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Research article

Helicopter EMS and rapid transport for ST-elevation myocardial infarction: The HEARTS study

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ABSTRACT

Background: Helicopter emergency medical services (HEMS) and ground EMS (GEMS) are both integral parts of out-of-hospital transport systems for patients with ST-elevation myocardial infarction (STEMI) undergoing emergency transport for primary percutaneous coronary intervention (PPCI). There are firm data linking time savings for PPCI transports with improved outcome. A previous pilot analysis generated preliminary estimates for potential HEMS-associated time savings for PPCI transports.

Methods: This non-interventional multicenter study conducted over the period 2012–2014 at six centers in the USA and in the State of Qatar assessed a consecutive series of HEMS transports for PPCI; at one center consecutive GEMS transports of at least 15 miles were also assessed if they came from sites that also used HEMS (dual-mode referring hospitals). The study assessed time from ground or air EMS dispatch to transport a patient to a cardiac center, through to the time of patient arrival at the receiving cardiac unit, to determine proportions of patients arriving within accepted 90- and 120-minute time windows for PPCI. Actual times were compared to “route-mapping” GEMS times generated using geographical information software. HEMS’ potential time savings were calculated using program-specific aircraft characteristics, and the potential time savings for HEMS was translated into estimated mortality benefit.

Results: The study included 257 HEMS and 27 GEMS cases. HEMS cases had a high rate of overall transport time (from dispatch to receiving cardiac unit arrival) that fell within the predefined windows of 90 minutes (67.7% of HEMS cases) and 120 minutes (91.1% of HEMS cases). As compared to the calculated GEMS times, HEMS was estimated to accrue a median time saving of 32 minutes (interquartile range, 17–46). The number needed to transport for HEMS to get one additional case to PPCI within 90 minutes was 3. In the varied contexts of this multicenter study, the number of lives saved by HEMS, solely through time savings, was calculated as 1.34 per 100 HEMS PPCI transports.

Conclusions: In this multicenter study, HEMS PPCI transport was found to be appropriate as defined by meeting predefined time windows. The overall estimate for lives saved through time savings alone was consistent with previous pilot data and was also generally consistent with favorable cost-effectiveness. Further research is necessary to confirm these findings, but judicious HEMS deployment for PPCI transports is justified by these data.

Keywords: Air medical transport, helicopter EMS, STEMI, logistics

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BACKGROUND

Out-of-hospital transport and care provided by helicopter emergency medical services (HEMS) or ground-ambulance EMS (GEMS) (which includes both transport modes) constitutes an important part of cardiac care systems. Both GEMS and HEMS programs participate in moving acute coronary syndrome patients to cardiac centers capable of immediate primary percutaneous coronary intervention (PPCI). In fact, although air medical transport's roots lie in trauma transports, HEMS use for cardiac cases, especially ST-elevation myocardial infarction (STEMI), has long been recognized as appropriate resource utilization.¹

Evidence indicates that HEMS contribute to the cost-effectiveness of PPCI. HEMS use can preserve a system's PCI cost-effectiveness when used for patients coming from long distances to the cardiac center.² Studies from Europe and the United States of America (USA) demonstrate that HEMS use can enable STEMI patients from remote regions to achieve similar outcomes as patients presenting directly to the cardiac center – outcomes that are better than those achieved by thrombolytic therapy at referring institutions.^{3,4} Options for HEMS use in cardiac care systems include both the more traditional interfacility (i.e., secondary) transports and an increasing assessment of the potential use of air response for scene (primary) cardiac cases.^{5,6}

At the heart of the HEMS cardiac logistics discussion lies the principle that “time is myocardium.” The importance of time is such that the use of estimated time savings as an endpoint is well established in cardiac systems research.^{7,8} If HEMS save time, it saves heart muscle; air-transport-related savings of time and heart muscle translates directly into mortality reduction for PPCI cases.^{4,6,9}

There is guiding evidence providing a basis to generate estimates of mortality benefit from time savings in STEMI transport. The literature defines the accepted time windows from presentation to intervention of 90 and 120 minutes.^{10–13} These time frames are arbitrary since each 30-minute reduction in time-to-PPCI improves mortality,¹⁴ and each reduction of 15 minutes’ “pre-PPCI” time saves 6.3 lives per 1000 cases.⁹

The tie between time savings and air transport's potential benefit for PPCI cases served as the basis for an initial HEMS cost-effectiveness analysis in a single state in Southwest USA. Using geographic information software (GIS) methods validated for HEMS transports, an Oklahoma study generated a rough estimate of 1.2–1.7 lives saved per 100 STEMI transports for PPCI.⁸

The current analysis was undertaken to assess the potential for time savings – and, by extension, the potential for lives saved – associated with HEMS use in a variety of settings. The first study goal was to assess the proportion of HEMS PPCI cases that were arriving at the PPCI suite within the pre-specified time windows of 90 and 120 minutes. HEMS transports arriving for PPCI outside of the intervention time windows would represent an obvious area warranting assessment for overutilization. The second study goal was to estimate the potential time savings accrued with the use of HEMS, as compared to GEMS, for PPCI transport.

METHODS

The study's main aim was to determine how many transported cases arrived within 90- and 120-minute PPCI windows. The secondary goal was to analyze STEMI transports for PPCI undertaken by different HEMS services and use of validated methods^{8,15,16} to characterize potential HEMS time savings as compared to theoretical GEMS transport of the same cases.

Study design, time frame, and information sources

The study was a non-interventional analysis of six participating programs' consecutive HEMS scene and interfacility transports for PPCI over a two-year period. At one of the six study centers, reliable GEMS time data were also obtainable; these consecutive cases were included in the study (for secondary analysis purposes) if they entailed transports of at least 10 miles' one-way distance. From January 2012 through to study completion in December 2014, flight records and transport or cardiac catheterization center databases were reviewed on an ongoing basis to provide the study data.

As the study commenced in 2013, roughly half the data were collected retrospectively while the remainder were technically collected prospectively. However, all data points collected for the study were routinely collected as part of daily medical-records documentation. The study was purely observational and did not entail any additional documentation or intervention beyond standard care

and usual record-keeping. Institutional ethics board approval for the study was obtained for all participating sites.

Transports eligible for inclusion

Eligible transports were limited to those cases undergoing HEMS transport for PPCI or for those GEMS cases transported at least 15 miles for PPCI (GEMS cases accrued from one study center only). In all cases, the transport diagnosis was STEMI. The diagnosis was EKG-demonstrated in all but two cases; the other two cases had new left bundle branch block that was attributed to acute myocardial infarction.

Cases that were transported to the cardiac center for anything other than planned PPCI, were not included. The study also did not include transports to the cardiac center, even if patients were taken to a cardiac catheterization suite (CCS), if the reason for transport was for anything (e.g., pacemaker placement) other than PPCI.

