HELICOPTER EMS

UTILIZATION AND OUTCOMES: AN EVIDENCE-BASED OVERVIEW

Stephen H. Thomas, MD MPH
Department of Emergency Medicine, Harvard Medical School & Beth Israel Deaconess Medical Center, Boston
Barts and The London School of Medicine and Dentistry, London

SThomasMD@GMail.com

TABLE OF CONTENTS

Selected abbreviations

AIS	Abbreviated Injury Scale (anatomy-based component score used to calculate ISS)
AMPT	Air Medical Prehospital Triage (tool developed at University of Pittsburgh)
CI	confidence interval (in this monograph, denotes a 95% CI)
EMS	Emergency Medical Services (out-of-hospital care services)
ETI	endotracheal intubation
GCS	Glasgow Coma Score
GEMS	ground EMS
GOS	Glasgow Outcome Score
HEMS	helicopter EMS (in this monograph, pertains to helicopter use for either scene or interfacility flights)
ISS	Injury Severity Score
MA	meta-analysis
NAEMSP	National Association of EMS Physicians
PCI	percutaneous coronary intervention
QALY	quality-adjusted life-year
RCT	randomized controlled trial
RSI	rapid sequence intubation (induction)
STEMI	ST-elevation myocardial infarction
TRISS	Trauma Injury Severity Score (mortality prognostic calculator for trauma)

INTRODUCTION

Discussion aim

This discussion strives to overview evidence addressing benefits accrued by utilization of helicopter EMS (HEMS). The primary goal is to analyze the HEMS literature to describe, qualitatively and quantitatively, potential benefits of air medical transport. Secondary goals include evaluating HEMS study methodologies and addressing HEMS triage and cost-effectiveness.

Monograph organization

After outlining the discussion objectives, the paper continues with background information provided to facilitate interpretation of HEMS studies. Next comes an annotated overview of selected studies from the HEMS outcomes literature. The evidence's lessons are then summarized in a section examining possible air transport benefits to patients and regional healthcare systems. The monograph concludes by addressing the intertwined subjects of triage, utilization review, and cost-effectiveness.

The state of the evidence

Paucity of publications is not among the challenges one faces in assessing the HEMS evidence base. HEMS' growth from its military nascence and its 1970s civilian roots (in Munich and Denver) was accompanied by a burgeoning number of HEMS-related publications.

The air medical transport community (not least this author) can occasionally be guilty of prolixity. It is not uncommon to find extended discussions on topics such as whether air medical transport truly began with a balloon evacuating Prussian-besieged Parisians, or with a French airplane extricating an injured Serbian during World War I. (The British, perhaps better record-keepers, have their own argument related to a well-documented 1917 flight of a Camel Corps gunshot victim.) Setting aside such historical reviews and other publications of a non-research nature, the assessor of HEMS literature is still left with thousands of "HEMS papers."

The sheer weight of the evidence becomes apparent when a review of available information is attempted. In a preface to updating the National Association of EMS Physicians (NAEMSP) HEMS guidelines, NAEMSP's Air Medical committee set out in 2000, to summarize the outcomes literature through 1999. Even at this early point – civilian HEMS in the USA had only been genuinely busy for about a decade – there was need to split the first annotated review into one paper covering trauma and another for non-trauma. The initial pair of papers appeared in NAEMSP's journal *Prehospital Emergency Care* (*PEC*).[1,2]

As the literature continued to grow, follow-up *PEC* annotated reviews appeared at shortening intervals. The first follow-up review covered four years (2000-03)[3] and the next covered just three (2004-07). [4]At that point, it became clear that the ever-growing quantity of HEMS papers was dictating follow-up review frequency that was impractical for even the unusually tolerant *PEC* editors. While the next decade (2007-16) was sporadically covered by subsequent annotated reviews[5-8] the evidence base had grown too large for recurring comprehensive summary. An updated listing of HEMS outcomes literature – the HEMS Outcomes Assessment Research Database, HOARD – can be obtained by emailing the author: SThomasMD@gmail.com.

HEMS studies are not lacking quantity, but what about quality? One of the first attempts at synthesizing the evidence arose from Alberta, where the health ministry's economics group reviewed HEMS outcomes studies published through 2007. The Institute of Health Economics found the evidentiary quality less than ideal, but found the data supported a conclusion that: "Overall, patients transported by helicopter showed a benefit in terms of survival, time interval to reach the healthcare facility, time interval to definite treatment, better results, or a benefit in general."[9]

The years since the Canadian report have seen myriad reviews of HEMS outcomes evidence. Specific conclusions vary, but there is a leitmotif of suboptimal evidence quality. Some of the evidentiary issues are unavoidable. An example is the paucity of data from studies of randomized controlled trial (RCT) or meta-analysis (MA) design.

An RCT of HEMS vs. GEMS would be difficult at best. The one RCT that has been tried[10] was substantially affected by on-scene provider unwillingness to triage cases away from HEMS. As of 2024, there are no other on-point RCT data.

Meta-analysis can account for some heterogeneity, but there are major barriers to MA of HEMS studies. Even with focus restricted to the most commonly studied group in HEMS (scene trauma), Cochrane reviewers concluded the evidence was not well-suited for MA.[11] A trauma MA from 2018[12] found only two papers that met predefined inclusion criteria; in this two-study MA, 84% of the weight came from Schiller's 2009 natural experiment.[13] Attempts at MA in other HEMS populations have also led to conclusions that the data were not well-suited for such assessment.[14,15]

With the acknowledgment that there are no rich stores of high-quality data to be found from HEMS RCT and MA designs, assessment of the state of HEMS outcomes evidence relies on either examining individual (mostly retrospective) studies, or settling for MA in non-ideal conditions. Although flawed, the evidence does impart some lessons.

In 2009, Ringburg[16] restricted analysis to the highest-quality HEMS trauma studies and proposed 2.7 as the best estimate for *W* (number of lives saved per 100 HEMS flights). Five years later, Abe[17] focused on high-quality HEMS trauma studies reporting survival odds ratio (OR) and concluded that 1.2-1.7 was the best postulated range for this endpoint. Moving from analyses of many studies, to execution of the same outcomes assessment across multiple large geographic areas (of the USA), Brown's Pittsburgh group[18] generated survival OR estimates similar to those of Abe.

As focus shifts from trauma to non-trauma diagnoses, the HEMS evidence base becomes even less robust. There are two main reasons. First, trauma cases have traditionally comprised the bulk of HEMS transports. This means that analysis *n* is higher for overall trauma outcomes, and also for assessment of HEMS in injury subgroups. Second, studies of trauma patients benefit from widely accepted (if imperfect) methods of acuity adjustment. Since cases triaged to HEMS are often perceived to be more urgent, it's important that HEMS outcomes studies take measures to reduce confounding by indication. For trauma studies, acuity confounding can be addressed using risk stratification tools (*e.g.* anatomic or physiologic scales). Such tools are less available for non-trauma populations, leaving studies of these patients susceptible to confounding.

Surrogate endpoints are commonly seen in non-trauma HEMS studies. The most important such endpoint, time savings, is based on the mantras "*Time is brain*" and "*Time is heart.*" The thinking is: there is HEMS utility if the helicopter gets a patient to time-dependent therapy that would have been delayed (or even missed) if GEMS had been used. Based on the previously noted mantras, the most important studies using time as a surrogate endpoint analyze patients with ST-elevation myocardial infarction (STEMI) or ischemic stroke (hereafter denoted simply as stroke).[19-21] It would be a mistake to assume that HEMS always saves time to definitive care.[22,23] However, the proven utility of HEMS in some time-critical situations has long been acknowledged in joint position statements from the Air Medical Physician Association (AMPA), the American College of Emergency Physicians (ACEP), and NAEMSP.[19]

In conclusion, the state of the evidence for HEMS is that there are few data from high-quality MA or RCT designs. This paucity of high-quality data translates into need for rigorous cohort-study methodology and, particularly for time-critical STEMI or stroke, employment of expedited transport as a surrogate endpoint. This monograph aims to shed light on effectiveness of these non-RCT data in answering questions about HEMS' association with outcomes.

Why HEMS evidence warrants our attention

As is so often the case in evidence-based medicine, the proper question regarding HEMS is not "*Is it ever helpful?*" but rather "*When is it helpful?*" The related question follows: "*Is it worth the cost?*"

Since the early 1990s, there have been calculations supporting the argument that regional costs of HEMS are no higher than costs of providing critical-care GEMS with similar response times.[24] The failure of such arguments to gain much traction is likely due in part to financial considerations and in part to considerations of aviation risks. Even without considering risks, it is understandable that since air transport manifests as a highly visible resource concentration in a relatively small number of helicopters, HEMS is viewed as a high-cost option.[17]

The need for HEMS discussion is based in part on continuing uncertainty about air transport's role, and in part on the fact that HEMS is already a significant and growing part of EMS. A look at the time period of roughly a decade tells the story: a 2007 overview estimated that in the USA, 753 helicopters and 150 dedicated fixed-wing (FW) aircraft were in EMS service, providing about 3% of all ambulance transports. Less than a decade later, 2015 data (accessed in late 2016) from the Atlas & Database of Air Medical Services tabulated 1045 EMS helicopters and 362 FW aircraft providing transport. A 2020 report on HEMS use provided an estimate of over 1500 HEMS aircraft operating in the US alone.[25] An estimate from a US leading HEMS expert (Thomas Judge, personal communication, March 2024) is that as of 2024 there are just over 1300 helicopters providing approximately 384,000 annual US transports.

Since HEMS is already a substantial part of the out-of-hospital care picture, there is good reason to closely examine its optimal utilization. This is particularly true given findings that volume can be as important for HEMS as for other parts of the healthcare system: the more experience a given unit attains, the better its effect on patient outcome.[26] Ongoing attention is needed to ensure that a situation does not develop in which too many HEMS units' covering a given area results in decreased per-service patient volume and diminished HEMS salutary effect.

Different portions of this monograph will have different relevance to various readers. Healthcare and EMS regional systems are widely disparate. None of this monograph's data or discussion should be applied without consideration of regional variability. Case mix and mission profile differences can result in differing conclusions about HEMS.

Between HEMS programs, mission profiles can be markedly different. A typical USA HEMS program[27] reports performing 54% interfacility transports, 33% scene runs, and 13% mission types that fall into "other" categories (*e.g.* neonatal, pediatric, transplant-related). The mission profile may be vastly different for a HEMS program elsewhere. The message to keep in mind is to make sure the HEMS evidence presented here (or elsewhere) is interpreted in light of regional needs.

Since few would argue that HEMS benefit is always predicated solely on time and logistics, any consideration of HEMS outcomes touches upon the broader subject of advanced levels of care in the prehospital setting. (*N.B.* For purposes of consistency within this monograph, "prehospital" is interchangeable with "out-of-hospital" and encompasses both scene and interfacility transports.) The HEMS crews' extended practice scope offers circumstances well-suited for assessing high-level advanced life support (ALS) care and its potential benefits. The best example of this lies in airway management and endotracheal intubation (ETI). Studies assessing prehospital ETI have provided important – if unintended – insight into HEMS' apparent improvement of patient outcome.[28,29]

Those reviewing the potential benefits of HEMS have often stressed the importance of considering crew capabilities as a separate issue from vehicle-related issues. Such separation may not always be practical, or even possible, but at least for research purposes it is reasonable to try and consider clinical care and logistics as two pathways to improved outcome. It is wise to keep in mind that even within a single region, HEMS crews may not always have the same composition (and in cases such as pediatric specialty transports the composition may be quite important).[30]

Many questions remain unanswered about HEMS. However, there *is* a large body of evidence addressing HEMS' potential outcomes influence. HEMS debate is often characterized by insufficient (or highly selective) reference to the extant evidence base. The literature may or may not provide concrete answers to given questions about HEMS, but there is likely guiding evidence of some sort on most questions. It is a goal of this presentation to facilitate the evidence-based medicine process as pertains to HEMS, by overviewing the existing knowledge base.

Discussion objectives

The discussion objectives are outlined below. These objectives can be used (for CME documentation purposes) as the objectives for Grand Rounds presentations covering this material. The material for the monograph is divided into the following sections:

1) Provide background on prehospital outcomes assessment studies and methodology.
2) Introduce the literature assessing HEMS outcomes.
3) Discuss possible benefits of HEMS to patients and healthcare systems.
4) Overview HEMS cost-benefit and cost-effectiveness considerations.
5) Address HEMS triage and utilization challenges.
6) Outline HEMS use recommendations.
7) Summarize evidence basis for judicious HEMS use.
8) Assemble listing of most important studies pertinent to HEMS outcomes considerations.

SECTION 1: DEFINING ENDPOINTS

HEMS can potentially have influence – positive or negative – on myriad outcomes relating to individual patients, prehospital systems, and regionalized healthcare. The breadth of relevant outcomes studies translates into numerous avenues for investigation. The majority of the most important outcomes studies are listed (with annotation) later in this monograph. First, this section will introduce the methodology of HEMS outcomes studies and consideration of the HEMS association with patient and system endpoints.

First endpoint: *Aviation safety*

If HEMS is inherently unsafe, then discussion of patient-related outcomes is irrelevant. Aviation risk involves patients as well as air medical crews. Although there is risk in any endeavor, presence of substantial risk associated with HEMS should carry weight in arguments against using the mode for patient transport.

Fortunately, there are detailed data available to inform the overall adjudication of HEMS risk. There are also superb analyses of the causes of HEMS accidents, and potential avenues for air medical aviation risk mitigation. Many years of ongoing work from experts such as University of Chicago's Ira Blumen (who has spent over three decades examining HEMS safety)[31] have informed the aviation safety conversation. This monograph's author is not an expert on these matters. The following points are offered as brief summary and justification of continued HEMS operations while safety work continues. Since the data tend to be collected on a national basis, the evidence that follows is presented with identification of country from which the analysis was based.

- Australia: A 2005 Australian study overviewing a decade of HEMS transports (1992-2002) found that helicopter transports were associated with one patient death per 50,164 missions.[32]
- Canada: A 2007 Canadian report takes the route of assessing patient fatality rates per mile traveled. The death rate for HEMS cases was a quarter of that for GEMS transports (0.4 *vs.* 1.7 patient deaths per million transport miles).[9]
- Germany: A 2008 German review comprising six HEMS transport years (1999-2004) found a decreasing crash rate and no aviation-related patient deaths.[33] German follow-up analysis in 2015 supported their case that properly planned and conducted aviation allows safe nighttime operations (traditionally eschewed by many European operators).[34]
- The Netherlands: A 2014 Dutch study of a more limited time period, restricted to nighttime flights (*n* = 513), found zero accidents and concluded that nighttime operations should not be precluded by safety considerations in that country.[35]
- United Kingdom (UK): A 2008 UK report[36] overviewed 5 years (1999-2004) of GEMS and HEMS transport-related fatalities; investigators identified zero HEMS- and 40 GEMS-associated fatalities. More recent (2014) analysis from the UK[37] estimates that over a quarter-century of British HEMS operations the fatal accident rate of .04 per 10,000 missions compares favorably with worldwide fatal accident rates (which are reported to range from .04 to .23 per 10,000 missions).
- Italy: A service-based approach was taken in the coastal northeastern region of Liguria, where 20 years of neonatal transports by one service were assessed. During the time frame in question, there were zero HEMS crashes and three GEMS accidents (for a GEMS accident rate of 1 in 1600 transports).[38]
- USA: One overview from 2008[9] reports that, based on two decades' data, there is less than one patient death per 100,000 USA HEMS missions. In 2016, detailed analysis of all USA HEMS-related accidents from 1983-2014 found that while overall accident rates declined by 71% over the past three decades, the injury severity profiles and the fraction of fatal accidents (36-50%) are not changing.[39]

There are *caveats* to interpreting the above numbers. Different countries' operations differ in safety-related aspects (*e.g.* whether flights are executed in night-time or poor-visibility conditions). Less easily measured – but likely more important – are inter-program variabilities in safety culture. The HEMS safety picture is too complex to be easily compressed into bullet points such as the above, but the data presented should be helpful to introduce the topic.

