meet at least one physiologic or anatomic NFTG criteria, especially given our sensitivity analysis results. It is also important to recognize that patients that may benefit from advanced care or otherwise directly access a high-level trauma center may benefit irrespective of the time-saved. Further, the distance/geographic location that this time-saving would be achieved will be dynamic based on traffic conditions, weather, and available EMS resources.

The accuracy of operationalizing a time-saving threshold must also be considered. To determine the potential time-saved by AMT, first responders assessing a patient on scene must assess how long it will take to activate, dispatch, and fly the helicopter to the scene of injury. They then must account for how long it will take for the air medical crew to assess the patient and safely load them in the helicopter (scene time), as well as the flight time to the intended trauma center. This must all consider the current weather and traffic conditions, obviously leading to significant cognitive load for these first responders. As a result, most first responders are familiar with their service area and will make a gestalt assessment of potential time saved for AMT. Thus, the minimum thresholds of 13 or 17 minutes for NFTG criteria or 23 minutes for the AMPT score are likely not realistic threshold holds that can be operationalized but should be modified to an actionable threshold for field use by first responders estimating the potential time-savings of AMT. This presents opportunities for leveraging existing technology such as GPS and dynamic navigation software to make a more robust assessment of the potential time saved and in-turn potential survival benefits for injured patients. Our findings provide a window of time saved that allows trauma and EMS systems to perform their own assessment based upon their unique mix of resources/volume to determine a time-savings threshold that will maximize benefit within their system.

Our study does have several limitations that merit discussion. First, the retrospective nature of this study limits our understanding of the rationale underlying the triage decisions made for each patient. Some factors that contribute to these triage decisions, such as local weather or helicopter availability, are not available for analysis. Use of the NFTG and AMPT criteria is the best available approximation of appropriateness for AMT transport; however, a true gold standard of AMT appropriateness is lacking. In addition, counter-factual ground and air transport times were generated by GIS which does require assumptions about travel speed, traffic conditions, and routing that may not always accurately reflect ground or helicopter ambulance travel. Air medical transport is subject to minimum weather conditions, and some patients may have not been able to undergo AMT because the helicopter was unable to safely fly. Another limitation inherent to our data set is the inclusion of only accredited trauma centers. Some trauma patients likely were transported to non-accredited hospitals and would not appear in our data set. Lastly, a substantial degree of heterogeneity exists across EMS agencies which may result in some variation in their approach to AMT utilization.

Despite these limitations, our findings can assist EMS clinicians and policy makers in AMT triage of severely injured patients. Air medical transport overtriage is a well-identified concern associated with worse system-level outcomes,[20] and reducing overtriage rates remains a priority. Air medical transport overtriage is costly and puts additional pressure on an already limited resource, potentially preventing other patients from receiving ideal transport following a traumatic injury. We may also be able to reduce undertriage of AMT patients by identifying those with the modest time-savings over ground transport that may have a survival benefit from helicopter transport.

CONCLUSION

Among patients meeting one of the physiologic or anatomic NFTG criteria, a time-savings of 13 to 17 minutes for AMT over ground transport was associated with improved survival. There is heterogeneity among this threshold of benefit among different patient groups that may be due to other benefits of AMT such as advanced capabilities. These findings can inform AMT triage guidelines.

AUTHORSHIP

S.B., L.L., and J.B.B. participated in the study design. S.B., J.B.B. participated in the data collection. S.B., L.L., and J.B.B. participated in the data analysis. S.B., L.L., D.S., T.B., F.X.G., and J.B.B. participated in data interpretation. S.B. and J.B.B. participated in the writing of the article. S.B., L.L., D.S., T.B., F.X.G., and J.B.B. participated in the critical revision of the article for important intellectual content.