Subjects were included regardless of age or time interval between initial medical presentation and cardiac intervention. As an observational study, the methodology did not dictate who was transported or who received thrombolytic therapy versus PPCI. The study did not include cases of rescue CCS intervention (after failed thrombolysis) or of facilitated PPCI (i.e., initial dose of thrombolytic therapy with plan for early CCS care) since the data on time-saving benefits for these cases are less concrete.

Study cases included both primary (scene) and secondary transports. Airplane (fixed-wing) transports were not included.

Study settings

The six participating HEMS programs (see Table 1) serve multiple referring facilities and receiving cardiac centers in the USA and in Qatar. Hospital facilities had access to an on-site landing zone (LZ), and short ambulance transport (within hospital grounds) which was sometimes required to get patients from the LZ to the receiving cardiac unit building.

Table 1. Logistics characteristics of study transport programs.

Service	Air transports/ year	Helicopter (speed)*	Bases	Mean patient transport distance**
A	2500	206L (120 mph)	6	36
B	1600	S76C + (170 mph)	1	24
C	1800	AS350B3 (150 mph)	5	50
D	3100	AS350B3 (150 mph)	8	73
E	3400	EC130 (145 mph)	8	43
F	1000	AW139 (160 mph)	1	29

*Routine operating average speeds in miles per hour (mph).

**Mean one-way transport distance for study patients flown by the service.

All programs had at least two aircraft (including backups) and most had multiple bases (see Table 1). Participating programs covered wide geographical areas. Although two programs' base positioning emphasized satellite location of aircraft in more rural areas, every study program transported patients from both rural and urban settings to urban hospitals. Three programs' protocols included the capability to execute primary (scene) transport of STEMI cases directly to CCS units; for the other programs, a radio call to the receiving hospital was possible to prepare the receiving emergency department (ED) for a STEMI case.

Each participating program base provided coverage range of about 100 miles from the helicopter's base. As shown in Table 1, the six study services transported STEMI patients an average one-way distance ranging from 24 to 73 miles.

The geographical regions covered included parts of the USA states of Ohio, Missouri, Kansas, Nebraska, Colorado, Texas, Oklahoma, and Arkansas. Some participating HEMS programs covered part or all of a given state, while others covered multiple states. Some geographic areas, particularly in the borders of states (e.g., Missouri/Kansas), were covered by more than one HEMS program participating in this study. The Qatar-based study program covered the entire country, an area of 4500 miles² with a population of approximately 2.7 million. Institutional ethics board approval for the study was obtained for the participating sites.

Patients were transported to many different receiving cardiac centers. In two study programs, all cases were transported to a single hospital. For the other four study programs, cases were transported to at least two (and usually many more) different receiving hospitals.

For the one study center contributing GEMS transport data to this study, the ambulance services providing ground transport were numerous; all were staffed by a pair of paramedics. Air medical crews of the participating flight programs included experienced non-physician providers such as advanced-care nurses or paramedics. None of the participating EMS programs instituted thrombolytic therapy. In terms of the care of STEMI patients, the participating air transport programs were similar in terms of patient care capabilities and operational approaches (e.g., emphasis on optimizing time efficiency).

Data collected and primary endpoint (time interval) calculations

The data collected included basic demographic information as well as scene (primary) vs. interfacility (secondary) transport category. Transport diagnosis was defined as the assigned diagnosis at the time of arrangement for transport.

Logistics information included the referring and receiving entity locations as well as times of the initial call for transport, EMS dispatch and arrival time of patients, and departure from the referring location. Arrival times at the receiving center LZ and receiving center clinical unit were also noted.

The study plan was to concentrate on two time measurements. The first and more meaningful time interval was the time elapsed between dispatch of EMS (ground or air) and EMS patient delivery at the receiving hospital cardiac unit. In keeping with previous STEMI transport studies, dispatch-to-CCS time was assessed as a continuous variable and also as a dichotomous variable indicating the proportion of cases for which the time fell within a specific time window (90 minutes and 120 minutes).

To allow focus on the transport speed's potential impact on time savings, the study also assessed a subdivision of dispatch-to-CCS time, defined as the transit time (TT). TT encompassed the elapsed time from HEMS/GEMS crew departure with the patient from the referring hospital to arrival at the receiving center LZ.

Secondary endpoint: Estimation of transit times and HEMS versus GEMS comparison

While this investigation's main aim was to define proportions of transports arriving for PPCI within accepted intervention time windows, a secondary goal was the characterization of potential time differences between actual and counterfactual transport modes. The aim was to address a few questions. For HEMS cases, how much time was potentially saved as compared to GEMS? For GEMS cases, how much time could have potentially been saved with HEMS? Addressing these questions required estimating TT for the counterfactual transport mode (i.e., the transport mode not actually used) and comparing that estimated TT (TT_{est}) against the actual TT.

All of this study's logistic estimates were generated using the public-domain GIS program Google Earth (www.earth.google.com, version 7.1.5.1557). This approach has been used and validated, both for air and ground transport estimates, for cardiac and other HEMS studies entailing TT calculations.^{15–20}

For the 27 study cases that went by GEMS, HEMS TT_{est} was generated for the applicable HEMS service. The average cruise speed of the helicopter was used along with the air mileage, and two minutes additional time was added on commencement and conclusion of flights (e.g., for circling of LZs). Thus, for a 120-mile flight in a 120-mph aircraft, the HEMS TT_{est} would be 64 minutes. Mileage was calculated from LZ to LZ.

For the 257 study cases that went by HEMS, ground ambulance TT ($GEMS\ TT_{est}$) was estimated. Point-to-point driving times from referring sites to receiving sites were calculated by GIS using an assumption of traveling at posted speed limits and normal traffic patterns. The GIS GEMS estimates did not account for the time of day; all GEMS estimates presumed normal traffic flow at posted speed limits. However, each of the 257 study cases were classified (for descriptive analysis) according to whether actual or hypothetical ground transport entailed rush-hour driving at either end of the transport. Rush hour was defined as ground travel at the times 0730–0930 or 1630–1830.

For the 257 HEMS-transported cases, HEMS TT was compared against GEMS TT_{est} . For the 27 GEMS cases, GEMS TT was compared against HEMS TT_{est} . These calculations were by a *a priori* plan not intended to represent actual estimates of how much time may or may not be saved by HEMS rather than GEMS. Rather, the calculations were set up to provide a focused (but limited) piece of information about potential time savings associated solely with the in-transit portion of the overall transport time.

At the one study program contributing both HEMS and GEMS cases, 12 facilities (of the center's 19 total referring sites) used both HEMS and GEMS for PPCI transports at least once during the study period. These sites—for their own reasons (including potentially weather, vehicle availability, or patient stability) were not characterized in this study—used either HEMS or GEMS for a given transport; double dispatch was not executed. These dozen facilities are denoted as “dual-mode” facilities in the Results and Discussion section of this paper. The dual-mode facilities' 72 cases (27 GEMS and 45 HEMS) served as a basis for exploratory analysis of actual HEMS versus GEMS time comparisons for air and ground execution of geographically identical transport runs.