Leaving aside HEMS programs' heterogeneity and helicopter aviation's specific areas of debate (*e.g.* risk-reducing effects of certain pilot training components or use of night-vision apparatus), there remains another major challenge to weighing HEMS safety: lack of GEMS safety data. The lack of this information has stymied even the most meticulous healthcare policy analysts assessing HEMS and GEMS. In 2013, Delgado concluded that, given uncertainty regarding GEMS transport-related fatality rates, true comparison of HEMS *vs.* GEMS transport safety was difficult.[40] A decade later, Hartmann reached much the same conclusion.[41]

Every aviation incident in the USA (and most developed countries) undergoes intense and appropriate scrutiny at the federal level, but GEMS accident-related death and disability are not similarly tracked. Lack of information inevitably leads to conclusions such as: "Unlike helicopter and fixed-wing EMS incidents, little is known about ambulance crashes."[42]

The picture on GEMS safety is not ideal, but neither is it fully opaque. National Highway Traffic Safety Administration (NHTSA) has in recent years began tracking ambulance crashes with tools such as the Fatal Accident Reporting System (FARS). NHTSA reports on its public website (www.ems.gov) that the two decades 1992-2011 saw 4,500 motor vehicle crashes (MVCs) involving GEMS; the agency estimated a mean of 33 deaths per year, related to GEMS. While these data are, as previously noted, not necessarily comprehensive, the NHTSA MVC rates for GEMS are generally in line with a two-year national survey of USA tort claim-related GEMS fatality data presented by Wang in 2008.[43]

Among the more recent safety analysis was one that employed interweaving of multiple databases to generate estimates of HEMS *vs.* GEMS risks for vehicle (crash) related injury or death. Hartmann's analysis,[41] which must be interpreted with understanding that rates were measured on a *per-hour* (not per-mile) basis, suggested that HEMS had a higher fatality rate (3.7x that of GEMS, with 95% CI 0.9-15.2 and $p = .065$) but GEMS' injury rate was 7.1x that of HEMS (95% CI 3.2-15.8, $p < .0001$). The work of Hartmann was restricted to focus on the more reliable metric of events per hour, but it is of course the case that the truly relevant metric is events (either fatalities or injuries) occurring per mile transported.

What is the bottom line on HEMS and safety? First, aviation safety should be the prime consideration in all cases for which helicopter transport is being considered. If a mission cannot be conducted within the envelope of acceptable risk – keeping in mind that risk is never eliminated in any transport – the aircraft should stay on the ground. However, blanket statements that "HEMS is risky" are lacking in evidence; such statements oversimplify the issues and distract from considered judgment. HEMS operations – like GEMS operations – can indeed be risky, but the literature shows they can also be safe.

Given data at hand, the conclusions of most policy researchers seem reasonable. First, HEMS must be conducted with meticulous attention to safety at all times. Second, if operations are conducted in a realistically achievable safety envelope, the mortality benefits of HEMS outweigh (on a utilitarian basis) the aviation-related mortality risks.[40] Finally, rational consideration of HEMS transport safety should include the risks associated with transport by non-HEMS means[42] or (for patient-centered risk) the outcomes risk from non-transport.[44]

Clinical outcomes endpoints: *Survival*

The most important outcome for HEMS studies is survival. If HEMS improves survival, then cost-effectiveness may be established by this endpoint alone. However, it is probable that *if* HEMS improves survival, there are other unmeasured (but still important) clinical benefits that contribute to a case for HEMS utility.[11,40] The point is worth emphasis: the emphasis on survival as the clinical endpoint is due in part to the difficulty of measuring other valued endpoints.

It's preferable for studies reporting on survival to include precise endpoint definition. Timing of vital status may be relevant; survival to hospital admission may be less meaningful than survival to hospital discharge. Functional status is also important since survival in a persistent vegetative state is clinically and economically quite different than discharge home. Many of the more recent HEMS trauma studies (particularly those studies that focus on head injury) specifically address discharge disposition. Disposition status should be specifically sought in a close reading of HEMS outcomes literature.

With the preceding *caveats*, the survival endpoint has advantages of clarity, objectivity, and relative ease of ascertainment. Researchers using survival as an endpoint don't need to make a case for the clinical and health-economic importance of decreasing mortality. When the research situation is one for which survival is an appropriate endpoint, the usual case will be that it is best for HEMS investigators to ask: *Does HEMS improve survival?*

Clinical endpoints other than survival

Survival may be the most important patient-centered HEMS endpoint, but there are others. This section provides a partial listing of non-mortality endpoints seen in the air transport literature.

The question of functional status, mentioned above, informs research designs assessing illness and injury with particular functional impact. Traumatic brain injury (TBI) and stroke are situations for which functional outcome is particularly important. For TBI or stroke, restriction of endpoint assessment to survival (without functional assessment), can paint an incomplete picture of HEMS benefits and economics. If flight crew deployment simply changes a scene death to an expensive hospitalization for a patient who never emerges from coma, there are obvious implications for HEMS' cost-benefit calculations.

The HEMS literature includes studies assessing non-mortality functional status. One of the early studies by Baxt's California group focused on TBI and found HEMS improved both mortality and also survivors' Glasgow Outcome Score (GOS).[45] More recent studies of HEMS trauma scene response to TBI have also identified both mortality and GOS benefits.[46,47] TBI data illustrate clear links between HEMS deployment, reduced secondary brain injury, and improved functional status.[48,49] Similar findings are present in a Danish assessment of long-term functional outcomes benefits of HEMS scene trauma response.[50]

A 2024 large-scale (*n* = 258,107) pediatric study from the US found HEMS both increased survival and improved functional outcome of those surviving to discharge.[51] With stroke, the evidence is indirect, requiring linkage from HEMS use to time savings to improved neurological outcome.[52] A 2024 study from Wisconsinserves as a reminder that functional survival assessment is also applicable to spinal cord injury; the group found that in patients requiring emergency operative decompression for spinal cord injury HEMS transport was associated with significantly better functional outcomes.[53]

Analgesia provision is a well-accepted endpoint, with relevance to both patient-comfort and physiology.[21] Investigators have assessed analgesia in both trauma and acute cardiac populations.[54,55] A natural-experiment design from Denmark is one of many studies that demonstrated that HEMS institution was associated with improved analgesia as compared to pre-HEMS cases managed by GEMS.[56]

Other reported endpoints are related to endotracheal intubation (ETI) and the overarching arena of airway management. A Danish natural experiment study found that ETI was more likely in TBI cases with HEMS.[56] In both adults and children, overall ETI success[57-59] and the additional endpoint of first-pass ETI success[60] have been assessed and generally found quite high. In Australia, for instance, physician-staffed HEMS responding to pediatric scenes were 100% successful with ETI, in a group in whom GEMS (lacking neuromuscular blockade) had as many undiagnosed esophageal ETIs as successful ETIs (29% for each).[61]

In the subset of pediatric cardiac arrest cases (reported from the Netherlands), HEMS corrected a 14% rate of esophageal intubations and achieved 100% ETI success (99% if a rigor-mortis case's ETI failure is included) in a group in which GEMS ETI success was 51%.[62] Additionally, peri-ETI physiology measures (*e.g.* oxygenation, ventilation) have been reported, with particular emphasis on their relationship to secondary brain injury in trauma cases.[48,63,64] More recent studies (from 2023) have continued to suggest that ETI's effects on TBI outcome are in part mediated by HEMS *vs.* GEMS operator status.[65]

Other non-mortality endpoints found in the HEMS literature include findings such as avoidance of undertriage to Level I trauma care,[66] minimization of patient-safety errors,[67] and better attention to endotracheal tube (ETT) cuff inflation pressures.[68] The HEMS cardiac literature includes studies reporting cardiology-specific endpoints (*e.g.* reinfarction).[55,69]

All non-mortality endpoints share one characteristic: the need for researchers to make a case for clinical relevance. Because of challenges in prehospital research, it is often necessary to evaluate HEMS effects using logistics or other surrogate endpoints.

Sometimes the surrogate endpoints' clinical impact is clear (*e.g.* assessment of functional outcome scores in TBI). In other cases, though, the clinical impact of a selected non-mortality endpoint (*e.g.* ETT cuff pressure) is less certain. It is the responsibility of the study authors to convince readers their endpoint is viable and defensible as a reflection of clinically important finding. Some of the most useful studies are those that tie their assessment of a non-mortality endpoint (*e.g.* protocol adherence for obtaining prehospital stroke scales[70] or administering epinephrine in anaphylaxis[71]) to demonstrated outcome improvements.

Non-clinical outcomes: *Systems & logistics*

Trauma outcomes studies benefit from registry-based data sources and well-accepted methods for case-mix adjustment. Large databases bring analytical power (high *n*); acuity scores allow statistical correction for HEMS cases' tendency to have greater injury severity than GEMS patients. These methodological advantages, so important in trauma studies, are not available to the same degree for studies in non-trauma populations.

For non-trauma populations, the difficulty in executing large, acuity-adjusted outcomes analysis translates into a greater role for non-mortality endpoints. Some of these endpoints have been mentioned in the previous subsection, but another class of endpoints – surrogate endpoints – is particularly important in non-trauma HEMS studies. The most important of these non-clinical endpoints is time savings.

The key to process (or logistics) endpoints such as time savings, is the ability to tie these non-clinical parameters to morbidity or mortality benefit. Given HEMS' roots in battlefield trauma evacuation, and given trauma systems' historical emphasis on time savings (*e.g.* "the Golden Hour" of Dr. R. Adams Cowley), it may be considered ironic that for injured patients, there remains no settled tie-in between HEMS time savings and improved outcomes. Trauma time savings' survival linkage may be clouded by the fact that at many injury scenes the necessary time-critical intervention can be provided by HEMS crews.

There are some data tying trauma-scene time savings to outcomes. A Boston group[72] assessing penetrating trauma cases from an NTDB nationwide database (thus with large *n* and high precision) reported that each minute of prehospital time savings translates into a 1% mortality improvement. Overall, though, in the decades since the first major HEMS outcomes study[73]) found air transport survival benefit in absence of time savings, the time-savings question has not been definitively answered. There are insufficient data to support use of time savings as a surrogate endpoint for trauma. Where these data *do* exist is in the realm of non-trauma: stroke and ST-elevation myocardial infarction (STEMI).

The twin mantras *Time is brain* and *Time is myocardium* have spawned a HEMS evidence base espousing time savings as a surrogate endpoint for stroke and STEMI studies.[21,22,70,74-78] In stroke patients, savings of 25 minutes (for HEMS dispatch to meet *en route* GEMS interfacility cases[78]) and 8 minutes (due to HEMS crews' better compliance in obtaining prehospital stroke scales[70]) have been highlighted as clinically important. For STEMI patients, data from urban areas (subject to traffic problems) have shown that even for short transport distances HEMS can reduce mortality up to 25% (by saving over 30 minutes compared to GEMS interfacility transport for primary PCI).[77]

For certain cases, the process endpoint is minimization of out-of-hospital time, not overall time. As an example, studies of interfacility obstetric transports have focused not just on whether HEMS got patients to tertiary care faster, but also on whether HEMS use allowed for patients to spend less time in the (riskier) in-transit setting.[44,79]

Other "efficiency" process endpoints have also been reported. HEMS-related process endpoints include facilitation of getting interfacility-transported aortic aneurysm patients to the operating theater,[80] scene-transported TBI[10] or stroke[74,81] patients to cranial computed tomography (CT), and STEMI patients to cardiac catheterization.[81]

Conclusions regarding endpoint definition

The first endpoint to be considered in HEMS, is aviation safety. If HEMS is inherently too risky, then operations should cease. Available data support continuing HEMS operations with continuing attention to optimizing safety.

For studies of HEMS in the injured, mortality assessment is facilitated by availability of large-scale trauma registry data and (even more importantly) acuity-adjustment methods; the latter are critical to prevent anti-HEMS study bias related to HEMS *vs.* GEMS case-mix and injury severity differences (*i.e.* higher crude mortality with HEMS).

Studies of HEMS in non-trauma diagnoses are limited by lesser access to large-scale registries. Even more problematic is HEMS investigators' inability to measure (or adjust for) illness severity. Non-trauma HEMS studies are thus less likely to assess mortality or functional outcome, and more likely to focus on secondary clinical endpoints (*e.g.* chest pain relief) or surrogate endpoints (*e.g.* time savings).

The assessment of non-mortality endpoints provides potentially valuable information on possible HEMS benefits, but for any endpoint other than mortality or morbidity, HEMS study authors must establish clinical relevance.

Financial endpoints (*e.g.* cost-benefit analysis) can be calculated only after clinical benefits of transport are known with some certainty; these financial endpoints are thus addressed later in this monograph.

SECTION 2: STUDY DESIGNS IN THE HEMS LITERATURE

This section outlines types of studies found in the HEMS outcomes evidence base. The opening subsection addresses a commonly noted problem – evidence quality – with HEMS research. Subsequent subsections list distinct types of research designs used by HEMS outcomes researchers. Illustrative examples of each type of design are provided in order to highlight some advantages and limitations of each methodology.

The randomized controlled trial

The well-conducted RCT is widely and appropriately acknowledged as an optimal source for evidence-based medicine. However, there have been only a few attempts at HEMS-related RCTs. Both ran into problems due to unwillingness of clinicians (referring hospital physicians[69] or prehospital care providers[10]) to allow their patients to be randomized away from HEMS. This type of clinician reluctance combines with a variety of other issues (*e.g.* ethics considerations) to render unlikely any successful execution of large-scale RCTs that include randomization away from HEMS.[21,82,83] The absence of RCT data has been acknowledged as a major limitation of the HEMS evidence base in systematic reviews, but those reviews also note that there is much to be learned from extant studies.[11] While some authors[25] continue to call for prospective RCTs – such studies would clearly be useful to inform decisions – the majority of investigators are not hopeful for HEMS *vs.* GEMS RCT execution.

Expert opinion

While reasonably considered to be a low-level evidence type, expert opinion is not without value. Where RCT data are lacking, consensus statements and judgments of leaders in various medical fields are potentially more important.

The lack of solid RCT evidence contributes to the inevitable nature of diversity in HEMS-effect judgments. Expert opinion on HEMS utility comes in a variety of forms, from commentary by leaders in the field (*e.g.* Varon's editorial addressing critical care and cardiology cases)[84] to government agency findings (*e.g.* from CDC and NHTSA panels) and position statements from organizations such as the American Stroke Association and NAEMSP.[85]

Case reports

Like expert opinion, case reports carry limited methodological weight in evidence-based medicine. However, given the unusual nature of HEMS aviation-related capabilities, some case reports are noteworthy for illustrating types of care that HEMS is uniquely situated to deliver. Usually, the emphasis is on HEMS' ability to quickly reach patients with some combination of expertise, equipment, or drugs. Examples of such reports follow:

- <u>Scene response for direct transport to tertiary time-windowed therapy</u>: Use of HEMS has allowed patients with diagnoses such as stroke, to bypass GEMS transport to community hospitals (lacking lysis capability) and instead be air-transported to expedited neurovascular intervention.[86]
- <u>Transport of pharmacologic agents to patients</u>: The HEMS literature includes myriad reports of drugs (*e.g.* prostacyclin)[87] or blood products (*e.g.* prothrombin complex concentrate[88]) that were transported in timely (life-saving) fashion that would not have been obtainable in time had GEMS been used.
- <u>Movement of advanced-level care to patients for whom GEMS access is time-consuming or impossible</u>: HEMS has been reported to be life-saving in various terrains ranging from mountains[89,90] to coastlines,[91] and in situations in which disasters impede GEMS access.[92]

Panel review

In panel review studies, groups of transports by HEMS (and often by GEMS as well) are discussed by healthcare providers who then adjudicate whether HEMS may have contributed to improved outcome. The panel approach is exampled by many studies. While some earlier panel studies concluding HEMS benefit was present come from the US,[93] with some follow-up work in Australia,[94] most of the high-quality panel studies arise from Europe – particularly

Scandinavia – and use a Delphi technique to work towards consensus.[95,96]

In comparison to some of the more complex, yet still imperfect, study designs, panel review projects are much easier to execute. Another advantage to these studies is their potential for clear identification of the mechanism responsible for HEMS' salutary effect (*e.g.* flight crew changes a misplaced airway inserted by GEMS). Of all HEMS study types, the panel review is theoretically among the most likely to provide a direct relationship between a particular HEMS characteristic (*e.g.* speed, airway skills) and better outcome.

The panel review study has significant limitations. The main weakness of the design is that it is inherently subject to biases, both for whether HEMS truly affected outcome and whether particular HEMS interventions saved lives. It is difficult to conceive that even the most well-intentioned reviewer could completely divorce preconceptions about HEMS utility from the assignation of putative HEMS benefit in borderline cases.

Patient-safety reports

Patient-safety studies, which are here considered separate from aviation-related safety, address whether certain populations are placed at particular risk by HEMS transport. Patient-safety studies in HEMS are best considered a necessary, but not sufficient, basis for contention that HEMS is useful; it's hard to justify the resource investment for most HEMS flights if the supporting case is simply that HEMS is no more unsafe than ground EMS. This research is still important, though, because if HEMS and associated vehicle characteristics (*e.g.* extra patient transfers, aircraft vibrations) increase risk, then judgments about flying individual patients may be altered.