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DISCLOSURE

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REFERENCES

1. Branas CC, MacKenzie EJ, Williams JC, Schwab CW, Teter HM, Flanigan MC, et al. Access to trauma centers in the United States. *JAMA*. 2005;293:2626–2633.
2. Bledsoe BE, Wesley AK, Eckstein M, Dunn TM, O'Keefe MF. Helicopter scene transport of trauma patients with nonlife-threatening injuries: a meta-analysis. *J Trauma*. 2006;60:1257–1265.
3. Brown JB, Gestring ML, Guyette FX, Rosengart MR, Stassen NA, Forsythe RM, et al. Helicopter transport improves survival following injury in the absence of a time-saving advantage. *Surgery*. 2016;159:947–959.
4. Brown JB, Stassen NA, Bankey PE, Sangosanya AT, Cheng JD, Gestring ML. Helicopters and the civilian trauma system: national utilization patterns demonstrate improved outcomes after traumatic injury. *J Trauma*. 2010;69:1030–1034.
5. Galvagno SM Jr., Haut ER, Zafar SN, Millin MG, Efron DT, Koenig GJ Jr., et al. Association between helicopter vs ground emergency medical services and survival for adults with major trauma. *JAMA*. 2012;307:1602–1610.
6. Jang JY, Kwon WK, Roh H, Moon JH, Hwang JS, Kim YJ, et al. Time-saving effects using helicopter transportation: comparison to a ground transportation time predicted using a social navigation software. *Medicine*. 2021;100:e26569.
7. Schneider AM, Ewing JA, Cull JD. Helicopter transport of trauma patients improves survival irrespective of transport time. *Am Surg*. 2021;87:538–542.

8. Sullivent EE, Faul M, Wald MM. Reduced mortality in injured adults transported by helicopter emergency medical services. *Prehosp Emerg Care*. 2011;15:295–302.
9. Chen X, Guyette FX, Peitzman AB, Billiar TR, Sperry JL, Brown JB. Identifying patients with time-sensitive injuries: association of mortality with increasing prehospital time. *J Trauma Acute Care Surg*. 2019;86:1015–1022.
10. Harmsen AM, Giannakopoulos GF, Moerbeek PR, Jansma EP, Bonjer HJ, Bloemers FW. The influence of prehospital time on trauma patients outcome: a systematic review. *Injury*. 2015;46:602–609.
11. Thomas SH, Brown KM, Oliver ZJ, Spaite DW, Lawner BJ, Sahni R, et al. An evidence-based guideline for the air medical transportation of prehospital trauma patients. *Prehosp Emerg Care*. 2014;18(Suppl 1):35–44.
12. Newgard CD, Fischer PE, Gestring M, Michaels HN, Jurkovich GJ, Lerner EB, et al. National guideline for the field triage of injured patients: recommendations of the National Expert Panel on field triage, 2021. *J Trauma Acute Care Surg*. 2022;93:e49–e60.
13. Brown JB, Gestring ML, Guyette FX, Rosengart MR, Stassen NA, Forsythe RM, et al. Development and validation of the air medical prehospital triage score for helicopter transport of trauma patients. *Ann Surg*. 2016;264:378–385.
14. Carr BG, Caplan JM, Pryor JP, Branas CC. A meta-analysis of prehospital care times for trauma. *Prehosp Emerg Care*. 2006;10:198–206.
15. <segmented logistic regression.pdf >.
16. Hastie T, Tibshirani R. Generalized additive models; some applications. In: *Generalized Linear Models: Proceedings of the GLIM 85 Conference held at Lancaster, UK, Sept. 16–19, 1985*. 1985; Springer. Abstract number.
17. Lerner EB, Moscati RM. The golden hour: scientific fact or medical "urban legend"? *Acad Emerg Med*. 2001;8:758–760.
18. Newgard CD, Schmicker RH, Hedges JR, Trickett JP, Davis DP, Bulger EM, et al. Emergency medical services intervals and survival in trauma: assessment of the "golden hour" in a North American prospective cohort. *Ann Emerg Med*. 2010;55:235–246.e4.
19. Chen X, Gestring ML, Rosengart MR, Billiar TR, Peitzman AB, Sperry JL, et al. Speed is not everything: identifying patients who may benefit from helicopter transport despite faster ground transport. *J Trauma Acute Care Surg*. 2018;84:549–557.
20. Deeb AP, Phelos HM, Peitzman AB, Billiar TR, Sperry JL, Brown JB. Geospatial assessment of helicopter emergency medical service overtriage. *J Trauma Acute Care Surg*. 2021;91:178–185.