Based on the best available literature estimates,^{9,14} the time savings defined as minimum for clinical significance was 15 minutes. In other words, HEMS time savings had to be at least 15 minutes to be defined as potentially clinically important. Time savings would be translated as per previous methodology, into an estimate (W) for “lives saved per 100 transports” from time savings alone.⁸

Cross-checking of estimated versus actual transit times

Due to a relatively straight line of travel and consistency of speed during a transport, HEMS TT tends to be constant and predictable using GIS.¹⁵ Investigators and experts have contended that there is similar utility of GIS tools for predicting ground ambulance transport times.^{18,19} However, since the evidence base for GIS transport time prediction is still evolving, a secondary goal of this study was to compare actual and estimated TT data. The study was designed from commencement to focus on HEMS TT, but exploratory analysis on GEMS TT was also included in order to provide an indication of TT_{est} accuracy.

For the 257 HEMS cases in this study, HEMS TT_{est} values were compared against actual HEMS TT. Similar comparisons were executed for GEMS TT_{est} data. Assessment of whether there was agreement in actual and estimated TTs was executed with Bland–Altman plotting and Pitman's test of difference in variance. An *a priori* decision was made, based upon evidence supporting 15 minutes as a supportable minimum clinically significant time saving for PPCI cases,¹⁴ that a TT_{est} would be tentatively classified as a reasonable approximation if it were within 7.5 minutes of the actual TT.

Data analysis

Data normality for continuous variables was assessed with skewness-kurtosis testing. Descriptive reporting of normal data utilized mean (\pm) and standard deviation (SD). The central tendency for non-normal data was assessed with median and interquartile range (IQR). Proportional data reporting included binomial exact confidence intervals (CIs).

Categorical results were analyzed with Fisher's exact test. Dichotomous dependent variables were assessed with logistic regression, with clustering of the study program to minimize the risk of overestimation of standard errors. For univariate comparison of non-parametric continuous data (e.g., time intervals), Kruskal–Wallis testing was used.

By way of an *a priori* plan, the study used HEMS TT and GEMS TT_{est} data to execute risk-difference calculations for the endpoint of dispatch to cardiac unit arrival within 90 minutes. The risk difference allowed determination of the number needed to treat (NNT₉₀) for the 90-minute window. The NNT₉₀ was therefore the number of cases that needed to be transported by HEMS to allow one additional case to achieve the overall transport time (i.e., from dispatch to the receiving cardiac unit arrival) of 90 minutes or less. The NNT was calculated only for the 90-minute window as this was judged *a priori* to be far more clinically important than the 120-minute window.¹³ A 90-minute transport window still allows time for achievement of PPCI within 120 minutes of the overall time from presentation. A 120-minute transport time (from dispatch to the cardiac unit arrival) would necessarily translate into an even longer interval from the initial hospital presentation to PPCI, and thus have less clinical effective relevance.

All statistical analysis and reporting were executed with Stata 14 software (StataCorp, 2015, College Station, TX). Significance was defined at the $p < 0.05$ level and CIs were reported at the 95% level.

RESULTS

The study population comprised 284 cases. Characteristics of the cases are shown in Table 2. Table 3 indicates pre-transport cardiac diagnosis (i.e., STEMI type where available). Assessment of the overall group of 284 GEMS and HEMS cases revealed that the HEMS cases were significantly more likely than the GEMS cases to be transported during rush hour (OR 3.8, 95% CI 2.1–6.8, $p < .001$).

Table 2. Characteristics of study transports ($n = 284$).

Site	n (% of 284)	% Male	Age (mean \pm SD*)	Interfacility**	Died***
A	22 (7.8%)	77.3%	59.6 \pm 11.7	19 (86.4%)	2 (9.1%)
B	95 (33.5%)	39.0%	61.0 \pm 12.5	95 (100%)	5 (5.3%)
C	11 (3.9%)	63.6%	65.7 \pm 12.0	10 (90.9%)	0 (0%)
D	69 (24.3%)	72.5%	63.2 \pm 11.1	64 (92.8%)	3 (4.4%)
E	86 (30.3%)	67.4%	61.4 \pm 11.9	86 (100%)	6 (7.0%)
F	1 (0.4%)	100%	64	1 (100%)	0 (0%)
Total	284	59.9%	61.8 \pm 11.9	275 (96.8%)	16 (5.6%)

*SD = standard deviation.

** n (% of study site n) of interfacility transports.*** n (% of study site n) of patients who died within seven days of arrival at cardiac unit.**Table 3. Diagnosis recorded at the time of transport ($n = 284$ cases).**

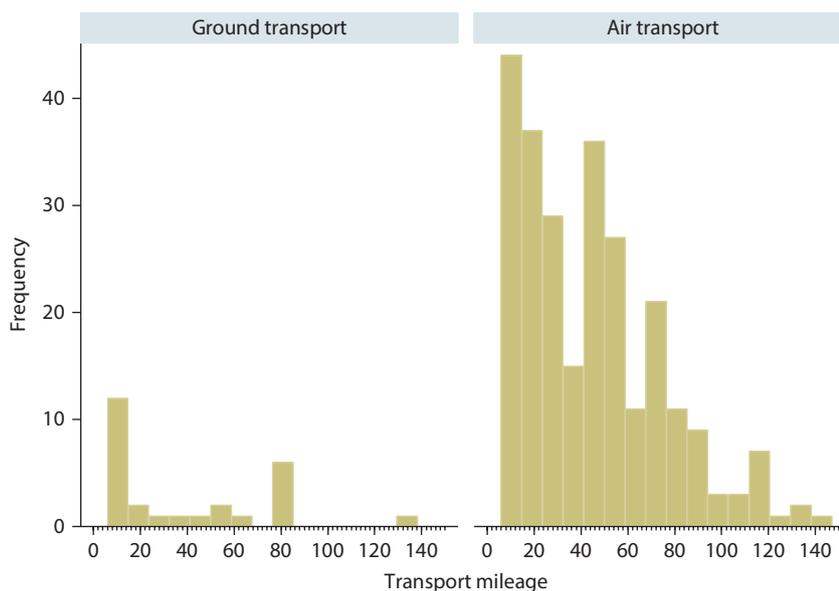
Diagnosis	n (% of 284)
Acute myocardial infarction (MI)	27 (9.5%)
Anterior MI	23 (8.1%)
Anterior-lateral MI	17 (6.0%)
Anterior-septal MI	11 (3.9%)
Inferior MI	93 (32.8%)
Inferior-posterior MI	1 (0.4%)
Inferior-lateral MI	17 (6.0%)
Left bundle branch block, presumed MI	2 (0.7%)
Lateral MI	5 (1.8%)
Posterior MI	2 (0.7%)
STEMI* (other information not recorded)	86 (30.3%)

*STEMI = ST-elevation myocardial infarction.