In general, the HEMS patient-safety studies fall into two categories. The first category addresses issues of potential importance, and outlines whether the hypothetical risks are confirmed in actual series. The second category addresses issues that are judged to be of potential clinical import, and outlines recommended measures to mitigate the risk. Overall, the literature supports a conclusion that HEMS may theoretically involve risks (*e.g.* related to vibration or altitude) but that flight crews are adept at recognizing and managing any risks that exist. Examples of patient-safety studies include the following:

- Early patient-safety studies assessed whether the electrical or vibration environment of HEMS increased pacemaker or post-thrombolysis complications in cardiac or stroke patients.[97-99]
- In an unusual extension of these types of studies, one prospective study administered tPA to mice and then transported them via HEMS or GEMS; post-transport analysis for any complications (such as bleeding) failed to identify HEMS risks.[100]
- Another study focusing on vibrations assessed the potential for worsening of neurological deficits in spinal-cord injury patients transported by air. The results suggested that HEMS was actually associated with fewer vibration-related pathological changes than a military ground ambulance comparator.[101]
- Related work on vibrations has suggested some possibilities for fracture-associated bleeding risk, particularly in patients with pelvic injuries, but there was no ground EMS control group. The investigators' sound recommendation was minimization of vibration-related bleeding risk by proper pre-flight splinting.[102]
- Whereas the previous points addressed potential problems related to vibrations, other studies have focused on the relationship between altitude and physiology. Information from an artificial lung-mimic model demonstrated that (at the altitudes most HEMS flights occur) there is some – although often overstated – potential for clinically significant changes in pneumothorax volume.[103] The clinical significance of minor changes in pneumothorax volume increases with altitude was pointedly questioned by a 2024 study from Colorado[104] finding a 0% incidence of altitude-associated worsening of pneumothorax.
- With respect to altitude changes, pneumothorax investigations have been complemented by other studies that have suggested a more likely target of clinical significance of pressure-volume change: endotracheal cuff pressures. While it is difficult to precisely know the clinical results, studies show that cuff pressures are yet another altitude-related facet to the special care issues facing flight crew.[68,105-108]
- One altitude-related point that does warrant consideration is the effect of hypobaric hypoxia on the HEMS crew. Many HEMS programs use supplemental oxygen for crew executing high-altitude transports in (unpressurized) HEMS units. The practice's wisdom was endorsed by findings of a 2024 study by Italian mountain medicine experts[109] who found that at altitudes commonly encountered by their HEMS crews (3000-5000 meters above sea level) there was an unrecognized (by the crews) decrease in psychomotor response times.

- Some studies have not assessed particular aviation risks, but rather examined the overall physiologic stability of HEMS *vs.* ground transports. The best of these investigations assess transports by the same medical crew, who execute transport in both air and ground ambulances. Example studies report no increase in adverse outcomes associated with the HEMS setting, for pediatric patients of high acuity.[60,110]

Time-savings analyses: *Trauma*

For trauma studies, the subject of time savings has been occasionally confusing. It seems that HEMS' potential impact on survival does not have a fully consistent association with time savings. From the earliest major HEMS trauma study by Baxt,[73] through more recent data from the USA and around the world,[23,111,112] there are data to that indicate imprecision regarding the line between time savings and survival improvement. While this is likely due to the fact that – at least in some cases – life-saving interventions (*e.g.* airway management, chest decompression) are provided at the scene,[112,113] the use of time as a surrogate endpoint for HEMS trauma studies is not well-grounded in the evidence base.

Of course, for some injuries, time to definitive care is important. In the UK, trauma guidelines in at least one region emphasize the importance of early airway management. These targets were emphasized in a 2024 demonstration[114] that HEMS deployment to trauma scenes is associated with a markedly faster time to definitive airway establishment (64 minutes from initial EMS call for HEMS patients as compared to 84 minutes for GEMS transports, who had to await ED arrival for airway management).

HEMS has long been postulated to improve outcome based on getting patients more quickly to definitive care. In addition to HEMS' potential and intuitive benefit for penetrating trauma requiring operative intervention, [115]there are unusual series in the literature. For example, citing a four-hour target for reduction of cervical spine dislocation (to reduce spinal cord damage), a Japanese group has reported utility of HEMS in enabling C-spine dislocation cases to achieve within-window reduction.[116] The recent (2022) Japanese series echoes a case made by Italian investigators as long ago as 1989: HEMS ability to quickly get severely injured spine-trauma cases to trauma centers was determined to result in outcome improvement as compared to slower GEMS.[117] Other reports (*e.g.* from San Antonio)[118] draw the conclusion that HEMS improves trauma mortality, when investigators find that HEMS' farther-away cases have the same survival rates as closer-in GEMS cases treated at the same center.

Time-savings analyses: *STEMI & ischemic stroke*

Although the use of time as a surrogate endpoint is not justified for trauma studies, for non-trauma diagnoses with time-windowed therapies there is substantial argument in favor of assessing a time-savings endpoint to see if HEMS is useful. One of the most important study types in the non-trauma HEMS literature, is reporting of whether HEMS use speeds time to receiving time-critical therapy such as percutaneous coronary intervention (PCI) or stroke thrombolysis. Closely related is the question as to whether HEMS use allowed patients to receive time-windowed therapy for which they'd been ineligible had HEMS been unavailable.[119]

Savings of time is directly correlated to improved outcome for at least two diagnoses: STEMI and stroke.[52,120-123] Example studies for each of these patient groups are found in the HEMS literature, with studies reporting time savings as a continuous variable and also assessing the dichotomous outcome of "arrived at receiving center within treatment window."[20,124,125] Compelling evidence makes the case that the mortality improvements occur with time savings even within those cases that meet traditional "windows" of 60 or 90 minutes – the conclusion being that the goal should be "as quickly as possible" rather than a specific time demarcation.[123] Benefits of faster primary PCI in STEMI appear to be maintained across the spectrum of patient-centered delay (*i.e.* different intervals between symptom onset and presentation to healthcare).[122,123]

Given the above, there is weight in analyses such as one demonstrating that HEMS gets patients to PCI an hour faster than if they'd gone by GEMS,[124] or another finding that HEMS triples the odds of patients' arriving at stroke centers in time to receive lysis.[20] A Danish logistics study has demonstrated that HEMS is associated with clinically significant PCI time improvement when transport distances exceed 60 km; the Danes concluded that HEMS can allow access to within-window PCI for transport distances up to 150 km.[126]

These types of time-savings studies are thus an important component of the HEMS outcomes literature for these non-trauma populations. HEMS should not be assumed to always result in time savings, [22]but the time savings that can be reaped with HEMS can have important implications for outcome and planning for STEMI and stroke regionalized systems.[119,127,128]

TRISS-based trauma survival research

Scoring systems such as the Glasgow Coma Score (GCS), Trauma Score (TS), and Injury Severity Score (ISS) are useful to stratify patient acuity for injured patients. Given the unadjusted higher mortality risk of HEMS trauma cases as compared to those transported by ground, such acuity adjustment is an absolute requirement for assessing relationships between transport mode and survival.[21]

The basic scoring systems, such as GCS and TS, are familiar. A more complex method, TRISS, is perhaps less familiar but it's broadly used and generally well-accepted (www.trauma.org/archive/scores/triss.html). TRISS incorporates physiologic (TS), anatomic (ISS), mechanism (blunt vs. penetrating), and age (55 years as cutoff) covariates in a logistic regression model with death as outcome. Since TRISS' applications (and misapplications) are relevant to assessment of the HEMS outcomes literature, a brief overview of the method is presented here.

TRISS' terms (β coefficients) are derived from the American College of Surgeons' Multiple Trauma Outcome Study (MTOS) database. As the MTOS database ages, more recent TRISS studies using those MTOS coefficients may be inaccurate;[11] reporting of *M* statistics (see below) is therefore of increased import. Some studies utilize variants of TRISS such as the TRISS-L (aimed at reducing bias related to prehospital intubation's impact on vital signs).[129] These TRISS variants are typically employed in similar fashion to standard TRISS.

Once TRISS has been used to model the anticipated mortality for a study population, the predicted mortality can then be compared to actual mortality. Some important steps must be taken to assure methodological rigor.

For TRISS to work best, there needs to be similarity between the investigator's study population (*i.e.* the potential group upon which TRISS will be used) and the MTOS population. It's not appropriate to employ unadjusted TRISS methodology on a study group that's significantly different from the MTOS source group from which TRISS coefficients were derived. Therefore, the first step in using TRISS for outcomes analysis is to ensure that the study group's injury acuity distribution is sufficiently similar to that of the MTOS population to enable use of the MTOS-derived regression coefficients. This is performed by calculating an "*M*" statistic.

Since *M* does not follow a statistical distribution, there is no test (*i.e.* calculation of a *p* value) to see if M is acceptable. However, a minimum of .88 (on a scale with maximum 1.0) is generally considered to be the threshold indicating acceptable casemix similarity; lower *M* implies lower acuity than that of the MTOS cohort.[11] Analyses have demonstrated that especially in locations outside of the USA, *M* statistics are substantially lower than levels appropriate for uncorrected TRISS use.[130,131]

If calculation of the *M* statistic denotes appropriateness of TRISS utilization, then a "*W*" statistic can be calculated. *W* estimates the number of lives saved for every 100 transports. When further stratification is necessary, or when *M* <.88, adjusted or standardized *W* can be calculated.

When *M* is calculated as too low for standard TRISS, enterprising investigators have essentially replicated the TRISS methodology with locally developed (and validated) logistic regression models. Using coefficients from those models, for instance, researchers from the Netherlands demonstrated a HEMS outcome benefit (*W*) of 2.5 lives per 100 pediatric scene dispatches (for cases with ISS >15).[131]

The last step in TRISS is calculation of a *z* statistic to test H_0 of no difference between 0 and the calculated *W*. There are different mechanisms for using the methodology. The most important variation is the use of a control group against which HEMS performance is compared. Many trauma studies use TRISS' MTOS population to provide a "control" group; in other words, the investigators simply demonstrate that a group of studied trauma patients survived "better than predicted" by TRISS. Obviously, this setup is subject to confounding by patient mix and a variety of other factors (*e.g.* trauma center quality of care) that may not reflect upon prehospital care.

The most compelling of HEMS TRISS studies are those characterized by simultaneous TRISS analysis on HEMS and ground EMS patients transported to the same receiving center(s). Such an approach reduces potential confounding by factors such as hospital care quality. TRISS can provide strong evidence for air transport benefit if actual mortality effects are (statistically) more substantially positive than those of GEMS. Examples are illustrative.

A province-wide study in Nova Scotia found a statistically significant outcomes worsening (as compared with TRISS-predicted) with GEMS, whereas air transport accrued a 25% outcomes improvement; as compared to the ground transport alternative, HEMS improved mortality by 35%.[83] Similar results – HEMS improved outcome whereas GEMS worsened outcome – were reported by another Canadian group (in Ontario) in 2016.[129] The more usual result is that GEMS-transported cases die at the predicted rate, whereas HEMS-attended cases have higher-than-predicted survival.[73,132] However, TRISS can also be helpful if both GEMS and HEMS groups have worse-than-predicted mortality, but the HEMS worsening (from TRISS predictions) is significantly less than that observed for GEMS cases; this was the result in a 2022 study from South Korea.[133]

Observational cohort studies

TRISS is, at its base, a type of observational cohort study (OCS). The cohort of HEMS cases is assessed for survival, and compared to a baseline of either a study-center GEMS cohort or the TRISS (MTOS) cohort. Since trauma is the only HEMS patient population for which there is a worldwide accepted survival model, TRISS is unique in its availability as a tool for HEMS researchers. However, there are myriad other OCS designs that have been deployed by those assessing HEMS' impact on survival and other endpoints.

The most straightforward OCS approaches attempt to match acuity and other characteristics for HEMS and GEMS patients and then perform outcomes comparisons. The approach that is simplest is an unadjusted outcomes comparison between HEMS transports to a particular center, and outcomes of cases who presented primarily to that center (by GEMS or private vehicle). This methodology tends to be aimed at demonstrating HEMS' ability to extend the reach of a center's care to farther-distant cases than those to whom the center is readily accessible by ground. These OCS designs have been executed for cardiac,[134] obstetric,[44] and neonatal[135] populations, with findings that HEMS transport of patients distant from specialty centers allows those patients to achieve outcomes equal to those of patients presenting primarily to study centers.

Other OCS designs include attempts to adjust for the fact that HEMS cases – regardless of diagnostic group – tend to be higher acuity than those who arrive at receiving centers by other means. OCS approaches for trauma have employed stratification by parameters such as ISS, TS, injury mechanism, and demographic factors.[136,137]

The advantage of these cohort approaches is that they employ classical, intuitive, and widely accepted statistical techniques to allow for between-group acuity adjustment (where such adjustment is clinically possible). The primary disadvantage of this type of study is that large populations are usually needed to produce useful results. This is because the outcome of interest – mortality – is infrequently affected by transport mode. In practice, this limitation means that even when a study of this design suggests same-stratum mortality differences between air and ground transported patients, statistical significance is not commonly achieved. Relatively low cell counts (since data are split into multiple tables) translate into low study power and wide confidence intervals that are likely to cross the null value.[137]

In another OCS methodology, investigators use matching to adjust for inherent acuity differences in HEMS and ground EMS patients. This is potentially useful when study *n* is low, but existing studies are weakened by problems such as residual confounding on unmatched variables (*e.g.* Revised TS, intubation).[138]

The most common method for analyzing OCS study data in HEMS is to incorporate the transport mode cohorts (air and ground) into a model (usually logistic regression-based) that explores the potential association between transport mode and outcome. One of the modeling problems associated with having relatively low outcomes numbers (*i.e.* low mortality) is that models often don't have the ability to incorporate enough covariates; there are so many potential confounders of the HEMS-outcome association that the required 20 outcomes per covariate ends up restricting model power.

OCS model-building tends to employ advanced techniques. Propensity scoring can assess for confounding by covariate patterns.[17,139,140] Instrumental variables (*e.g.* distance from trauma center) can help replicate conditions of an RCT.[140]

Natural experiments

Although it's a type of OCS, natural experiment methodology warrants special mention as a study design that can be uniquely positioned to provide insight into HEMS' outcome effect. Natural experiment designs are not prospectively defined plans, but rather naturally occurring situations in which HEMS availability changes. Whether for mechanical issues, weather problems, or simple aircraft unavailability, sometimes when HEMS is called there are no helicopters available. On a larger time scale, HEMS services may come and go as a regional resource. The crux of natural experiment design is analysis of outcomes in HEMS-transported patients *vs.* patients who would have gone by HEMS if the service were available. At its best, a natural experiment can approach pseudo-randomization; detailed discussion of the natural experiment design in HEMS can be found in a 2023 systematic review of these studies.[141]

From the very definition of natural experiment design just given, it's apparent that the major issue with these studies is selection bias: the "non-HEMS" group must include all of those patients who would have gone by HEMS if the helicopter were indeed available. But what if the referring hospital never bothers to call for HEMS due to obvious unavailability (*e.g.* due to weather)? What if the lack of HEMS availability means that the referring hospital doesn't even transfer the patient to the trauma center (*e.g.* due to travel distances)? The biggest problem with natural experiment designs is that they sometimes fail to assess outcomes in those non-HEMS patients that the investigators never knew about.

Methodology that fails to include the entire population of HEMS-eligible patients predictably finds little or no HEMS-associated mortality difference. Such was the case with the trauma HEMS natural experiment studies from Texas[142] and North Carolina.[143] The Texas findings of no decrease in the post-HEMS era's trauma mortality hardly came as a surprise, given their findings of significantly shorter transport times and markedly lower injury acuity seen in their trauma patients after HEMS discontinuation. Selection bias meant that patients who would have earlier been flown, were simply kept (and possibly died) at the distant community hospitals. The North Carolina study had more numerous flaws, not least its assessment of a GEMS cohort that was actually smaller than the *n* of excluded cases (*e.g.* those who died at referring hospitals while waiting for transport).

A true population-based study, comprising all injured patients in a given region, gives more useful results. The initial such study was a methodologically rigorous effort from Oregon,[144] where there was a situation in which some, but not all, of the state's referring rural centers lost access to HEMS. Mortality changes before and after the time of HEMS discontinuation were assessed in the "no-HEMS" hospitals (where mortality increased 4-fold) and also in matched hospitals that continued using HEMS (mortality was unchanged). Similar positive findings for HEMS' mortality improvement were found in another well-executed natural experiment analysis that covered a province in Canada.[145]

The advantage of the natural experiment type of study lies in its potential to methodologically approximate the optimal (but largely unachievable) study design: the RCT. In actual implementation natural experiment studies fall short of assuring such an ideal, but changes in HEMS availability over large geographical areas provide opportunities for population-based means of assessing HEMS utility.

A few other natural experiment studies have assessed changes in trauma mortality when HEMS availability changes in the direction of *added* helicopter coverage. In Long Island,[13] investigators found that when an additional HEMS unit was added to a geographically isolated area of their trauma center catchment region, the number of HEMS-transported patients out of the region doubled and the regional trauma mortality decreased significantly. Trauma mortality was also demonstrated to decrease significantly with the addition of a HEMS unit into a well-developed Danish trauma system.[146]

A 2024 report from Finland[78] eliminated selection bias by examining HEMS deployment for what was termed "hybrid transports." In assessing stroke patients transported from a referring hospital to a stroke center, the default approach was to send the GEMS unit with the patient along its way towards the stroke center while simultaneously dispatching HEMS (from an airport near the stroke center) to meet the GEMS units partway; HEMS then completed the transport. This system was used unless HEMS was unavailable (usually due to weather), thus creating a potential natural experiment. The Finns assessed the time savings associated with HEMS hybrid transport as compared to those GEMS-only transports, and found that helicopter use was associated with a clinically significant (per the authors' judgment) time savings of 25 minutes.