HEMS cases ($n = 257$): Descriptive results and primary endpoint (time from dispatch to receiving unit)

At all study sites except one, all cases were transported by helicopter. At the single study site (E) contributing both air and ground transports, HEMS cases numbered 59 (68.6% of all cases contributed to the study from that site). This section reports on the overall results for the 257 cases that underwent air transport.

The median air mileage for the 257 HEMS cases was 45 miles (IQR 20–62). Air mileage ranged from 6 to 147 miles. Figure 1 shows the distribution of air transport mileage.

**Figure 1. Ground miles for ground transports ($n = 27$) and air miles for helicopter transports ($n = 257$).**

For those cases that were transported by air, the median time from dispatch of HEMS to ultimate patient arrival at the receiving cardiac unit was 78 minutes (IQR 59–97). This dispatch-to-receiving time interval fell within the 90- and 120-minute windows in 174 (67.7% of 257) and 234 (91.1% of 257) cases, respectively.

For the 23 HEMS cases with dispatch-to-receiving time intervals that fell outside the 120-minute window, analysis of available information was executed to identify where delays occurred. The median delay from the time EMS services received the call for transport, to the time the services' dispatched aircraft was one minute (IQR 0–2). The median wait time for HEMS arrival at the referring facility (i.e., time from HEMS dispatch to arrival at the referring hospital) was 50 minutes (IQR 36–62). The median patient stabilization time (i.e., time between HEMS crew arrival at the referring facility and departure from the referring facility) was 20 minutes (IQR 16–36); limited data were available to characterize clinical issues during this time period, but one patient was known to be in and out of cardiac arrest. The median flight time from the referring facility to the receiving unit was 42 minutes (IQR 32–48).

Analysis of the above 23 cases demonstrated that the main contributor to prolonged time from HEMS dispatch to receiving-unit arrival was the transport distance. The available information did not allow characterization of all reasons for prolonged times, but assessment of the median transport distance for the 23 out-of-window cases demonstrated significantly ($p = 0.0001$) longer transports (median 87 miles, IQR 63–114) as compared to HEMS cases in which the 120-minute window was met (median 38 miles, IQR 17–57).

GEMS cases ($n = 27$): Descriptive results and primary endpoint (time from dispatch to receiving unit)

One study site contributed both HEMS and GEMS cases. GEMS cases numbered 27, constituting 31.3% of the study site's cases and 9.5% of the overall study population of 284. This section reports on results of the 27 GEMS cases; due to the small sample size, the data should be considered preliminary and hypothesis-generating.

GEMS cases were no different from HEMS cases with respect to age ($p = 0.675$), sex ($p = 1.00$), or mortality ($p = 0.655$).

GEMS cases' transport distance was not statistically different from HEMS cases' transport distance. As assessed by radial-distance (i.e., "as the crow flies") calculations, the GEMS transports' median distance from referring to receiving facilities was 16 miles (IQR 9–65). As assessed by actual (driven) ground mileage, which is longer than the radial-distance GEMS mileage (due to inevitable departures from straight-line driving), GEMS cases' median mileage was 17 (IQR 14–79) miles and the mean was 41 ± 33 miles. Non-parametric comparison of the GEMS cases' actual-driven transport mileage was executed to assess its central tendency as compared to that of HEMS transports. The resulting p value ($p = 0.434$) was not significant.

For those cases that were transported by ground, the median time from dispatch of EMS to ultimate patient arrival at the receiving cardiac unit was 84 minutes (IQR 62–141). As compared to the HEMS interval from dispatch to the receiving-unit arrival, the GEMS time interval approached, but did not reach, statistical significance ($p = 0.0582$).

The GEMS dispatch-to-receiving time interval fell within the 90- and 120-minute windows in 14 (51.9% of 27) and 20 (74.1% of 27) cases, respectively. These proportions of GEMS cases with dispatch-to-receiving-unit time intervals within predefined windows were significantly less than HEMS cases for the 120-minute endpoint ($p = 0.014$), but not for the 90-minute endpoint ($p = 0.133$).

For the seven GEMS cases with dispatch-to-receiving time intervals that fell outside the 120-minute window, analysis of available information was executed to identify where delays occurred. The median delay from GEMS services' receiving call for transport to the time the services dispatched the ambulance was 0 minutes (IQR 0–7). The median wait time for the GEMS arrival at the referring facility (i.e., time from GEMS dispatch to arrival at the referring hospital) was 57 minutes (IQR 28–103). The median patient stabilization time (i.e., time between GEMS crew arrival at the referring facility and departure from the referring facility) was 16 minutes (IQR 4–48). The median ambulance driving time from the referring facility to the receiving unit was 84 minutes (IQR 41–109).

As was the case with HEMS transports that fell outside the 120-minute window, the analysis of the above seven cases demonstrated that the primary contributor to prolonged time intervals from GEMS dispatch to receiving-unit arrival was the longer distance of transports. The available information

did not allow characterization of all reasons for prolonged times, but assessment of median transport distance for the seven out-of-window cases demonstrated significantly ($p = 0.013$) longer transports (median 81 miles, IQR 17–81) as compared to GEMS cases in which the 120-minute window was met (median 14 miles, IQR 14–49).

Secondary endpoint: Estimated travel times for the counterfactual transport mode

For the 257 HEMS cases, GEMS mileage and TT data were generated using GIS estimation. Since the actual travel distance varied widely for different transport runs (i.e., flights from one specific location to another), descriptive analysis focused on the difference between HEMS and GEMS mileage and TT.

For the overall set of 257 HEMS cases, the median air transport mileage was 45 miles (IQR 20–62) and the estimated median GEMS (driving) mileage was 51 miles (IQR 23–77). The distance excess, due to inability of ground vehicles to drive in straight-line transit was a median of 7 miles (IQR 4–12); HEMS (straight line point-to-point) mileage was a median 17.2% (IQR 13–20) shorter than GEMS driving mileage.

HEMS therefore saved TT due to both increased vehicle speed and decreased actual travel mileage. As compared to GEMS TT_{est} , HEMS use in the 257 overall transports was associated with a statistically significant ($p = 0.0001$) median time saving of 32 minutes (IQR 17–46). HEMS was a median 60.3% (IQR 56.8–64.1) faster than GEMS TT_{est} . The proportion of cases in which HEMS TT saved at least 15 minutes over GEMS TT_{est} was 79.4% (95% CI 73.9–84.1); HEMS saved at least 30 minutes over GEMS TT_{est} in 52.5% (95% CI 46.2–58.8) of cases.

Rather than the previously noted proportions of HEMS cases arriving at cardiac care units within the 90- and 120-minute windows (67.7% and 91.1%, respectively), replacement of the actual HEMS TT with GEMS TT_{est} (and presuming no change in other components of overall time) would have resulted in significantly lower proportions of cases within the 90- and 120-minute window. The proportion of cases arriving at cardiac units within the 90- and 120-minute windows would drop down to 34.2% and 57.6%, respectively (both decreases in proportion with $p < 0.0001$).