Population-based mortality assessments

One relative of the natural experiment discussion is the population-based analysis of trauma mortality with correlation to HEMS coverage. Trauma mortality in regions with HEMS coverage is compared to mortality in areas that lack air medical coverage but which are otherwise identical. Such research is limited by residual confounding and other problems related to the inability to tease out HEMS' contribution to mortality differences in disparate regions.

There are some data from population-based studies. Preliminary work by the ADAMS (*A*tlas and *D*atabase of *A*ir *M*edical *S*ervices) group has found a correlation between ready availability of HEMS (*i.e.* 10-minutes' distance) and decreased trauma mortality as measured by ratio of fatalities per 1000 injuries (R = 0.70).[147] Another population-based study, based in Massachusetts, found that HEMS availability was associated with a 13-22% reduction in trauma mortality.[148] A Pennsylvania state-based population analysis, based upon doubling of HEMS assets within a decade, found that for scene runs >11 miles from trauma centers there was a 1% worsening in mortality for each mile of increase in distance from the scene to the nearest HEMS base.[82]

In healthcare systems with relative homogeneity there is capability to assess overall mortality with HEMS as compared to GEMS transport. Scandinavia, with nationalized healthcare and high-quality research, has provided more than its share of scientific inquiry into population-based assessment of HEMS' benefit. From Denmark there, investigators found no difference in vital status one year post-transport by HEMS *vs.* GEMS.[149]A Norwegian group looking at all-diagnosis transports reported that HEMS was found to improve mortality in those with an acute threat to life.[150]

HEMS outcome as an incidental finding

Some interesting evidence suggesting HEMS' positive effects on outcomes comes from studies that were focused on questions unrelated to transport modality. Conclusions drawn from such studies are necessarily limited due to the fact that the investigations weren't intending to address HEMS. However, the limitation of "non-HEMS focus" can also be an advantage: these studies tend to be executed by parties with no bias in the HEMS debate.

One example of such a study is a traumatic brain injury analysis from Pennsylvania in which investigators found ETI by HEMS – but not GEMS - MS ETI) improved both survival and functional outcome in patients with head injuries.[28] Editorialists[151] reviewing the study wrote, "Their data show that out-of-hospital ETI performed by trained flight EMS providers using a rapid sequence intubation protocol was associated with decreased mortality and improved neurologic outcome. This suggests that there may be something in the technical expertise of the flight crew or in the airway management practices after ETI that has potent effects on outcome."

Another trauma airway study, this one from Oregon,[29] also focused on factors other than transport modality but found strong evidence for HEMS-mediated outcomes improvement. In a set of analyses of varying design, the authors report: "Helicopter transport was associated with lower mortality in all transported patients at all distances." Varying model setups for the Oregon study, which included over 8,000 scene trauma patients transported to Level I care, found odds ratios for HEMS-associated survival improvement ranging from 0.34 to 0.38 (all were statistically significant). As the study's authors write: "Although this study was not designed to study the impact of helicopter transport, its impact was seen in all three models, signifying that helicopter transport does indeed impact survival in all trauma patients, not just those with an out-of-hospital ETI."[29]

Other types of evidence

While the preceding categories comprise the bulk of the HEMS literature, miscellaneous reports comprise an additional category of "other evidence." While the weight given to this category tends to be less than that afforded more traditional studies, some mention of this lower-level evidence is warranted.

One unusual design is artificial neural network (ANN) analysis. While potentially prone to biases in setting up the model, repeated ANN iterations that consistently demonstrate HEMS outcomes improvement can be persuasive. As an example, the ANN study reported by Davis identified HEMS (as compared to ground transport) as saving a statistically significant 3.6 lives per 100 transports of brain injured patients with head AIS of at least 3; when analysis focused on patients with GCS 3-8, 7.1 lives were saved per 100 transports.[152]

There are miscellaneous case reports and opinion articles that address potential association of HEMS with improved outcomes. These cover myriad situations ranging from field thoracotomies[153] to cases of cranio-cervical dislocation.[116]

Other reports that are not classically included in the body of "outcomes literature" address endpoints such as analgesia or peri-ETI physiology. These reports' relevance to the HEMS debate stems from extant literature that points out the areas in question (*e.g.* analgesia practice, airway management physiology) represent clinical arenas in which GEMS practice is identified as sometimes lacking.[154] For example, California data show that even after GEMS ETI at trauma scenes, brain-injured patients have better outcomes with HEMS (rather than GEMS) transport.[155]

Case reports, opinion pieces, and surrogate-outcome studies that don't actually execute direct HEMS *vs.* GEMS comparisons can never provide definitive answers to the HEMS debate. However, given the absence of RCTs, these lower-level evidentiary types can occasionally be useful to those researching the HEMS question.

Meta-analysis (MA)

Execution of rigorous MA has proved challenging for HEMS researchers. There is no shortage of reviews, systematic and otherwise, but those reviews with high rigor tend to conclude that pooled effect estimates are not appropriate.[11,15,92]

When pooled effect estimates are occasionally reported, they are noteworthy for either a small *N* of studies or a high heterogeneity. noted by the authors to be limited by heterogeneity. For scene trauma, a MA[12] reported I^2 of 0% with an effect estimate of 30% mortality reduction, but the review was based on only two natural-experiment (before and after) studies.[13,146]

The CCT CORE group has executed two meta-analyses. The first,[141] addressing studies evaluating HEMS deployment using a natural experiment design, found an acceptable I^2 (43%) and estimated of HEMS-associated increase in survival as OR 1.66 (95% CI 1.23-2.22). The second,[156] focusing solely on cases with ISS at least 9 (a lower cutoff than the traditionally used ISS>15), identified high I^2 (89%) precluding pooled effect estimation; the authors noted that all six studies included in the review identified statistically significant HEMS-associated survival improvement.

An MA of HEMS for stroke, for instance, reports I^2 values of 87-92% (depending on endpoint).[157] It seems likely that as HEMS evidence improves in quality (and MA techniques are further refined), MA may become more of an option for at least some diagnostic populations. Additionally, subsets of trauma may become more amenable to meta-analysis. In 2024, Enomoto published a meta-analysis of HEMS use in pediatric trauma. The Japanese found that HEMS was associated with significant outcomes improvement when used for injured children (OR 1.5, 95% CI 1.4-1.7).

The Enomoto results were not changed in sensitivity analyses that included physician *vs.* non-physician crew configuration. With the *caveats* that attend defining crew capabilities based on credentials rather than practice scope, it is noted that Lavery published a 2025 MA (of 23 articles) concluding that physician-crewed response (often by HEMS) improved outcome (pooled adjusted effect estimate 1.49, 95% CI 1.31-1.69) as compared to paramedic-only prehospital care for the ill or injured.[158]

Section 3: HEMS literature

In an early (pre-2000) iteration of this monograph, this section's stated aim was to serve as a collection point for all English-language HEMS outcomes studies. The state of the evidence was such that outcomes studies were not easy to find, so there was utility in annotated bibliographies. More recently, the growth of the HEMS literature and the ease of internet-based evidence access have rendered bibliography preparation more difficult and less necessary.

Despite ready availability of comprehensive internet-based evidence retrieval, there remains a potential role for the assembly of key studies in one place. With the passage of time, evidentiary accumulation and statistical (MA) evolution are rendering MA more tenable. While inherently non-comprehensive (and inevitably subjective) the collection of HEMS outcomes studies in this monograph may be useful to as a time-saver for HEMS researchers.

With *caveats* acknowledged, this section of the monograph is offered as an overview of selected HEMS outcomes studies. Within each diagnostic group, older studies are listed first. For reasons of space, only the first author's last name is listed, along with the publication year. Each paper's full citation is provided in the reference section.

Mixed-diagnosis patient populations

This subsection includes some well-known studies, and some lesser-known but arguably important publications, that address outcomes in a general population of HEMS transports. The catch-all nature of the diagnostic groups largely precludes meaningful HEMS *vs.* GEMS outcomes comparisons, but there are useful lessons in these studies.

Karper (1991) Ambulance helicopters in the mountains. An evaluation of the 1-year activity at the Dombas base; *Tidsskr Nor Laegeforen* [159]

HEMS panel-review methodology of a year (242 missions) of HEMS work in interior Norway. There was judged some outcome improvement in 15% scene and 33% IF cases, at a cost of 10 million NOK. With assessment of 13 lives saved, the cost per life saved (not cost per QALY) of about $75000 was judged by the authors to be too high to support HEMS.

Kee (1992) Interhospital transfers by helicopter: the first 50 patients of the Careflight project; *J R Soc Med* [160]

Panel review determined 28% of the HEMS flights would not have been able to be transported by ground. Additionally, in looking at an acuity group (sickness score exceeding 18) with expected 0% survival in the case of GEMS transport, HEMS allowed 50% survival.

Lindbeck (1993) Aeromedical evacuation of rural victims of non-traumatic cardiac arrest; *Ann Emerg Med* [161]

The authors, while highlighting logistics advantages to rural HEMS utilization (*e.g.* improved availability of ALS in less-populated settings), make a strong argument against HEMS benefit for patients in arrest at time of HEMS activation.

Arfken (1998) Effectiveness of helicopter versus ground ambulance services for interfacility transport; *J Trauma* [162]

Comparing HEMS *vs.* GEMS outcomes in a diagnostically disparate population is difficult. Due to the methodologic challenges (*e.g.* use of a non-validated scoring system to generate pooled acuity estimates), the authors acknowledge strong possibility that their negative findings were confounded by higher acuity in HEMS cases.

Werman (1999) Helicopter transport of patients to tertiary care centers after cardiac arrest; *Am J Emerg Med* [163]

As a follow-up to conclusions of Lindbeck *et al*. HEMS utilization can potentially be useful for patients who are post-arrest (*i.e.* after return of spontaneous circulation).

Gerritse (2010) Advanced medical life support procedures in vitally compromised children by a helicopter emergency medical service; *BMC Emerg Med* [164]

HEMS response to all-diagnosis pediatric cases was evaluated. The air medical crews executed HEMS-only procedures in 65%; overall, HEMS performed procedures in 78% in which HEMS is more experienced than GEMS. HEMS intubated 38% of cases; perhaps more importantly, 23% of children intubated/ventilated by GEMS required HEMS correction of potentially lethal airway/ventilation problems. HEMS also provided better analgesia.

DiBartolomeo (2014) Cross-sectional investigation of helicopter EMS activities in Europe: a feasibility study; *Scientific*

World J [165]

The "feasibility" part of this study was assessment of a European (11 countries) research network. A single day's HEMS transports were assessed by an expert panel. The judgment was that HEMS was associated with major decrease of death risk in 47% of cases, with possible decrease in additional 22%. Earlier and faster transport were the main mediators of improved outcome, since most patients were time-critical diagnoses (cardiac 36%, trauma 36%); it was also noted that ETI (which was performed in 25% of cases) was usually not an option without HEMS.

<u>Peters (2014)</u> First-pass intubation success rate during rapid sequence induction of prehospital anaesthesia by physicians versus paramedics; *Eur J Emerg Med* [166]

This unique approach compared ETI success by GEMS and HEMS, on the same patient set, with the same medications. The HEMS crews arrived and supervised GEMS' initial ETI attempts (under rapid sequence induction medications administered by HEMS). If GEMS ETI failed, flight crews attempted ETI. The authors averred that physicians bring added expertise to the scene of the critically ill or injured patient requiring airway management; the helicopter was simply the mechanism by which physicians got to the patient. Given literature that increasingly stresses importance of first-pass ETI (in order to minimize physiologic derangement and other risks attendant to airway management), there is clinical import to the authors' finding of HEMS crew first-pass ETI success rates nearly double those of GEMS (84.5% versus 46.5%).

<u>Aiolfi (2018)</u> Air versus ground transportation in isolated severe head trauma: A National Trauma Data Bank study; *J Emerg Med* [167]

Improved TBI outcome regardless of AIS; HEMS improved survival overall (OR 0.55) and in all three AIS strata from serious/3 through severe/4 and critical/5 (3, OR .35; 4, OR .44; 5 OR .76).

<u>Osteras (2018)</u> Outcomes after cancelled HEMS missions due to concurrencies: a retrospective cohort study; *Acta Anaesthesiologica Scand* [150]

Assessing HEMS-requested cases, for which some went by GEMS (due to HEMS unavailability), the authors found that HEMS appeared to improve outcome in the patients of higher acuity ("more likely threat to life" as assessed by physiologic scoring). The overall mortality was the same for HEMS and GEMS; given the findings that HEMS patient acuity was far higher (HEMS rate of "threat to life" cases was nearly triple that of GEMS) the finding of equal outcome should not be taken as demonstration of no transport-associated outcome effect. The chance of residual confounding is increased by the report that in subset analysis of higher-acuity cases (NACA 5-6), HEMS cases had significantly lower mortality (per Breslow testing of Kaplan-Meier curve).

<u>Zakariassen (2019)</u> Loss of life-years due to unavailable HEMS: a single base study from rural Norway; *Scan J Primary Health Care* [168]

An expert panel assessed scene and interfacility transports, assigning life-years' loss due to HEMS unavailability. HEMS loss was associated with loss of life-years in 0.2% of cases (18 life-years lost in four years of missed transports).

<u>Risgaard (2019)</u> Impact of physician-staffed helicopters on pre-hospital patient outcomes: a systematic review; *Acta Anesth Scand* [15]

The authors focused on what outcomes benefit may be associated with HEMS staffed by doctors. They identified 18 studies, and concluded that despite too much heterogeneity for formal meta-analysis there was "possible survival benefit of physician-staffed HEMS."

<u>Alstrup (2021)</u> Association of helicopter *vs.* ground emergency medical transportation with 1-year mortality in Denmark; *JAMA Network Open* [149]

Taking advantage of an excellent population-based follow-up in Denmark, the authors assessed vital status one year post-transport, for all-diagnosis HEMS *vs.* GEMS. Point estimates for mortality hazard ratios were slightly, but not statistically significantly, lower for HEMS for the overall group (0.94, 95% CI .84-1.06) and for a pre-planned subgroup analysis focusing on those with highest acuity (0.91, 95% CI 0.73-1.14).

<u>Joseph (2022)</u> Helicopter versus ground ambulance transport for interfacility transfer of critically ill children; *Am J Emerg Med* [169]

Using a natural experiment approach (GEMS cases were those for whom HEMS was requested but declined), the authors reported HEMS association with savings in transport time (143 *vs.* 289 minutes, p <.001); mortality was lower but the difference was non-significant (OR 0.84, 95% CI 0.40-1.84, p = .65).

Wothe (2022) & Olson (2024) Outcomes of patients undergoing interfacility ECMO transfer based on cannulation location and mode of transport; *Crit Care Explor* [170] & Outcomes of interfacility VV-ECMO transfers; *ASAIO J* [171]

This observational case series of V-V ECMO patients assessed whether transport mode (air *vs.* ground) was associated with either complications or in-hospital mortality. The University of Minnesota group found that HEMS and GEMS were equally viable options for ECMO transport. Updated results from the Minnesota group, published in 2024, continued to suggest safety of both modes of transport for V-V ECMO; cannula complications and some post-transport issues were less common (in the 2024 report) with HEMS but overall outcomes were similar.

Trauma: *Scene response*

The main spur for HEMS development in many countries was the concept of scene response to injured patients. Largely because of the sizeable databases maintained around the world in trauma registries, much of the HEMS literature focuses on trauma, and most of these studies focus on scene response.

Baxt (1983) The impact of rotorcraft aeromedical emergency care service on trauma mortality; *JAMA* [73]

Perhaps the landmark study in HEMS and trauma mortality was this TRISS-based calculation of HEMS mortality effect as compared to outcomes from GEMS cases transported to the same center. Dated ground unit capabilities (*e.g.* use of esophageal obturator airways) may limit the study's current applicability, but such limitations do not completely negate the study results: in most locations contemporary HEMS crew capabilities remain more advanced than those of GEMS.

Baxt (1985) Hospital-based rotorcraft aeromedical emergency care services and trauma mortality: A multicenter study; *Ann Emerg Med* [172]

Baxt followed his single-center analysis (#1 above) with a seven-site multicenter study. HEMS improved outcomes in all seven locations – 21% overall mortality reduction – with statistical significance achieved in five. There was no GEMS control group (TRISS-estimated mortality was the control); it was thus difficult to identify incremental contributions of HEMS in well-functioning trauma systems.

Urdaneta (1987) Role of an emergency helicopter transport service in rural trauma; *Arch Surg* [173]

This panel review study classified HEMS' utility for rural trauma. The study found that HEMS was essential in 14.0%, helpful in 12.9%, and "not a factor" in 56.6% of patients (a fourth category included patients who died despite the delivery of maximal emergency medical care).

Schiller (1988) Effect of helicopter transport of trauma victims on survival in an urban trauma center; *J Trauma* [174]

Despite substantial potential for residual confounding by acuity differences (*e.g.* HEMS patients' GCS was lower than that of the ground group), the authors made a cogent argument that HEMS has little mortality impact when used in an urban area with rapid GEMS times.

Schwartz (1990) A comparison of ground paramedics and aeromedical treatment of severe blunt trauma patients; *Conn Med* [175]

For these Connecticut cases with severe injury, TRISS methods were applied. HEMS was estimated to account for an estimated 5 lives saved per 100 cases.

Nardi (1994) Impact of emergency medical helicopter service on mortality for trauma in north-east Italy: A regional prospective audit; *Euro J Emerg Med* [176]

In the region where this analysis was conducted, HEMS practice levels were well beyond those of responding GEMS (*e.g.* ETI occurred in 81% of HEMS patients and virtually none of the GEMS cases). To the extent that its regional prehospital capability characteristics are generalizable, the study shows HEMS can improve mortality in situations where ground EMS capabilities are limited or widely dispersed.

Nicholl (1995) Effects of London helicopter emergency medical service on survival after trauma; *BMJ* [177]

This oft-cited study was quite complex, in large part because of trauma system issues that were beyond the control of the authors. For instance, the study discarded most transports to trauma centers and instead found that HEMS transports to non-trauma hospitals was not associated with improvement in outcome. The study's outcomes validity is questioned by the subsequent finding of Younge *et al* (reference 7 below) of the inappropriateness of using unadjusted TRISS (as was done by these authors) in the U.K. population. Younge's study actually included the cases analyzed in this earlier report (as well as many other cases), but in using the statistically appropriate *Ws* statistic Younge found

HEMS transports to trauma centers improved outcome.

Celli (1997) Severe head trauma: review of factors influencing the prognosis; *Minerva Chir* [178]

This analysis of HEMS' effect on cases with TBI used a non-HEMS control group that included both ambulance and other modes (*e.g.* police). The authors found that HEMS provided more prehospital interventions and improved outcomes (20% mortality *vs.* 54% mortality by non-HEMS). The authors attributed improved outcomes to improved physiology as manifest by significantly lesser problems with uncontrollable increased intracranial pressure.

Cunningham (1997) A comparison of the association of helicopter and ground ambulance transport with the outcome of injury in trauma patients transported from the scene; *J Trauma* [137]

In analyzing a large group of low-acuity cases, low *n* of mid- and high-acuity patients limits the power of attempts to find whether HEMS impacts outcome. In all eight of the subgroups in the mid-range of injury acuity (TS 5-12 and ISS 2-40), HEMS was associated with survival improvements, but the difference was only significant in two of these subgroups. The authors' conclusions – that low overall acuity meant need for improved triage – were reasonable. However, having spent years as a flight physician in the rural North Carolina setting of this study (Dr. Cunningham was a respected mentor), this monograph's author was left wishing there were more discussion of the realities related to limited regional GEMS coverage (*e.g.* using HEMS service to quickly get ALS to an isolated patient, or to prevent an area's losing ALS response during long-distance ground transport).

Younge (1997) Interpretation of the W_s statistic: Application to an integrated trauma system; *J Trauma* [179]

Complexity may account for the infrequency with which this excellent work is cited. The authors, determining that *M* statistic assessment rendered uncorrected TRISS inappropriate for London HEMS data (see Nicholl paper, above), found HEMS resulted in 4 excess survivors per 100 patients. Survival benefit could have been due to HEMS, receiving facility characteristics, or some combination of the two.

Cocanour (1997) Are scene flights for penetrating trauma justified?; *J Trauma* [113]

Artificially calculated metropolitan ground transport times are frequently used in HEMS studies, but the method warrants particular justification – absent in this report from Houston – when employed in a city well-known for traffic snarls. The study's authors also failed to acknowledge potential outcomes impact related to their own clinical findings (*e.g.* HEMS crew ETI in cases of failed GEMS airway management). HEMS crew provided care outside GEMS responders in 4.9% of patients overall (2.5% for ALS; 6.7% for BLS). The authors concluded that HEMS should be used only when critically injured patients were likely to require advanced interventions, or when HEMS response could hasten arrival at the receiving TC. The lack of certainty over identifying these preceding conditions may limit the otherwise intuitive conclusion that HEMS utility is usually low in inner-city areas.

Abbott (1998) Aggressive out-of-hospital treatment regimen for severe closed head injury in patients undergoing air medical transport; *Air Med J* [180]

In this study based in San Diego County, TBI cases were matched with GEMS controls. HEMS decreased mortality 11%, also (for survivors) HEMS more likely to discharge to rehab rather than extended-care facilities.

Brathwaite (1998) A critical analysis of on-scene helicopter transport on survival in a statewide trauma system; *J Trauma* [181]

Effect modification is demonstrated in a multivariate logistic regression reporting HEMS effects on survival vary with ISS level. There was no mortality benefit for the lowest (ISS <15) or highest (ISS >61) strata of injury acuity, but for the other three groups HEMS was associated with a 2.1-2.6x increase in survival likelihood. HEMS won't help the trivially or mortally injured.

Jacobs (1999) Helicopter air medical transport: ten-year outcomes for trauma patients in a New England program; *Conn Med* [182]

HEMS mortality reduction was found to be 13% in this Connecticut study. The survival improvement occurred in the midrange of acuity: Trauma Score stratification identified 35% reduction in mortality for TS 4-13 with no HEMS benefit at TS extremes.

DiBartolomeo (2001) Effects of two patterns of prehospital care on the outcome of patients with severe head injury; *Arch Surg* [183]

The authors' thoughtful discussion of their negative results from this analysis of TBI outcome for patients receiving basic life support *vs.* advanced/HEMS response included acknowledgment of confounding. Interestingly, the study's TBI-centered results are inconsistent with overall trauma mortality results from a previous paper published by the same group (Nardi, above).

Oppe (2001) The effect of medical care by a helicopter trauma team on the probability of survival and the quality of life of hospitalised victims; *Accident Analysis & Prevention* [184]

In the Netherlands, GEMS transport from the scene is often quick; HEMS is used to transport an experienced physician-nurse team to the trauma scene whence patients are taken to trauma centers by ground (with the HEMS team often in attendance). The Dutch HEMS system, assessed in Rotterdam by these authors, has been consistently found to have significant positive impact on outcome. This study identified a 17% benefit for HEMS use in blunt trauma.

Chappell (2002) Impact of discontinuing a hospital-based air ambulance service on trauma patient outcomes; *J Trauma* [142]

Selection bias crippled this natural experiment, in which investigators found that loss of HEMS from their center was associated with decreases in both acuity and prehospital times. The study failed to track outcomes for patients in the post-HEMS era, who were not transported to the regional trauma center (and instead died at the scene or rural hospital). Mann executed the same study design (but with markedly improved methodology to eliminate selection bias) and produced much more reliable – oppositely directed – results.

Shatney (2002) The utility of helicopter transport of trauma patients from the injury scene in an urban trauma system; *J Trauma* [185]

In one of the more unusual exercises in GEMS time estimation, two physicians teamed with a nurse and a retired paramedic to estimate GEMS transport times for cases stretching back over a decade in an often-congested urban area (the south part of San Francisco Bay). Although the time savings conclusions were thus questionable, the study's finding that HEMS cases benefited a maximum of 23% of patients resonated with what would be expected in an area that had no HEMS triage guidelines. The authors underlined the importance of cooperation of air and ground EMS agencies and their medical directors, with respect to generating policies guiding appropriate dispatch of air medical resources.

Frankema (2004) Beneficial effect of helicopter emergency medical services on survival of severely injured patients; *Brit J Surg* [186]

In another contribution from the Dutch (see preceding reference by Oppe *et al*), this prospective assessment of their model of HEMS scene response with subsequent GEMS transport found mortality benefit compared to the GEMS response and transfer. HEMS was associated with a nearly three-fold survival improvement in blunt trauma patients (OR 2.8, 95% CI 1.1 to 7.5).

Wang (2004) Out-of-hospital endotracheal intubation and outcome after traumatic brain injury; *Ann Emerg Med* [28]

There are sound reasons evaluators of medical evidence are taught to be wary of conclusions that were not part of original study questions. However, especially when the investigation is methodologically rigorous, an "incidental finding" can represent useful and unbiased information. This statewide trauma registry study's objective was to evaluate prehospital ETI, not HEMS. However, the results demonstrating HEMS' association with improvements in survival and functional outcome were relevant to the HEMS debate (as noted in the accompanying editorial to the study). Prominent prehospital editorialists highlighting HEMS' positive outcomes effect pointed out that the mortality and functional outcome benefits from air transport may have been related to airway management or other factors such as speed.

Buntman (2005) The effect of air medical transport on survival after trauma in Johannesburg, South Africa; *South African Med J* [187]

There are some oddities to the study's methodology, and the usual TRISS-related concerns are present. The HEMS group survival was nearly that predicted by TRISS, whereas the GEMS group had a dozen more deaths than predicted. The direct comparison of HEMS *vs.* GEMS patients, and the fact that the multivariate analysis accounted for most (if not all) relevant confounders, support findings of a HEMS mortality benefit of 11.2 lives per 100 transports.

Davis (2005) The impact of aeromedical response to patients with moderate to severe traumatic brain injury; *Ann Emerg Med* [188]

An assessment of 15 years of scene-transported head trauma patients found that HEMS improved survival and functional outcome (OR 1.9, 95% CI 1.6 to 2.3). Subgroup analyses yielded significant outcome improvements for patients with head AIS 3 (OR 1.9, 95% CI 1.2 to 3.0), AIS 4+ (OR 1.7, 95% 1.4 to 2.0), and GCS between 3 and 8 (OR 1.8, 95% CI 1.5 to 2.2). There was no statistically significant improvement for patients with higher GCS scores, but the point estimates were in favor of HEMS for both groups and the wide 95% CIs (indicating low power) were predictable given low mortality in such patients. Prehospital ETI by HEMS crews was found to improve outcome as compared with ED ETI (OR 1.4, 95% CI 1.1 to 1.8) whereas prehospital ground EMS ETI worsened outcome. The ETI findings lay a solid foundation for an argument that some of HEMS' survival benefit in TBI is mediated by airway management.

Davis (2005) A follow-up analysis of factors associated with head-injury mortality after paramedic rapid sequence intubation; *J Trauma* [155]

In a follow-up study to earlier work assessing peri-ETI physiologic parameters, the UCSD group assessed the impact of HEMS *vs.* GEMS transport of TBI patients undergoing scene ETI (which was performed mostly by GEMS, even for HEMS-transported cases). HEMS was a predictor of survival, and also was associated with 40% improved odds of discharge (to home or rehabilitation facility). The authors judged that outcome improvement was due to less frequent inadvertent hyperventilation in HEMS TBI cases.

Frink (2007) The influence of transportation mode on mortality in polytraumatized patients: An analysis based on the German Trauma Registry; *Unfallchirurg* [189]

Although the study's focus (ISS >15 cases transported with a physician in attendance) limits generalization, there was an important lesson about over-focus on the surrogate outcome of time savings in trauma. Compared to GEMS, HEMS took longer to get to the scene (18 *vs.* 14 minutes) and stayed longer on the scene (26 *vs.* 22 minutes). However, TRISS analysis found HEMS was associated with improved outcomes. Airway management may have been responsible: despite similar ISS for GEMS and HEMS cases, ETI was much more common (80% *vs.* 60%) in the HEMS group.

Davis (2008) Air medical response to traumatic brain injury; *J Trauma* [152]

In one of the only artificial neural network analyses in the HEMS evidence base, the UCSD group assessed impact of air transport on outcome of patients with head AIS at least 3. The authors found that, in a number of modeling approaches, air medical response to head-injured patients was consistently associated with improvement in outcome. The outcome benefit was even more concentrated in patients with more critical injuries.

Ringburg (2009) HEMS: Impact on on-scene times; *J Trauma* [112]

Published a few years after Frink's study (see above), the Dutch confirmed that HEMS response may offer advanced on-scene interventions that justify prehospital time prolongation. After the initial univariate analysis confirmed the notion that prolongation of on-scene times increases mortality, the authors found that the outcomes detriment due to longer on-scene times was completely reversed when HEMS was present. The study conclusion was that early interventions from the HEMS crews allow "golden-hour" assessments and procedures to be completed long before trauma center arrival.

Talving (2009) Helicopter evacuation of trauma victims in Los Angeles: Does it improve survival?; *World J Surg* [190]

HEMS deployment based solely on GEMS time (30 minutes) and ACS triage criteria was found to be associated with significant helicopter overuse in southern California. Point estimates for HEMS' mortality benefit are positive but not statistically significant; associated CIs are wide due to a very low number of total endpoints (just 36 deaths). The low *n* of deaths also calls into question appropriateness of the authors' 12-covariate regression model; the rule of thumb is a maximum of one covariate for each 10-15 outcomes.

Berlot (2009) Influence of prehospital treatment on the outcome of patients with severe blunt traumatic brain injury: A single-centre study; *Euro J Emerg Med* [111]

Consistent with previous European reports (see above) that HEMS prolongation of on-scene time doesn't result in worse outcomes, this Italian group found longer on-scene times for HEMS *vs.* GEMS cases with ISS >14 and head AIS >3, but also found HEMS to be associated with lower overall mortality (21% *vs.* 25%) and more likely survival with zero or minor impairment (54% *vs.* 44%). The authors concluded that reduction in time to advanced care contributed to improved outcome. The study identified reduction in secondary brain injury (*e.g.* due to better airway and hemodynamic management) as the major mechanism by which HEMS transport resulted in better neurological outcomes.

Brown (2010) Helicopters and the civilian trauma system: National utilization patterns demonstrate improved outcomes after traumatic injury; *J Trauma* [191]

The National Trauma Data Bank (NTDB) has served as a data source for roughly a dozen HEMS outcomes studies; this was one of the first (and best). With large numbers (HEMS *n* 41,987, GEMS *n* 216,400) the authors were able to adjust for many factors in modeling that identified a 22% mortality benefit associated with HEMS scene transport. The study study's broad array of covariates included age, sex, insurance status, mechanism of injury, prehospital times (calculated for HEMS due to straight-line travel and assuming 150 mph transport speed; unavailable for GEMS), ISS, GCS, admission systolic blood pressure and respiratory rate, hospital and ICU admission and length of stay, mechanical ventilation duration, ED and hospital disposition, and hospital trauma center designation. In addition to the outcomes advantage, significant findings included high acuity for HEMS patients nationwide (nearly half requiring ICU, a fifth intubated for an average of a week, a fifth requiring urgent operative intervention); the authors wrote that "On a national level, patients being selected for HEMS are appropriately sicker and are more likely to use trauma center resources than those transported by ground ambulance." The study also found, in terms of triage, that ISS dropped off only as distance from the trauma center increased -- so HEMS is being appropriately used to get patients in timely fashion, to trauma centers, for logistics reasons when this is necessary. The study reported another counter-argument to "overutilization" charges: <15% of HEMS patients nationwide, were discharged within 24 hours.

Sullivent (2011) Reduced mortality in injured adults transported by HEMS; *Prehosp Emerg Care* [192]

In a Centers for Disease Control (CDC) analysis of the 2007 NTDB data, the overall *n* was slightly different from that of Brown (which also looked at NTDB during a similar time frame) due to differing methodology (*e.g.* restriction of analysis to adults with stringent exclusions for missing values). Multivariate logistic regression adjusting for age, gender, ISS, and RTS identified a 39% reduction in mortality associated with HEMS. As compared to the Brown, the more-stringent threshold for data availability probably contributed to the CDC group's finding of a greater mortality benefit than had been reported by Brown; missing variables probably bias studies against HEMS.[193]

Stewart (2011) Association of direct helicopter versus ground transport and in-hospital mortality in trauma patients: A propensity score analysis; *Acad Emerg Med* [139]

Propensity scoring is an important technique to allow for covariate-pattern balancing; the method can control confounding of treatment selection (*i.e.* HEMS deployment). In one of the earliest reports using HEMS propensity-score modeling, this population-based assessment from Oklahoma found a 33% reduction in mortality associated with HEMS scene response.

Bulger (2012) Impact of prehospital mode of transport after severe injury: A multicenter evaluation from the Resuscitation Outcomes Consortium; *J Trauma* [194]

In a secondary analysis of patients in a hypertonic saline study, there were no HEMS-associated differences in outcomes for TBI or shock cases. The study was not powered for a transport mode endpoint and there was inadequate adjustment for confounders such as transport distance, study site (there were 10 centers), or varying levels of prehospital care. On the one hand, the finding of "no outcomes difference" was the take-home message of the discussants providing the commentary accompanying the paper. On the other hand, those who believe HEMS may improve outcome can highlight the fact that deployment of HEMS to patients who were far more seriously injured and much further from receiving centers, allowed equalization of mortality for closer-in cases with less acuity. TRISS calculations predicted significantly worse survival for HEMS patients in two of the three study cohorts (Shock+TBI and TBI only), but in both of these cohorts the actual survival was similar for HEMS and GEMS patients. The authors concluded that HEMS may overcome limitations of distance and access to specialty care.