Based on the risk difference calculations of 33.5% (95% CI 25.3–41.6) for the 90-minute window, NNT_{90} was calculated to determine HEMS' potential contribution to achieving this goal. HEMS' NNT_{90} for the study cases was 3.0 (95% CI 2.5–3.8); in order to gain one additional case achieving the 90-minute window, three cases must be transported by HEMS.

An analysis similar to that of the HEMS transport mentioned earlier was performed on the 27 GEMS cases. HEMS TT_{est} values were calculated and compared to actual GEMS TT. For the overall set of 27 GEMS cases, median ground mileage was 17 miles (IQR 14–79); GIS-measured air travel distance for the same set was statistically similar ($p = 0.085$) with a median of 16 miles (IQR 9–65). Despite the similarity in mileage, substitution of HEMS TT_{est} for actual GEMS TT resulted in faster overall transport times (from dispatch to the receiving cardiac unit). For the 27 GEMS cases, use of HEMS rather than GEMS was calculated to have been associated with a statistically significant ($p = 0.012$) median time saving of 16 minutes (IQR 9–65).

In terms of the overall transport time, use of the HEMS mode rather than the actual GEMS mode would have increased the point estimates for the proportion of cases meeting the 90- and 120-minute overall transport-time windows. The actual proportion of GEMS cases meeting the 90-minute window was 51.9% and this was calculated to increase to 74.1% with HEMS use; the corresponding odds ratio of 2.65 was not statistically significant ($p = 0.095$) and had a wide 95% CI (0.84–8.34). Similarly, the actual proportion of GEMS cases meeting the 120-minute window (74.1%) was calculated to increase to 92.6% if HEMS were used; the corresponding odds ratio of 4.38 was not statistically significant ($p = 0.085$) with a wide 95% CI (0.82–23.4). Due to the lack of statistical significance for HEMS-associated change in the likelihood of meeting the 90-minute window, HEMS' NNT_{90} was not calculated for the 27 cases that actually went by GEMS.

As per the study's plan and using previously reported methods, preliminary analyses were executed to frame HEMS' calculated time savings in light of the known impact of time savings on mortality given PPCI occurs within 150 minutes.^{8,9} HEMS cost data were not readily available for this study, but the data did allow for an effectiveness assessment, even if such an assessment was limited in scope to mortality associated with time savings, without assessment of other factors influencing mortality or any factors influencing morbidity. Extrapolating well-accepted relationships between time and outcome from cardiac effectiveness literature,⁹ this study's finding that HEMS use saved a median of 32 minutes to PPCI corresponded to an absolute mortality reduction of 13.44 lives per 1000

transports. For this dataset of 257 HEMS transports, the estimate is that HEMS' time savings resulted in 3.24 lives saved; the number of lives saved per 100 transports was thus 1.34.

Cross-checking of estimated versus actual transit times

For the 257 HEMS cases, the TT_{est} closely ($p < 0.001$) predicted TT and the overall median difference between TT and TT_{est} was -1 minute (i.e., the estimated time tended to be one-minute short of the actual TT). Estimate errors ranged from -10 minutes (i.e., the actual HEMS time was 10 minutes longer than estimated) to 9 minutes, with an IQR of -1 to 0. It is important to emphasize that this TT estimate covered only the point-to-point flying time. Pitman's test revealed that agreement between HEMS TT and TT_{est} did not change over increasing transport distance ($r = -0.069$, $p = 0.267$).

For the 27 GEMS cases, the TT_{est} closely ($p < 0.001$) predicted TT and the overall median difference between TT and TT_{est} was the same (-1 minute) as the result for HEMS. However, compared to the HEMS estimates, the variation around GEMS TT_{est} was broader, especially with longer mileages (see Figure 2). GEMS TT_{est} ranged from 15 minutes too long (i.e., TT_{est} was 15 minutes longer than the actual-driven TT) to 56 minutes too short (i.e., TT_{est} underestimated the actual-driven TT by 56 minutes); the IQR was -4 to 4. Pitman's test revealed that agreement between GEMS TT and TT_{est} worsened significantly ($r = 0.524$, $p = 0.005$) with increasing transport distance.

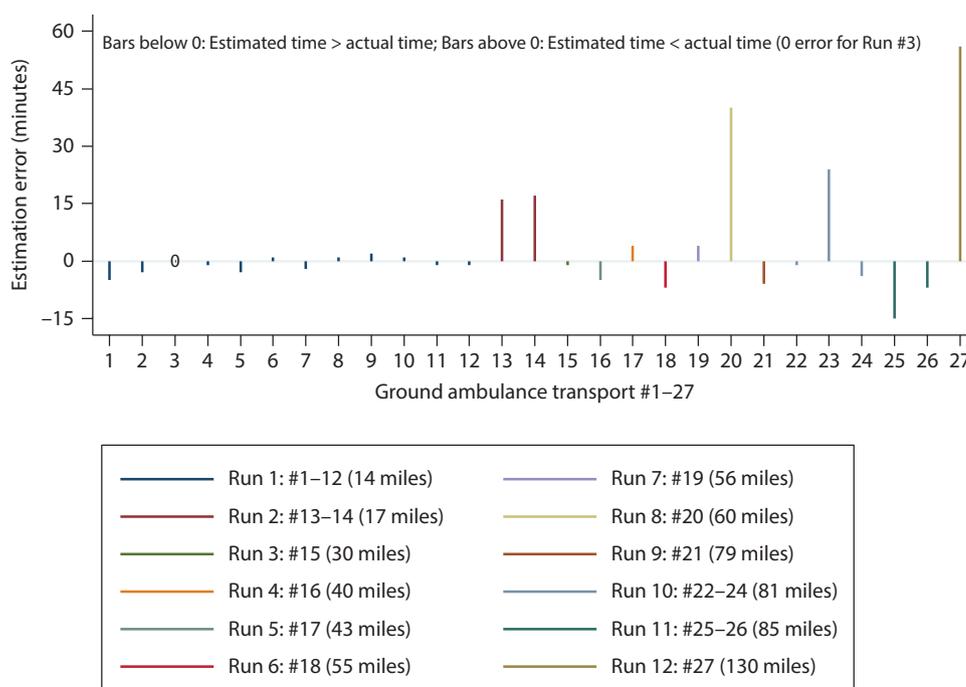


Figure 2. Estimated versus actual ground ambulance transit times.

Hypothesis-generating analysis: A dozen centers using both HEMS and GEMS transports

During the study period, one study site at which all transports went to the same receiving cardiac center contributed a total of 72 cases transferred from “dual-mode” hospitals that used both HEMS and GEMS. Since the data were limited in number, this section reports limited analysis related to these dozen dual-mode facilities' use of both HEMS and GEMS transport vehicles for the same transport run (i.e., from their facility to the same receiving cardiac facility). The analysis was hypothesis-generating, in that the results presented herein were not the main thrust of the current study, and the numbers of involved facilities were too small for definitive conclusions. The information presented in this part of the discussion is, however, useful to provide a direction for future analysis on another way to analyze logistics differences between HEMS and GEMS transport.