Galvagno (2012) Association between helicopter *vs.* ground emergency medical services and survival for adults with major trauma; *JAMA* [195]

There are few HEMS outcomes studies in the flagship journals of medicine; this NTDB analysis was characterized by methodological rigor expected in a JAMA study. In a quarter-million ISS >15 cases from the 2007-2009 NTDB, investigators from Maryland used multiple approaches to address issues with data quality, confounding, and propensity for HEMS use. Every model found association between HEMS and outcome; the most conservative OR estimates were 1.16 (NNT 65) for patients taken to Level I centers and 1.15 (NNT 69) for patients at Level IIs. The authors averred that in addition to the mortality findings, there were likely other unmeasured but potentially important HEMS benefits. The study data did not allow for adjustment for crew characteristics, logistics factors, or prehospital interventions. Given the broad readership of JAMA, it was useful that the authors pointed out the impossibility of predicting at the time of triage, which patients would meet their study's ISS inclusion criterion; the point is all too frequently elided in discussions of HEMS overuse.

de Jongh (2012) The effect of HEMS on trauma patient mortality in the Netherlands; *Injury* [138]

Methodologic challenges account for the relative infrequency with which matching studies are seen in the EM literature. One of the major barriers, overcoming residual confounding, likely combined with low power to contributed to the negative findings from one of the only Dutch trauma studies failing to identify a HEMS benefit. The OR point estimate for HEMS was actually favorable (0.8) despite residual confounding by higher HEMS injury acuity (measured by RTS), but the wide CI crossed the null value.

Desmettre T (2012) Impact of emergency medical helicopter transport directly to a university hospital trauma center on mortality of severe blunt trauma patients until discharge; *Critical Care* [196]

Staffing models for this French study setting included physicians in both HEMS and GEMS, but flight physicians came with trauma center experience that translated into more aggressive care in terms of ETI and blood transfusion. In analyzing 1958 scene-transported injured adults who required ICU admission within 72 hours of injury, the authors found HEMS was associated with significantly decreased mortality odds (OR 0.68, 95% CI 0.47-0.98, p = .035).

Rose (2012) Is helicopter evacuation effective in rural trauma transport?; *Amer Surg* [197]

Stratifying cases by mean distance from trauma center and ISS, Alabama authors found no HEMS mortality improvement. Minimal descriptive or analytic statistics as well as lack of consideration of confounders (*e.g.* crew expertise, prehospital interventions, injury types, physiologic data) severely restrict the ability to judge this study's contribution to the evidence base.

Ryb (2013) Does helicopter transport improve outcomes independently of emergency medical system time? *J Trauma* [198]

The 2007 NTDB cases with ISS and RTS availability were assessed by these investigators, who repeated the findings of other analyses of similar datasets (this study's mortality OR for GEMS was 1.78). HEMS benefit was identified for all injury severity levels, although subgroup analysis suggested that HEMS actually worsened outcome for patients who were more physiologically unstable (defined by RTS).

Kleber (2013) Trauma-related preventable deaths in Berlin 2010: need to change prehospital management strategies and trauma management education; *World J Surg* [199]

This Berlin group examined all trauma deaths in their metropolitan area for a year, assigning them categories as non-preventable, probably preventable, or definitely preventable. HEMS was associated with 0% rate of either the probably or definitely preventable deaths; GEMS transported 14 definitely preventable and 51 probably preventable deaths (p <.001).

Andruszkow (2013) Survival benefit of helicopter emergency medical services compared to ground emergency medical services in traumatized patients; *Critical Care* [200]

The definition of ISS >15 as indicating severe injury is so common that a HEMS analysis using a lower cutoff is noteworthy. When inclusion in HEMS analysis was set at ISS at least 9, these German investigators assessing three years of German Level I/II trauma center data (8231 GEMS and 4989 HEMS) found a 25% HEMS mortality reduction. The study thus contributes to the case for lowering the ISS cutoff at which HEMS should be judged potentially useful. Besides its inclusion of patients with "less severe" ISS, noteworthy aspects of the study included the fact that the results remained the same regardless of trauma center level, and the fact that prehospital care attendants were physician-level in both HEMS and GEMS cohorts. HEMS patients were more likely to receive aggressive interventions of endotracheal intubation, thoracostomy, and/or hemodynamic support.

Giannakopoulos (2013) Helicopter Emergency Medical Services save lives: Outcome in a cohort of 1073 polytraumatized patients; *Eur J Emerg Med* [132]

Like other Dutch studies, the study demonstrated substantial HEMS survival benefit. Focusing on patients with ISS >15, analysis found that while GEMS patients had TRISS-predicted survival HEMS-attended cases showed an excess 5.4 survivors per 100 deployments.

Abe (2014) Association between helicopter with physician versus ground EMS and survival for adults with major trauma in Japan; *Critical Care* [17]

For Japanese National Trauma Data Bank cases with ISS >15, investigators using propensity scoring, conditional logistic regression, and multiple-model testing found HEMS reduced mortality by 23%.

Andruszkow (2014) Ten years of HEMS in Germany: Do we still need the helicopter rescue in multiple traumatized patients? *Injury* [201]

This nationwide study demonstrated HEMS improved outcome by a 14% margin that was stable over a decade of transport. Over that same decade, major trauma incidence was unchanged but HEMS use declined by 1.6% each year; the authors expressed concern that HEMS was being underused.

Missios (2014) Transport mode to level I and II trauma centers and survival of pediatric patients with traumatic brain injury; *J Neurotrauma* [202]

Investigators assessing NTDB data used propensity-scored multivariate modeling to assess HEMS' association with outcome in children with TBI (3,142 HEMS and 12,562 GEMS). Park

Bekelis (2015) Prehospital helicopter transport and survival of patients with traumatic brain injury; *Ann Surg* [203]

Adding to literature that makes a compelling case for HEMS' potentially improving outcome in TBI cases, this NTDB study of nearly 210,000 cases found HEMS nearly doubled chances of post-TBI survival (OR 1.8 with *W* of 5).

Garner (2015) The Head Injury Retrieval Trial (HIRT): A single-centre randomized controlled trial of physician prehospital management of severe blunt head injury compared with management by paramedics only; *Emerg Med J* [10]

This superbly designed trial took years of planning, and it would be difficult to imagine how it could have been executed with better foresight. Unfortunately, the reluctance of GEMS providers to allow patients to be randomized away from HEMS virtually eliminated elucidation of outcomes lessons: the study accrued nowhere near the thousands of cases needed for sufficient power given the expected HEMS impact. The authors' intent-to-treat (ITT) analysis – while favoring HEMS – was underpowered and the results were non-significant. The approach to report "as-treated" data was the authors' only analytic option, but these positive results (HEMS mortality improvement of 16% with NNT of 6) are subject to criticism as being post-hoc. For some observers, this study appears to be the nail in the coffin for the idea of large-scale trials hoping to randomize cases to HEMS or GEMS.

Greenberg (2015) Ankle fractures and modality of transport at a Level I trauma center: Does transport by helicopter or ground ambulance influence the incidence of complications?; *J Foot Ankle Surg* [204]

For those who felt the need for an analysis as to whether HEMS offered benefit to patients with isolated foot and ankle injuries, here it is, done well and including a full decade of experience. HEMS doesn't improve outcomes in such patients.

den Hartog (2015) Survival benefit of physician-staffed HEMS assistance for severely injured patients; *Injury* [205]

In a registry-based observational study this Dutch group found clear benefit from HEMS response to patients with ISS at least 15. The 3-year study included 1495 GEMS cases and 681 with HEMS assistance. In a multivariate model the authors found that HEMS assistance resulted in an additional savings of 5.3 lives per 100 cases.

Kim (2015) Effective transport for trauma patients under current circumstances in Korea; *J Korean Med Sci* [206]

Korea's developing trauma system utilizes HEMS for both logistics and as a means to get advanced prehospital physicians to trauma scenes. The relatively small study (HEMS *n* = 79, GEMS *n* = 1547) found a significant HEMS outcomes improvement. Using TRISS methods the authors reported a HEMS *W* of 6.7 as compared to GEMS *W* of -0.8 (*i.e.* HEMS *W* differential from GEMS of 7.5 translating to NNT of 13.3).

Shaw (2016) It's all about location, location, location: A new perspective on trauma transport; *Ann Surg* [207]

This interesting analysis began with a broadly sweeping (and broadly incorrect) statement that "previous studies have not adjusted for the time and distance that would have been traveled had a helicopter not been used." The authors took a novel approach that assessed a decade of an institutional trauma registry's scene-transported patients to determine the impact of geography on outcome. HEMS patients had higher crude mortality (4.1% *vs.* 1.9%) but HEMS was associated with 30% mortality reduction in models that controlled for non-geographic covariates. However, when geographic covariates were included in the model the benefit associated with HEMS disappeared. HEMS patients were not too low in acuity – only 12% of the air cohort was hospitalized <24 hours. The authors offered the possibility that any HEMS benefit was actually offset by delays in helicopter response and getting to the patient.

Ahmed (2016) Survival of trauma victims transported by helicopter who required cardiopulmonary resuscitation within the first hour of hospital arrival; *South Med J* [208]

In another NTDB analysis (years 2007-2010), the author took an unusual approach of defining the study cohort as patients suffering cardiac arrest within an hour of trauma center arrival. There were substantial casemix differences (*e.g.* blunt *vs.* penetrating mechanism, ISS) between HEMS and GEMS; propensity score methods were used to adjust for these differences with a subsequent finding of absolute mortality reduction of 1%.

Tsuchiya (2016) Outcomes after helicopter versus ground EMS for major trauma – propensity score and instrumental variable analyses: a retrospective nationwide cohort study; *Scand J Trauma Resusc Emerg Med* [140]

In a large-scale analysis of Japan's national data bank cases with ISS >15, the authors used a variety of methodological approaches, all of which yielded similar HEMS-favorable results. Significant difference in mortality was identified in the propensity score model (*W* 2.3), as well as an inverse probability of treatment model (*W* 3.9) and an instrumental variable model (*W* 6.5).

Andruszkow (2016) Impact of HEMS in traumatized patients: Which patient benefits most?; *PLoS One* [209]

In a large German trauma registry analysis of over 50,000 cases (16,000 HEMS), HEMS was associated with 19% mortality reduction. The study joins the growing evidence base using an ISS cutoff lower than the traditional 15, to define severe injury and study inclusion. In fact, the investigators emphasized HEMS was actually most beneficial in their low-ISS (9-15) cases, for which the OR was .66. HEMS was also found to be notably effective for mortality reduction in patients older than 55 (OR 0.62).

Buchanan (2016) Does mode of transport confer a mortality benefit in trauma patients? Characteristics and outcomes at an Ontario Lead Trauma Hospital; *CJEM* [129]

In another departure from the standard ISS >15 cutoff to define severe injury, this registry-based observational assessment included cases with ISS >11 (387 HEMS and 2759 GEMS) transported to the same receiving center over nearly two decades. As compared to mortality predicted by TRISS-L (a modification intended to reduce bias from prehospital ETI) the authors found HEMS to be associated with 5.2 fewer deaths per 100 transports. As compared to predicted, GEMS was associated with 1.4 extra deaths per 100 transports. The *W* differential of 6.6 (translating to NNT 15.2) is noteworthy for its applicability to cases with ISS at least 12.

Brown (2016) Helicopter transport improves survival following injury in the absence of a time-saving advantage; *J Trauma* [23]

In an NTDB analysis covering 2007-2012 transports, the Pittsburgh group stratified transport times in 5-minute increments, and used propensity score techniques to adjust for confounders. HEMS was found to have a survival benefit for prehospital transport times ranging from 6 to 30 minutes; the benefit ranged (depending on time stratum) between 46% and 80% increase in survival odds.

Brown (2016) Helicopters and injured kids: Improved survival with scene air medical transport in the pediatric trauma population; *J Trauma* [210]

In an NTDB analysis, this group focused on pediatric cases (<16 years of age). Propensity-score analysis of 25,700 HEMS-GEMS case pairings identified a 28% reduction in mortality. Subgroup analysis focusing on cases with transport time >15 minutes confirmed HEMS benefit (survival OR 1.72, 95% CI 1.26-2.36).

Polites (2017) Mortality following helicopter versus ground transport of injured children; *Injury* [211]

More NTDB analysis, this time on injured children, confirmed that HEMS saves lives in children with severe injuries (ISS at least 15, OR .66) but doesn't impact mortality in less-severe cases. The absolute mortality reduction from 11.1% to 9.0% corresponded to a 19% relative reduction in risk of death.

Englum (2017) Current use and outcomes of helicopter transport in pediatric trauma: A review of 18,291 transports; *J Pediatr Surg* [212]

Another NTDB pediatric trauma analysis, this time focusing on just those cases with ISS >8, transported to Level I/II pediatric centers. In propensity scoring models, HEMS improved outcome by 30% (OR 0.7), with NNT 47 to save one life.

Werman (2017) Do trauma patients aged 55 and older benefit from air medical transport?; *Prehosp Emerg Care* [213]

The group from Ohio State University assessed older trauma patients, finding mortality improvement with HEMS response. Scene transport of adults >54 years to either Level 1 or Level 2 centers had positive mortality effect (OR .60, 95% CI 0.39-0.91, p = .017).

Zhu (2017) Improved survival for rural trauma patients transported by helicopter to a verified trauma center; *Acad Emerg Med* [214]

Assessing rural Indiana cases with transport distances of 10-35 miles (which distance is reasonable for either GEMS or HEMS), these investigators assessed mortality in adults. HEMS improved survival: OR 2.69 (1.21-5.97).

Farach (2017) Helicopter transport from the scene of injury: are there improved outcomes for pediatric trauma patients?; *Pediatr Emerg Care* [215]

A single-center analysis found that HEMS did not improve mortality, but instead was associated with increased hospital LOS. The study finding, in combination with the methodology, poses questions about HEMS utility but also about the potential for residual confounding.

Chen (2018) Speed is not everything: identifying patients who may benefit from helicopter transport despite faster ground transport; *J Trauma* [216]

This propensity-score analysis of HEMS *vs.* GEMS transport identified an overall mortality increment with GEMS (OR 1.22, 95% CI 1.03-1.45, p = .02). The study included additional focus on time. HEMS improved mortality – even if pre-trauma center times were longer than those for GEMS – if and only if any of the following were present: abnormal respiratory rate, GCS <9, or hemo/pneumothorax.

Blasius (2021) HEMS and hospital treatment levels affect survival in pediatric trauma patients; *J Clin Med* [217]

The national registry-based analysis adjusted for both acuity and receiving-center trauma level (I, II, or III) in Germany (where both HEMS and GEMS responses involve physicians). Investigators identified for a group with ISS at least 9, HEMS outcome improvement OR 0.49 (95% CI 0.28-0.85).

Hakakian (2019) Analysis of transport to an ACS Level 1 trauma center; *Air Med J* [218]

Investigators from this New Jersey trauma center examined HEMS and GEMS cases, finding HEMS to have substantially higher acuity. When overall mortality was found to be similar, the authors concluded that HEMS was improving outcome.

Michaels (2019) Helicopter *vs.* ground ambulance: review of national database for outcomes in survival in transferred trauma patients in the USA; *Trauma Surg Acute Care Open* [219]

The authors focused on 2014 (*i.e.* relatively recent at the time the paper was published) NTDB cases. In a model that adjusted for numerous potential confounders, HEMS was associated with substantial mortality improvement (OR 0.43, 95% CI 0.41-0.44, p <.0001).

Moors (2019) A physician-based HEMS was associated with an additional 2.5 lives saved per 100 dispatches of severely injured pediatric patients; *Air Med J* [131]

This Rotterdam group limited assessment to pediatric scene responses in a group with ISS >15, finding W of 2.5 (*i.e.* the lives saved per 100 dispatches). Note: HEMS included a physician whereas GEMS did not. The authors appropriately used a straightforward logistic regression approach after M statistic for their data was found too low to apply TRISS.

Ageron (2020) Association of helicopter transportation and improved mortality for patients with major trauma in the northern French alps trauma system; *Scand J Trauma Resusc Emerg Med* [220]

This HEMS and GEMS group practice scopes were essentially the same (*e.g.* cohorts had same proportion of ETI cases), and found HEMS mortality benefit despite not improving time to TC: W (standardized by TRISS) of 1.8 with 95% CI 0.8-2.9), and improved mortality OR 0.70 with 95% CI 0.53-0.92. The Ageron study is noteworthy for particularly meticulous attention to statistical detail (W confirmation with M for TRISS, multiple imputation, sensitivity analysis, reporting of both discrimination and calibration for the logistic regression model).

Beaumont (2020) Helicopter and ground EMS transportation to hospital after major trauma in England: a comparative cohort study; *Trauma Surg Acute Care Open J* [221]

Finding a non-significant HEMS benefit (OR 0.85 with 95% CI 0.68-1.05), the authors concluded there was need for large datasets to identify as significant, the mortality improvement from HEMS in their area.

Enomoto (2020) Association between physician-staffed helicopter *vs.* ground EMS and mortality for pediatric trauma patients: a retrospective nationwide cohort study; *PLoS One* [222]

This Japanese group assessed Japan National Trauma Data Bank data, identifying a non-significant contribution of HEMS to mortality improvement (HEMS mortality 0.82 with 95% CI 0.42-1.58).

Nasser (2020) The impact of prehospital transport mode on mortality of penetrating trauma patients; *Air Med J* [223]

The study's authors assessed nationwide penetrating trauma data from the NTDB's database (TQIP data), and identified a mortality benefit associated with HEMS (OR 0.66, 95% CI 0.59-0,74, p <.0001). Times were not included in this analysis, so it is not clear what extent of mortality benefit was due to time savings (a report[72] from the same investigator found a 1% mortality improvement for each minute of time savings, in a study drawing cases from a similar NTDB source).

Colnaric (2020) Association between mode of transportation and outcomes of adult trauma patients with blunt injury across different prehospital time intervals in the US: a matched cohort study; *J Emerg Med* [224]

The study's goal was to stratify prehospital times, and assess whether HEMS was associated with outcomes differences. There was an overall HEMS survival benefit (96.8% *vs.* 96.2%; p = 0.002); better survival was due to improved survival in <30-minute interval (97.7% *vs.* 93.2%, p = .004); GEMS patients had higher survival in 61-90-minute group and survival was similar for HEMS and GEMS in the >90-minute group.

Colnaric (2021) Association between mode of transportation and outcomes in penetrating trauma across different prehospital time intervals: a matched cohort study; *J Emerg Med* [225]

This study was unusual in its focus (within the NTDB dataset) on penetrating mechanisms. The study's goal was to stratify prehospital times (as done in a similar paper from the same group, that addressed blunt trauma), and assess whether HEMS was associated with outcomes differences. There was an overall HEMS mortality benefit for prehospital times <60 minutes (92.5% *vs.* 87.0%, *p* = .002), that was due to benefit for 30-60 minutes (92.2% *vs.* 85.2%, *p* = .001); there was no HEMS mortality benefit for prehospital times <30 minutes or >60 minutes.

Ota (2021) The utility of physician-staffed helicopters for managing individuals who experience severe isolated head trauma; *J Rural Med* [226]

In a study with potential patient overlap with Hosomi (see below), Japan National Trauma Data Bank data for head AIS 3-5 were assessed. The HEMS survival improvement was not statistically significant (OR 1.07 with 95% CI 0.91-1.26).

Kushida (2021) A comparison of physician-staffed helicopters and ground ambulances transport for the outcome of severe thoracic trauma patients; *Am J Emerg Med* [227]

In cases with thoracic AIS at least 3, HEMS improved outcomes in this JTDB study: OR 1.69 (95% CI 1.51-1.88). (Note there is potential for case overlap with some other JTDB studies (see Ota, above).

Nabeta (2021) Comparison of physician-staffed helicopter with ground-based EMS for trauma patients; *Am J Emerg Med* [228]

In a single-center study focusing on rural cases with ISS >15, the HEMS transports were found to have four-fold the distance of GEMS cases. Therefore, when the authors found no mortality difference, they concluded HEMS was helpful.

Hosomi (2022) Association of prehospital helicopter transport with reduced mortality in TBI in Japan: a nationwide retrospective cohort study; *J Neurotrauma* [229]

This group assessed Japan National Trauma Data Bank data, focusing on head AIS of 3-5. Overall mortality benefit was similar in both classical multivariable logistic and propensity-scored logistic models: OR 0.83 (95% CI 0.74-0.92). In subgroup analyses, HEMS mortality improvement was noteworthy when severe TBI (AIS 3-5) was associated with either decreased LOC (OR 0.60, 95% CI 0.45-0.80) or very high (>50) ISS (OR 0.69, 95% CI 0.48-0.99).

Duffens (2022) Association of risk of mortality in pediatric patients transferred from the scene by helicopter with major but not minor injuries; *Pediatr Emerg Care* [230]

After adjusting for transport time – a confusing adjustment, given the uncertainty that equally rapid transport could be obtained with alternate transport mode – the authors concluded that HEMS improved mortality pediatric scene flights with ISS >15. The OR for mortality was 0.48 (95% CI 0.26-0.88, *p* = .01).

Guinzburg (2022) Association of risk of mortality in pediatric patients transferred from the scene by helicopter with major but not minor injuries; *Euro J Emerg Med* [231]

The authors used univariable analysis, thus leaving open substantial probability for residual confounding. Results were stratified by military *vs.* civilian, and by penetrating *vs.* non-penetrating mechanism. The findings included: no association between HEMS and mortality for overall analysis, or for combat/non-combat pair of stratified analyses, with HEMS improvement of mortality for penetrating (OR 0.59, 95% CI 0.34-0.98) but not non-penetrating injury (OR 0.84, 95% CI 0.43-1.52).

Elkbuli (2022) EMS transport time and trauma outcomes at an urban Level 1 trauma center: evaluation of prehospital EMS response; *Amer Surg* [232]

The study's authors concluded that HEMS was helpful, since HEMS cases had lower adjusted mortality than GEMS despite HEMS cases' having higher acuity, more hemodynamic instability, and lower transport time. However, the reported adjusted survival OR CI included the null: OR 1.17, 95% CI 0.82-1.67.

Lee (2022) Comparative study on the outcome of trauma patients transferred by doctor helicopters and ground ambulance in South Korea; *Disast Med Public Health Preparedness* [133]

A TRISS analysis used HEMS and GEMS (*vs.* TRISS, as control) cases with ISS>15. The authors calculated HEMS *W* of 9.8 (9.8% absolute reduction in mortality).

Amin (2023) Which method of transportation is associated with better outcomes for patients with firearm injuries to the head and neck?; *J Oral Maxillofac Surg* [233]

In unadjusted univariate analysis, HEMS cases (which had significantly lower GCS and higher ISS than GEMS) had worse outcomes by prespecified definition of tracheostomy need (26.5% *vs.* 8.2%).

Benhamed (2023) Risk factors and mortality associated with undertriage after major trauma in a physician-led prehospital system *Eur J Trauma Emerg Surg* [66]

Univariate analysis found that HEMS crews were significantly less likely to undertriage severely injured (ISS>15) to non-Level 1 centers (13.1% vs 22.4%)

Bou Saba (2023) Factors associated with survival in adult trauma patients undergoing angiography with and without embolization across trauma centers in the US *Emerg Radiol* [234]

In an analysis of all ACS NTDB bases undergoing angiography at receiving centers, HEMS was associated with improved survival (OR 1.74, 95% CI 1.33-2.28).

Deeb (2023) Direct trauma center access by HEMS is associated with improved survival after injury. *Ann Surg* [235]

HEMS direct to TC (compared to GEMS to non-TC and then later HEMS interfacility to TC) had survival improvement in overall group (OR 2.78, 95% CI 2.24-3.44) and in prespecified subgroup analysis of >70 miles' transport distance (OR 3.25, 95% CI 1.47-7.20).

Lapidus (2023) Trauma patient transport to hospital using HEMS or road ambulance in Sweden: a comparison of survival and prehospital time intervals. *Scand J Trauma Resusc Emerg Med* [236]

In ISS<9 HEMS had no survival improvement, but HEMS significantly improved survival in all three of the other ISS groups (9-15, 16-24, 25+); in the lower three ISS strata GOS median was the same for HEMS and GEMS but HEMS had statistically significantly worse GOS; for the highest ISS stratum HEMS GOS median was one point lower than GEMS but difference did not reach significance (p = .09)

Ciaraglia (2024) Comparison of helicopter and ground transportation in pediatric trauma patients. *Pediatr Res* [51]

Using a decade (2007-2016) of NTDB scene-responses pediatric (<18 years) cases, the authors generated a propensity-matched cohort pairing with a total n = 59,502 (29,751 in GEMS and an equal number of HEMS). In addition to assessing for HEMS *vs.* GEMS effect on mortality, the authors assessed functional outcome using an endpoint "discharged home without services." In the propensity-matched analysis HEMS was associated with lower mortality (OR 0.69, 95% CI .64-.75) and HEMS cases had significantly higher odds of being discharged home without services (OR 1.29, 95% CI 1.20-1.39).

Zadorozny (2024) Prehospital time following injury is independently associated with the need for in-hospital blood and early mortality for specific injury types. *Air Med J* [237]

In unadjusted analysis (for ISS>9 cases, after excluding prolonged scene-time cases and those with prehospital transfusion) HEMS 24-hour mortality was significantly (p <.001) lower than GEMS (1.6% *vs.* 3.8%, OR 2.45 with 95% CI 2.00-3.00); overall in-hospital mortality was not different (p = .958)

Bradford (2024) Temporal changes in the prehospital management of trauma patients: 2014-2021. *Am J Surg* [238]

The report's aim was to evaluate trends in prehospital care, not HEMS *vs.* GEMS transport. There was thus little information provided (*e.g.* model post-estimation) to complement a presented result that HEMS was found to have a non-significant but favorable point estimate in favor of trauma mortality reduction (OR 0.6, 95% CI 0.3-1.6).

Trauma: *Interfacility transport*

Secondary air transport of trauma has received less attention than scene HEMS response. However, there are some studies that address use of the helicopter to move patients from community hospitals to trauma centers. Investigators examining HEMS for interfacility transports have either excluded scene runs from the analysis (this subsection of studies), or lumped scene and interfacility transports together in varying proportions across studies (see next subsection).

Moylan (1988) Factors improving survival in multisystem trauma patients; *Ann Surg* [239]

Classical statistical analysis has since been replaced by complicated propensity-scoring, instrumental variables, and other advanced multivariate techniques. However, the straightforward assessment of trauma outcome stratified by injury severity as reported in this study, has the strength of being intuitive. This study shared with some other investigations, the tandem findings of HEMS mortality benefit and lack of time savings with interfacility air transport.

Boyd (1989) Emergency interhospital transport of the major trauma patient: Air versus ground; *J Trauma* [240]

Time and evolution of rural hospitals' trauma stabilization abilities may have eroded the results of this early TRISS study. For instance, in the Georgia setting studied, only 8 of the 31 referring hospitals had 24-hour staffing by physicians. At the time of its publication the study was an important example of the principle that HEMS could potentially be useful for interfacility transports as well as those from injury scenes.

Mann (2002) Injury mortality following the loss of air medical support for rural interhospital transport; *Acad Emerg Med* [144]

When selection bias is eliminated by assessing all trauma cases – those transported by HEMS, those transported by GEMS, and those kept at referring hospitals – results can be compelling. In such an all-inclusive and well-designed analysis, Oregonians reported a significant HEMS benefit after covering nearly all of the bases. There was some potential confounding related to overall trauma commitment (*i.e.* a hospital pulling out of the HEMS network could potentially have lesser overall commitment to trauma care) but this investigation stands as a superb example of the natural experiment design.

Slater (2002) Helicopter transportation of burn patients; *Burns* [241]

A group of Pennsylvania burn surgeons determined that HEMS benefits some cases but that the resource is overutilized. The contribution of this study to the HEMS evidence base is the authors' reporting of post-transport discussions with the local GEMS providers who called for HEMS. In acknowledging a HEMS dispatch issue lacking an easy solution, the authors point out that there are non-physiologic determinants of GEMS' calling HEMS (*e.g.* ability to pay, need to preserve local ground EMS availability) that have been largely ignored by the scores of HEMS triage studies.

Brown (2011) Helicopters improve survival in seriously injured patients requiring interfacility transfer for definitive care; *J Trauma* [242]

One of the largest ground-versus-air transport comparisons in the interfacility trauma literature (HEMS *n* 14,771, GEMS *n* 60,008), this NTDB analysis followed the same lines as the scene trauma study by the same authors (above). Multivariate regression was negative for HEMS survival benefit; 6% improvement in OR with 95% CI that crossed the null (0.99 to 1.13, p = .07). For ISS <15, HEMS was associated with no survival benefit but the authors speculated that morbidity improvements in this group warranted further study. For ISS >15 cases – 49% of all flights – HEMS improved mortality by 9%. Compared to GEMS, HEMS patients were far more severely injured (*e.g.* peri-transport deaths 10x higher), and required substantially more resources (*e.g.* emergency operation 50% more likely operation).

Borst (2014) Reduced mortality in severely injured patients using hospital-based HEMS in interhospital transport; *J Korean Med Sci* [243]

When an investigation excludes more non-HEMS cases – hundreds of whom died while awaiting GEMS arrival for transport – than it actually uses to constitute its GEMS group, selection bias is unavoidable. The finding that HEMS got trauma patients to Level 1 care 95 minutes faster than GEMS was not accompanied by any mortality benefit, but the results simply prove that HEMS won't improve outcome when assessed against a severely restricted group of "non-HEMS" cases that survive long enough to be driven to high-level care.

Kim (2017) When birds can't fly: An analysis of interfacility ground transport using advanced life support when HEMS is unavailable; *J Trauma* [143]

The investigators assessed only ISS >15, from cases transported from at least 30 km distance. Both GEMS and HEMS survival exceeded TRISS-predicted but HEMS *W* was 6 compared to GEMS.

Malekpour (2017) Mode of transport and clinical outcome in rural trauma; *Amer Surg* [244]

An analysis of rural cases in Pennsylvania found that HEMS increased survival odds: OR 1.57 (95% 1.03-2.40, p = 0.036). Some details (inclusion, acuity adjustment) were not quite clear but the analysis was reported as controlling for confounding.

Sun (2017) Impact of prehospital transportation on survival in skiers and snowboarders with TBI; *World Neurosurg* [245]

An analysis of scene TBI cases from the NTDB, focusing on skiers and snowboarders, found HEMS improved survival. Relatively small number led to wide CIs, but the findings were statistically significant: HEMS NNT was calculated at 10 with the basic logistic regression model finding a survival OR of 8.6.

Pakkanen (2017) Physician-staffed HEMS has a beneficial impact on the incidence of prehospital hypoxia and secured airways on patients with severe TBI; *Scand J Trauma Resusc Emerg Med* [46]

This Finnish group found that HEMS was associated with reduced mortality in TBI (54% *vs.* 43%, $p = .045$), and that the survival improvement was associated with improved 6-month GOS 4-5 (42% *vs.* 28%, $p = .022$). The authors postulated that the mechanisms for improvement were related to HEMS cases having less arrival hypoxemia (10% to 2%) and more frequent ETI (16% to 95%) despite HEMS and GEMS cases having similar incidence of on-scene hypoxemia.

Smith (2019) Prehospital analysis of northern trauma outcome measures: the PHANTOM study; *Emerg Med J* [246]

These English authors focused on HEMS-delivered Enhanced Care Teams (ECTs) which could potentially take patients by ground (occasionally the ECTs deployed to scenes by ground). While exact transport modes weren't the main point of the study – transport mode data were not always precisely clear – the HEMS ECT use was associated with improved survival and a *W* of 6.18 (95% CI 3.19-9.17).

Weinlich (2019) Competitive advantage gained from the use of HEMS for trauma patients; *Injury* [47]

The authors assessed Frankfurt-area centers' data in the German national trauma registry, looking at all ISS scores but defining a serious-injury cutoff at ISS >9. HEMS mortality OR was 0.21 (95% CI 0.06-0.73, $p = .014$) ordinal-endpoint GOS coefficient was 0.17 (95% CI .15-.32, $p = .043$) – note that GOS ranges from 1/dead to 5/good. One of the study's noteworthy findings was its reporting of substantial issues with use of the acuity stratification score NACA (a score sometimes encountered in European studies).

Stassen (2020) HEMS in trauma does not influence mortality in South Africa; *Air Med J* [247]

The authors executed a case-control study with matching on MOI, ISS, age, sex, and comorbidities. Not all factors were matched on all pairs. The results were a finding of no difference in mortality with HEMS (matched-cohort OR 1.35 (95% CI 0.5-3.4; $p = .50$).

Ford (2020) Does helicopter retrieval improve survival of severely injured trauma patients from rural Western Australia?; *Air Med J* [248]

In a paper that focused on both HEMS and the question of direct (from scene) transport to trauma center (TC), the authors assessed ISS >15 cases 50-250 km from the TC. Comparison of direct (HEMS) scene to TC center *vs.* GEMS to non-TC with later TC transfer (by GEMS or air), the HEMS group had higher acuity but GEMS had 51% higher mortality than scene-HEMS-to-TC (15.3% mortality *vs.* 10.2% mortality).