The only dual-mode facility transport time data point that was reasonably expected to be independent of referring-site characteristics (e.g., geographic location), was the time interval from the

initial call for transport to dispatch of the air or ground transport vehicle. In the study cases, dispatch time was usually instantaneous (i.e., vehicle dispatch within a minute of initial call for transport). In statistically similar ($p = 0.360$) proportions, 84.4% of HEMS cases and 74.1% of GEMS cases were characterized by immediate dispatch. There were no statistically significant differences ($p = 0.464$) between dispatch times for HEMS (median 0, IQR 0–0) and those for GEMS (median 0, IQR 0–3).

Unlike dispatch times, other clinically important time parameters were expected to be related to referring-site characteristics. Formal statistical analysis of these parameters (i.e., analysis by referring site) was precluded by low site-specific n and imbalance of HEMS and GEMS transport modes across different sites. For the 72 cases from dual-mode facilities, Table 4 presents the HEMS and GEMS transport n and median overall transport time from ground or air EMS dispatch through to arrival at the receiving cardiac unit. The low number of cases, which precluded run-specific analysis and prevented generation of a single “summary statistic” precisely describing time differences, enabled information for each of the 72 air and ground transports to be represented in Figures 3–5. These figures convey a preliminary sense of GEMS versus HEMS time distributions for each run for the various time intervals.

The first time interval depicted for the dual-mode referring hospitals is response time, defined by the time interval from the EMS vehicle dispatch to the crew arrival at the patient (at the referring hospital). Figure 3 depicts the response times for HEMS and GEMS (with the jittering of markers to facilitate interpretation), for each of the dozen dual-mode referring facilities’ HEMS and GEMS runs to the same receiving center.

Table 4. Twelve referring centers* contributing both air and ground transport cases (n = 72 cases).

Center	Total cases	Air cases (% center total)	Ground cases (% center total)	Air cases: dispatch to receiving center minutes (median)	Ground cases: dispatch to receiving center minutes (median)
1	3	2 (66.7%)	1 (33.3%)	197	212
2	8	6 (75.0%)	2 (25.0%)	88	99
3	12	9 (75.0%)	3 (25.0%)	97	180
4	3	2 (66.7%)	1 (33.3%)	180	100
5	3	2 (66.7%)	1 (33.3%)	54	65
6	2	1 (50.0%)	1 (50.0%)	71	97
7	4	3 (75.0%)	1 (25.0%)	90	92
8	3	2 (66.7%)	1 (33.3%)	100	198
9	4	3 (75.0%)	1 (25.0%)	80	75
10	3	2 (66.7%)	1 (33.3%)	93	110
11	6	4 (66.7%)	2 (33.3%)	64	190
12	21	9 (42.9%)	12 (57.1%)	52	62

*All 72 cases were transported to the same receiving cardiac facility.

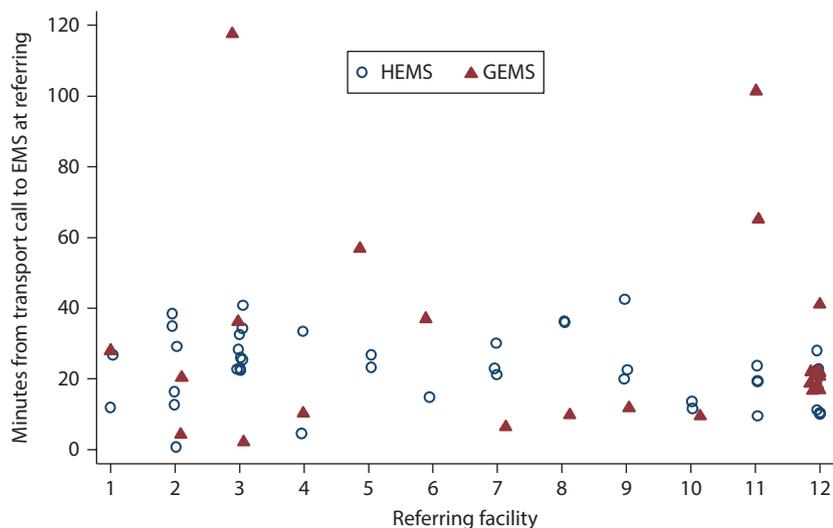


Figure 3. Facilities using both helicopter (HEMS) and ground (GEMS) transport: minutes from transport service dispatch to arrival at the referring site.

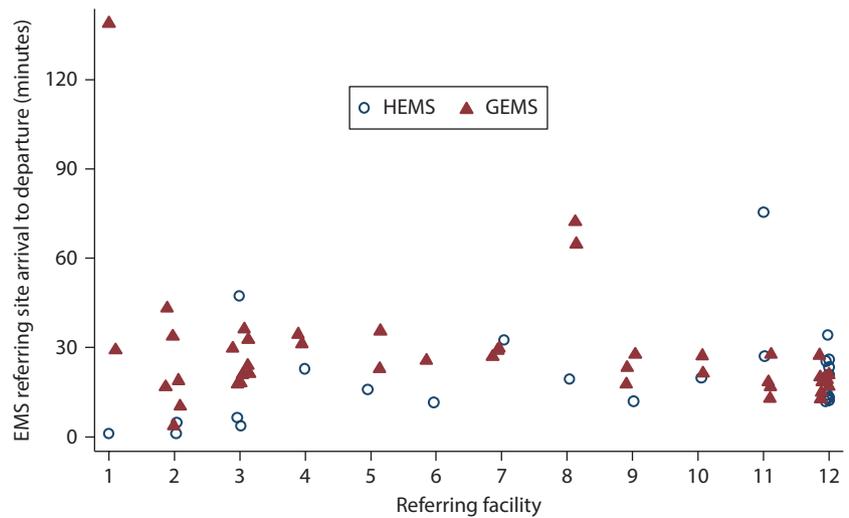


Figure 4. Facilities using both helicopter (HEMS) and ground (GEMS) transport: minutes from the transport service referring site arrival to departure with patient.

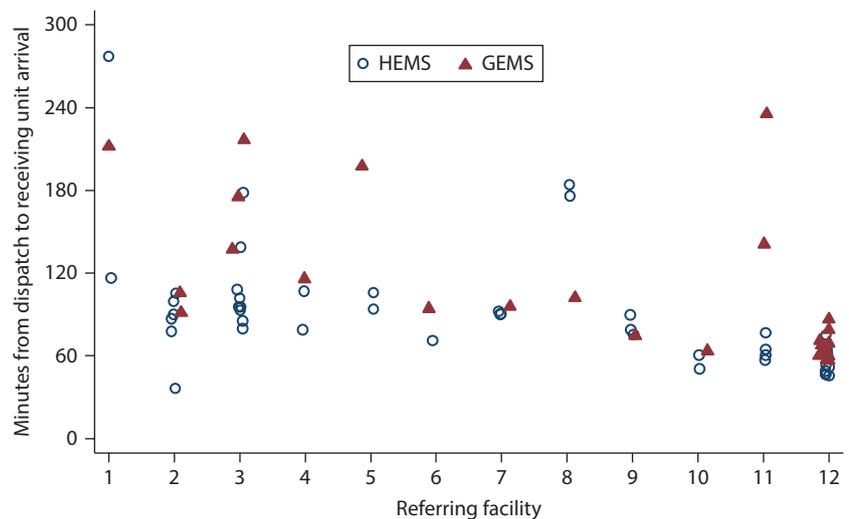


Figure 5. Facilities using both helicopter (HEMS) and ground (GEMS) transport: minutes from the transport service dispatch to arrival at the final receiving cardiac unit.

The next time interval encompassed minutes from EMS arrival at referring sites to EMS/patient departure from those sites to the receiving center (Figure 4).

The final and most clinically relevant time interval commenced with EMS dispatch and concluded with receiving cardiac unit arrival. These data are presented in Figure 5 and represent preliminary information on the total amount of transport-related time savings (or lack thereof) associated with HEMS versus GEMS transport for PPCI.

DISCUSSION

Use of HEMS for cardiac transports, particularly for PPCI, has long been a part of many cardiac care networks. Air or ground EMS deployment brings crews with expertise in out-of-hospital care, but in STEMI cases undergoing transport for PPCI, it is likely that the most critical contribution to outcomes are those that speed up the time to opening of the infarct-related artery. With acknowledgment that the medical care expertise provided by air or ground EMS crews is without doubt often lifesaving, the remainder of this discussion can focus on the independently important surrogate outcome of time savings for PPCI.

The life savings associated with the time savings is not necessarily consistent for all types of cardiac patients, but there is the basis of evidence to presume that savings of time directly translate into better outcomes for primary PCI administered within three hours of initial patient presentation.^{14,21} In fact, the upper inflection point of the sigmoidal fractional polynomial curve depicting the association of time and mortality is roughly 200 minutes.²¹ Despite the importance of focusing on meeting certain time windows (e.g., 90 minutes), it is clear that saving of minutes in PPCI cases corresponds to improved outcome.²² The focus on meeting the predefined time intervals in this study is justified by the literature,^{13,23} but the time windows are best for quality benchmarking and the main point of emphasis is that “faster is better” (as is evidenced by some more recent literature using 60-minute PPCI windows).²⁴

It is not surprising that the preexisting evidence base for HEMS use for PPCI transports makes a point that HEMS can speed time to PPCI if the air medical resources are employed judiciously.^{4–6} The current study aimed to assess HEMS use for PPCI across multiple systems as a follow-up to a previous pilot study assessing HEMS use for PPCI transports in a southwestern state (Oklahoma) in the USA.⁸

This study, coordinated by the multicenter air medical research consortium Critical Care Transport Collaborative Outcomes Research Effort (CCT CORE, www.CCTCORE.org), was designed primarily to determine whether air transport for PPCI was associated with high rates of achievement of “within-window” PPCI times. The study also set out to characterize whether a significant proportion of cases going by either HEMS or GEMS mode appeared to be more appropriate *vis-à-vis* time considerations, to go by the non-used (counterfactual) transport mode. With full understanding that there are many potential benefits of HEMS transport that have nothing to do with time, this analysis focused solely on logistics. For this study, HEMS was deemed potentially useful only if HEMS achieved a time saving – at least 15 minutes – that was defined *a priori* as being clinically significant.⁹

The first and most important results of this study are the data indicating that HEMS – as currently used in the multiple settings we analyzed – were consistently associated with a large proportion of patients arriving at PPCI centers within predefined windows of clinical significance. Adjudication of HEMS utilization appropriateness in the studied systems is supported (although, of course, not definitively demonstrated) by the findings that two-thirds of HEMS cases had the overall transport time (i.e., from EMS dispatch to the arrival at the receiving cardiac unit) of 90 minutes or less, and over 90% had overall transport times of less than two hours. These data are quite likely to be reliable since the recording of the transport times is embedded within the routine and objective approaches to prehospital documentation.

Demonstrating that HEMS cases are arriving at the receiving cardiac centers within these 90- and 120-minute time windows is distinctly not the same as demonstrating that patients’ PPCI times fell within these windows; lack of these calculations (due to non-available data) constitutes the most important limitation to this study. Nonetheless, while achieving within-window transport times is not a sufficient justification for HEMS use, it is for many systems a necessary component for the utilization of air transport. The use of the 90- and 120-minute surrogate endpoints for overall transport time is consistent with previous literature, and the overall findings are in alignment with cardiac system time goals.^{7,14}

A helicopter getting a case to PPCI within a certain time window does not necessarily mean that ground ambulance use would not have allowed equally timely cardiac intervention. It is plausible for some cases – particularly those for which HEMS is used for low-mileage transfers – that even when HEMS get patients to cardiac care within a pre-specified window, GEMS deployment could have achieved even faster transport. For this reason, it is necessary to calculate an estimated time for the alternative transport mode (i.e., the counterfactual mode) – literally, “the road not taken.”

To estimate the time for transit (TT) from referring to receiving sites, this study used GIS approaches that have been validated by both our group and others.^{16,18–20,25,26} The “routing approach” to GEMS time estimation has also been carefully evaluated by logistics investigators who have concluded that this approach (as used in the current study) is distinctly preferred as giving the most accurate estimations (since other methods such as those based solely on mileage underestimate actual transit times).²⁷

While the logistics calculations are reasonably robust in their evidence base, it is important to note that they are necessitated even with their flaws, due to consistent and profound difficulties (leading to study terminations) in the few trials attempting to randomize cardiac and other patient types to air or ground transport.^{4,28} However, regardless of the necessity, use of calculated GEMS times

is inherently artificial and is thus a limitation in the current study. Calculated GEMS TT_{est} can be either faster or slower than what the actual GEMS TT would have been (as shown in Figure 2). Specifically, road traffic congestion can affect ground ambulances and result in significant prolongation of ground transport times.^{29,30} It is a noteworthy, although indirect indicator that in the current study, HEMS cases were nearly four times more likely (OR 3.8) to occur during rush hour than GEMS cases.

This study was focused on HEMS, but the cases included a total of 27 GEMS transports from a dozen centers transporting cases to one cardiac center. It is a limitation that the analysis included GEMS cases from only one study site; the remaining study locations were not able to contribute GEMS data. There is little reason to suspect bias due to low GEMS numbers, but the low GEMS numbers should be considered a limitation that prevents broad generalization of the relevant results.

The accuracy of the overall study set GIS estimates for ground transport were supported by the finding of minimal difference between GEMS TT_{est} and actual GEMS TT for the study cases that went by ground ambulance. In fact, the data suggests that errors in GEMS and HEMS TT_{est} would bias this study's results in favor of the ground transport modality. As shown in Figure 2, in only one case did the GEMS TT_{est} overestimate the actual GEMS TT by a margin that just met the *a priori* 15-minute cutoff defining clinical significance; in all of the other cases ($n = 5$, 18.5% of 27) where the GEMS TT was different by at least 15 minutes from the GEMS TT_{est} , the GIS time underestimated the actual TT. In two cases (7.4% of 27), the GEMS TT was at least half an hour longer than the GEMS TT_{est} .

The HEMS TT_{est} data were, for reasons related to straight-line travel at near-constant speed, consistent with existing evidence suggesting predictability within the same transport "run" (i.e., point-to-point transport geography).¹⁵ While aircraft can occasionally deviate due to weather conditions or other aviation-related purposes, there are no stoplights, and major deviations from straight-line travel are rare. The data from this study that demonstrated minimal variation around HEMS TT and HEMS TT_{est} are consistent with the overall evidence base indicating the relative predictability of HEMS transport time.^{18–20,25,26}

When the HEMS and GEMS TT and TT_{est} results are taken together, the conclusion is that this study's dataset provides an interpretation of potential HEMS transit-time savings that is, if anything, biased against HEMS. In other words, the available information suggests that the estimated transit times for air transport were at the least, reasonably accurate, and if they erred it was likely that our estimated HEMS transit durations were actually too long. The next question, and an additional study limitation, is the degree to which TT, as either reported TT or calculated TT_{est} in this study, should be considered representative of overall transport time.

Svenson et al., have clearly demonstrated that in a large regional network, it is a fallacy to presume that response times to referring facilities are always faster for GEMS – even when ambulances are presumably stationed "on-site" at the referring hospitals.³¹ Thus, in the absence of site-specific data, it is not appropriate to draw any conclusions about the relative air versus ground EMS response time (i.e., time from call for EMS transport to arrival of GEMS or HEMS to the patient's side).

While the current study data does not allow for the calculation of response times for most of the cases, analysis of the 72 cases from the dozen facilities using both HEMS and GEMS (for the same transport run) provides preliminary indications on relevant points. The only time that truly approaches independence from referring site characteristics (e.g., distance) is the dispatch time, which was statistically similar for GEMS and HEMS in this study.

The other time periods for dual-mode referring hospitals are intrinsically related to factors such as geography, and thus, are appropriately analyzed with clustering based on the referring site. It is a study weakness that this dataset is insufficient for robust analysis along these lines. Information on the turnaround time at the referring sites was lacking, which could be associated with the selection of transport mode. However, graphic depictions of time intervals for the dual-mode referring sites (see Figures 3–5) provide strong evidence against a consistent delay associated with use of HEMS rather than GEMS transport. For example, the only four cases (5.6% of 72) in which response times approached or exceeded an hour were all GEMS cases (Figure 3). Patient stabilization time, previously reported as an important indicator of PPCI transport performance,³² did not appear systematically longer (or shorter) for HEMS as compared to GEMS cases (Figure 4). The overall conclusion is that TT and TT_{est} are acceptable as representations of overall time savings (or lack thereof) associated with HEMS transport for this study set.

As shown in Figure 5, the overall transport time – from dispatch to cardiac unit arrival – did not appear to uniformly favor HEMS or GEMS for "same-run" transports. However, the illustration should be

interpreted with consideration of the previously noted study limitation of too-low n for site-specific analysis. It is possible that an appropriately powered study of the same dozen hospitals would indeed demonstrate a transport-mode-related time difference. With that caveat, Figure 5 (which depicts only 72 of the overall study cases) nevertheless has important implications for further research. The graph's depiction is quite likely to represent a demonstration that, for the dozen referring study hospitals depicted, air and ground triage is working quite well; HEMS is used when the helicopter is needed to get patients to PPCI quickly, and GEMS is used otherwise (e.g., when traffic is not a problem).

The consideration of Figure 5 leads to a concluding point about this study's major limitation: its artificiality in logistics calculations. The risks related to retrospectively assigning "likely travel time" by ground have been discussed in detail elsewhere.^{33,34} These risks are non-trivial as referring facilities will, in real time, have access to a myriad of information (e.g., weather and traffic) that are not identifiable in a retrospective analysis such as this. A long GEMS response time, for example, could well be due to the fact that HEMS was not available for long-distance transport and GEMS – delayed but at least available – constituted the only transport option. Similarly, short-distance HEMS transports are occasionally necessitated by the need to save valuable minutes for metropolitan transports, that if transported by ground, would be caught in rush-hour traffic snarls.³⁵

Despite the many limitations addressed, the study provides some useful estimates for the HEMS impact on PPCI time savings. By extension, this impact on time savings can be translated into an estimate for HEMS' (time-associated) impact on mortality. The study's aim was to reproduce pilot data from the same methodology used on a limited basis in a southwestern USA state (Oklahoma).⁸ It is noteworthy that the point estimate for lives saved per 100 HEMS PPCI transports calculated in the current analysis (W of 1.34) is remarkably consistent with the pilot study's W estimate of 1.2–1.7. While the NNT analysis is necessarily considered to be preliminary, there is ample justification in the previously discussed literature to use the NNT calculations herein as a coarse estimate of benefit from HEMS in this particular population.

The interpretation of a W value requires complex considerations ranging from the financial to the clinical. As Delgado et al., have demonstrated, the economics of HEMS cost-effectiveness analyses are multifaceted and require a complete discussion of their own.³⁶ This study is limited by its logistics focus (and thus by lack of financial data) to simply report the W calculated. With the emphasis that precise estimation of cost-effectiveness requires many other variables (e.g., cost of ground ambulance coverage), it is noteworthy that this study's W calculation meets the evidentiary threshold for HEMS' cost-effectiveness for other diagnoses at the level of \$100,000 per quality-adjusted life-year (QALY).^{36,37} It is premature to draw definitive conclusions regarding HEMS' cost-effectiveness for PPCI transport, but the preliminary indication suggests that there is solid basis for continuing judicious use of HEMS for PPCI pending further study.

CONCLUSIONS

In a multicenter study conducted in a variety of settings, HEMS use for PPCI was found to meet predefined standards for appropriateness in over 90% of cases. Using time savings as a validated surrogate endpoint, air medical transport appeared in the study centers to be associated with mortality benefit ($W = 1.3$) that is consistent with pilot PPCI HEMS transport data, and is also in alignment with calculations demonstrating cost-effectiveness thresholds for air medical transport. Further study is required to focus on other factors influencing mortality in HEMS and GEMS PPCI transport, and also to assess whether there are non-mortality risk, cost, or benefit considerations that should influence the transport mode selection for patients needing PPCI.

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Previous presentation/publication

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2014;130:A13837 with the citation: Helicopter EMS transport time savings for ST-elevation myocardial infarctions.

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