Stewart (2021) Association of interfacility helicopter *vs.* ground ambulance transport and in-hospital mortality among trauma patients; *Prehosp Emerg Care* [249]

A statewide trauma registry analysis identified HEMS as being faster for all distances. Cases with transport distances >90 miles were less acute and judged to be likely transported for resource reasons (no HEMS mortality improvement was seen in this group). At <90 miles distance, HEMS 72-hour mortality improved (Cox HR 0.65, 95% CI 0.48-0.90). The overall mortality assessment failed to identify statistical significance (HEMS mortality Cox HR 0.95, 95% CI 0.77 to 1.18).

Udekwu (2021) Evaluation of statewide utilization of HEMS for interfacility transfer; *J Trauma* [250]

HEMS improved outcome with mortality OR 0.35 (95% CI 0.31-0.40, $p < .0001$). in an attempt to assess potential triage parameters, the investigators were not successful: normal vital signs, AIS, or GCS were not predictive of absence of benefit from HEMS.

Patterson (2022) Interfacility helicopter transport to a tertiary pediatric trauma center; *J Pediatr Surg* [251]

This analysis focused primarily on whether HEMS was being overtriaged. GEMS and HEMS cases (age <19) were assessed for likelihood of need for operative intervention as a measure of transport appropriateness. HEMS cases had higher ISS and more frequent operation, but as defined by the criterion of ISS<15 overtriage was common.

Hosseinpour (2023) Interfacility transfer of pediatric trauma patients to higher levels of care; *J Trauma Acute Care Surg* [252]

The HEMS contribution to decreased mortality was favorable, but not statistically significant, for the authors' dichotomous grouping of injury severity: ISS <25 (OR .58, 95% CI .36-1.56, *p* = .152) or for ISS >24 (OR .87, 95% CI .27-3.45, *p* = .692).

Stener (2024) Interfacility ambulance versus helicopter transport of traumatic spinal cord injury; *Wisconsin Med J* [53]

In spinal injury patients requiring urgent surgical decompression, GEMS and HEMS patients had similar demographics, injury severity score, and initial spinal cord injury scale score, but those transported by HEMS had significantly more improvement in spinal cord injury scale. The improvement, which was most pronounced at the higher severity end of the spinal cord injury scale, was not related to time savings (transport times were similar).

Trauma: *Combined scene & interfacility mission types*

Moront (1996) Helicopter transport of injured children: System effectiveness and triage criteria; *J Pediatr Surg* [253]

The finding that HEMS use for pediatric trauma saved 11 lives per 1,000 transports was correctly reported by the authors as indicating suboptimal triage. However, in pediatric trauma a lower *W* should be accepted as favorable, due to cost-benefit ramifications of saving a child's life (*i.e.* saving such a life results in decades of life-years gained). Despite the fact that the study did not rigorously adjust for many potential confounders the *W* of 1.1 was one of the earliest demonstrations of HEMS benefit in pediatric trauma.

Kerr (1999) Differences in mortality rates among trauma patients transported by helicopter and ambulance in Maryland; *Prehosp Disast Med* [254]

The MIEMSS statewide system was analyzed, with a finding that HEMS improved outcomes particularly for those with severe (ISS >31) injuries.

Thomas (2002) HEMS transport and blunt trauma mortality; *J Trauma* [255]

Using classical logistic regression, the authors of this multicenter study (including this monograph's author) examined nearly 17,000 HEMS and GEMS cases and found a 24% mortality reduction associated with air transport. The study adjusted for ISS, prehospital level of care (ALS *vs.* BLS), and scene *vs.* interfacility mission type.

Biewener (2004) Impact of helicopter transport and hospital level on mortality of polytrauma patients; *J Trauma* [256]

In Germany, for patients injured close enough to trauma centers that GEMS transport to trauma care was logistically feasible, HEMS deployment was found to offer no mortality benefit. As distance from trauma centers increased and the GEMS transport option was limited to getting patients to local facilities (with subsequent movement to Level I care), HEMS use from scene to Level I center reduced mortality by 19%.

Larson (2004) Effective use of the air ambulance for pediatric trauma; *J Trauma* [257]

In assessing two pathways for pediatric trauma patients to get to tertiary care, it was found HEMS directly from the scene afforded no benefit over GEMS from scene to referring hospital followed by subsequent HEMS transfer to tertiary care. The authors concluded HEMS should be used for secondary transport after stabilization at referring hospitals, but they acknowledged the likelihood of residual confounding by severity since the study groups were distinctly different (*e.g.* scene transports were more likely MVC trauma and pedestrians struck).

Mitchell (2007) Air versus ground transport of major trauma patients to a tertiary trauma centre: A province-wide comparison using TRISS analysis; *Can J Surg* [83]

Canadian population-based HEMS studies comprise an important part of HEMS' evidence base. This analysis from a rural maritime province assessed HEMS use in adult blunt trauma cases with ISS >11 (notably, this is less than the usual ISS cutoff of 15). Mortality improved 35% as compared to GEMS and the difference in *W* between HEMS and GEMS was 8.8. The study is particularly strong given its inclusion of every trauma patient in the province who was transferred to tertiary care.

Schiller (2009) The effect of adding a second helicopter on trauma-related mortality in a county-based trauma system; *Prehosp Emerg Care* [13]

Published 7 years after the well-done HEMS natural experiment by Mann *et al* (see above), this study assessed trauma mortality in a discrete population (eastern Long Island) before and after addition of a HEMS unit. HEMS' addition to the system was associated with mortality reduction of 26.5%. Air transport to the regional trauma center increased by 130%, with a commensurate decrease in community (non-trauma center) hospitals' providing care for injured patients. Interestingly, interfacility HEMS transports from the community hospitals remained stable (*i.e.* there was no increase in HEMS utilization for interfacility transport; the increased utilization was for scene flights).

McVey (2010) Air *vs.* ground transport of the major trauma patient: A natural experiment; *Prehosp Emerg Care* [145]

Province-wide database studies are superb methods to eliminate selection bias: all trauma cases in a province are included regardless of transport modality or hospital location. In one of the best such population-based studies, Canadian adult trauma patients were split into 3 groups: *Group 1* consisted of adults HEMS-transported to a trauma center. *Group 2* patients were those who were initially triaged to HEMS (*i.e.* accepted by the online Medical Control Physician for air transport), but who were GEMS-transported (*e.g.* weather or aviation issues). *Group 3* included all other GEMS cases. The natural experiment was successful in that there was no difference between *Group 1* and *Group 2* with respect to mean age, gender, percentage with blunt injury, AIS, and ISS; *Group 3* was of lesser acuity. There was no difference in the time between injury and trauma center arrival, between *Group 1* and *Group 2*. As compared to *Group 2* patients (whose mortality was equal to TRISS-predicted), *Group 1* status was associated with significant survival improvement (5.61 more lives per 100 transports). *Group 3* patients had the worst outcome, with a survival *less* than that predicted by TRISS (W = -2.02).

Rhinehart (2013) The association between air ambulance distribution and trauma mortality; *Ann Surg* [82]

Over a single decade, HEMS assets in the study state – Pennsylvania – more than doubled. In a meticulous statistical approach investigators identified an association between trauma mortality and distance between geographic injury location and the nearest HEMS base; the association reached significance once the trauma scene was more than 10 miles from the nearest trauma center. At 11 miles and further from the trauma center, there was a 1% increase in mortality for every mile distance to the nearest HEMS base. There was no association between mortality and extra HEMS bases (*i.e.* more than one) and there was no HEMS-base effect on mortality for interfacility transports.

Hesselfeldt (2013) Impact of a physician-staffed helicopter on a regional trauma system: A prospective, controlled, observational study; *Acta Anesthesiol Scand* [146]

This Danish study adds to the solid natural-experiment evidence base suggesting HEMS improves outcomes. Of course, a natural experiment design is not an RCT, and it is possible that other factors (*e.g.* improved overall trauma care) occurred simultaneously with the introduction of HEMS. The overall (all ISS) mortality was higher in GEMS (OR 6.9, 95% CI 1.5-32.5, p = .01). For ISS>15, HEMS was associated with survival doubling (risk ratio 2) and a favorable NNT of 7 (*i.e.* one life saved for every 7 HEMS transports as compared to GEMS). Furthermore, HEMS transport from the scene was noted to achieve reduction in need for secondary transfer; this finding has cost-effectiveness implications since that initial stop at the community hospital costs time and money. (Note: Subsequent follow-up study assessing long-term benefits demonstrated improved economic/functional-outcome parameters in the HEMS cases. [50]

Hannay (2014) Retrospective review of injury severity, interventions, and outcomes among helicopter and non-helicopter transport patients at a Level 1 urban trauma centre; *Can J Surg* [258]

At a renowned Level 1 center in Georgia, analysis of 14,440 trauma cases found that HEMS was associated with reduced mortality (OR 0.41, 95% CI 0.33–0.49). The authors also found that HEMS-transported patients were significantly more likely to be high acuity (*e.g.* GCS was lower for HEMS, ISS for HEMS patients was nearly twice the GEMS median of 9) or require major interventions (*e.g.* airway management, massive transfusion, operation, ICU admission). The study had limitations (*e.g.* including in the analysis private-vehicle transports) that were acknowledged by the authors, and which may have contributed to the fact that this paper's estimate for HEMS' mortality benefit was substantially higher than that of the bulk of the literature.

Stewart (2015) Helicopter versus ground EMS for the transportation of traumatically injured children; *J Pediatr Surg* [259]

In a decade of pediatric patients evaluated by trauma services at two Level 1 centers, using methodology that included geographical (time/distance) information and acuity measures, HEMS had no impact on mortality. Furthermore, 22% of the transported patients had low ISS (below 10) and were hospitalized less than a day. Interestingly, the study also found that, depending on adjustment for geographic variables, ground transport had a "protective" effect in its association with shorter hospitalization duration; GEMS was associated with a 53-69% decrease (depending on model) in hospital days. The authors postulated that HEMS interventions at the trauma scene may be causing complications and thus increasing hospitalization times for the air-transported cases. They also offer the possibility of residual confounding, since the air-transported patients were far more severely injured than those who went by ground. Some of the authors' points about potential HEMS crew harm at the scene are ironically extrapolated from the GEMS literature (*e.g.* on airway management) with no supporting data in the HEMS evidence base. However, conclusions about pediatric HEMS overtriage in the study area are more soundly base. The failure to include any point estimates, much less 95% confidence intervals, for the impact of transport mode on outcomes does not help the framing of this paper in the overall evidence base.

Hirshon (2016) Maryland's HEMS experience from 2001 to 2011: System improvements and patients' outcomes; *Ann Emerg Med* [260]

This large-scale analysis of over 180,000 HEMS and GEMS transports focused on changes in HEMS dispatch criteria implemented in stages over the study time period. As such, the main point of the study dealt with improving triage. The authors found that HEMS triage improvements resulted in 49% reduction of HEMS deployment with a concomitant increase in GEMS utilization. HEMS *W* was calculated on a weekly basis and graphed over the entire study period. The reduction in (unnecessary) HEMS use did not impact the fact that HEMS improved outcome, thus making the case for better triage (*i.e.* reducing HEMS use but keeping the resource deploying for those who need it most). HEMS' *W* mostly ranged between 2 and 3 over the study decade, and HEMS' mortality improvement was significantly better than TRISS-predicted and also higher than GEMS-associated mortality improvement.

Al Thani (2017) Hospital mortality based on the model of EMS transportation; *Air Med Journal* [261]

This single-center study from Qatar found no association between transport mode and mortality. There were few details presented on the multivariable modeling; the presented methods and results leave open possibility of residual confounding (crude mortality for HEMS was 2.5x that of GEMS).

Dominguez (2020) Helicopter transport has decreased over time and transport from scene or hospital matters; *Air Med J* [25]

An analysis of adults from the ACS Trauma Quality Improvement Program (TQIP), covering the years 2010-16, used multivariable logistic regression to identify an overall HEMS mortality benefit: OR 0.74 (95% CI 0.71-0.77). However, on stratified analysis the HEMS benefit was limited to scene trauma (OR 0.63); for interfacility cases HEMS *worsened* outcome (OR 1.22). The scene and interfacility findings were both statistically significant, but the authors themselves noted that the results for interfacility transports "more likely indicated" residual confounding. The authors' call for a prospective assessment of HEMS *vs.* GEMS shows that as late as 2020 the hope for a transport-allocation RCT is not altogether gone.

Cardiac

Some early HEMS programs, particularly in the USA, included an emphasis on cardiac transportation for tertiary care such as primary PCI. As the ties between time savings and improved outcome become more clearly understood, there is a proportionate increase in studies of HEMS' logistics contributions to cardiac care networks.

Fromm (1991) Bleeding complications following initiation of thrombolytic therapy for acute myocardial infarction: A comparison of helicopter-transported and non-transported patients; *Ann Emerg Med* [97]

This early report went far towards establishing the safety – at least with respect to bleeding complications – of HEMS transport of patients after thrombolysis administration.

Straumann (1999) Hospital transfer for primary coronary angioplasty in high risk patients with acute myocardial infarction; *Heart* [134]

Interhospital transport of acute cardiac cases was found to be both safe and feasible, even for unstable patients. Streamlining of interfacility transport operations can significantly extend the coverage area of a primary angioplasty center.

Grines (2002) A randomized trial of transfer for primary angioplasty versus on-site thrombolysis in patients with high-risk myocardial infarction*; J Amer Coll Cardiol* [69]

Although most of the patients in the "Air PAMI" trial actually traveled by ground, this study introduced the case for use of HEMS as a component of early transport of patients for primary PCI (rather than lysis at the referring hospital). The study's results were surprising: despite the transported group's having triple the time to definitive therapy (155 *vs.* 51 minutes), interfacility transfer for primary PCI was associated with a six-fold improvement in the composite outcome.

Blankenship (2007) Rapid triage and transport of patients with STEMI for PCI in a rural health system; *Am J Cardiol* [262]

A before-and-after study reported improvements associated with instituting a new triage and HEMS transfer system. Contributions specific to HEMS were not able to be elucidated, but transport protocol changes included measures intended to speed patients on their way to PCI. Infusions of heparin and nitroglycerin were eliminated and referring physicians made a single call to activate both HEMS transport and receiving-center PCI teams. The overall time savings of 100 minutes included a HEMS dispatch streamlining of 19 minutes and the data suggested an additional 10 minutes' time savings from bypassing the receiving center's ED. The proportion of patients with door to wire-crossing times <90 minutes increased from 0% to 24%; the % with times <120 minutes increased from 2% to 67%.

Phillips (2013) Helicopter transport effectiveness for patients being transported for primary percutaneous coronary intervention; *Air Med J* [119]

Time savings accrued with HEMS as compared to GEMS were estimated using what is becoming a standard geographical information software (GIS) approach. In the southwestern USA state of Oklahoma, 59 was calculated to be the number needed to treat (transport by HEMS *vs.* GEMS) in order to save a single life solely due to time savings. The study was designed as a pilot validation for a larger multicenter trial (see reference below) that eventually confirmed the preliminary findings.

Schoos (2014) Search and rescue helicopter-assisted transfer of ST-elevation myocardial infarction patients from an island in the Baltic Sea: results from over 100 rescue missions; *Emerg Med J* [263]

Using methods reminiscent of some of the early trauma literature, the authors of this review of 101 STEMI cases conclude that HEMS improved outcome based upon the capability of the aircraft to extend the reach of primary PCI. The patients, who were all flown from offshore island locations, comprised a group for whom surface transport was simply not an option. In a sense, the study doesn't add too much to the literature due to the inevitable lack of precise controls for acuity and casemix. On the other hand, it's hard to dispute the favorable cost-benefit for these 101 individuals who received timely PCI solely due to the presence of HEMS; depending on how one calculates the benefits (as discussed in a later section) this group could account for substantial return on investment in HEMS.

Moens (2015) Air versus ground transport of patients with acute myocardial infarction: Experience in a rural-based helicopter medical service; *Euro J Emerg Med J* [124]

Using time as a surrogate endpoint, these Belgians examined use of HEMS as a mechanism to get STEMI patients to PCI more quickly. In a 5-year analysis of 342 STEMI patients transported for primary PCI by air, HEMS times were compared to software-generated GEMS times. The characteristics of the rural location were such that HEMS was faster in primary response time (11 *vs.* 32 minutes) as well as transport time (12 minutes *vs.* 50 minutes). Overall, the median system time gained by HEMS was calculated to be 60 minutes (interquartile range, 47-72 minutes), which time savings corresponds to substantial improvement in mortality (see discussion elsewhere in this monograph).

Pathan (2017) HEMS and rapid transport for STEMI: The HEARTS Study; *J Emerg Med Trauma Acute Care* [264]

A multicenter assessment of time savings associated with HEMS transport to primary PCI identified a number needed to treat (transport by HEMS rather than GEMS) of 3, in order to get one additional patient to PCI within a predefined 90-minute window. HEMS saved a median of 32 minutes over GEMS, correlating to substantial mortality benefit as discussed elsewhere in this monograph. HEMS was also appropriately used, with over 91% of air-transported cases arriving at PCI within 120 minutes of aircraft dispatch.

Gunnarsson (2017) Outcomes of physician-staffed *vs.* non-physician-staffed helicopter transport for STEMI; *J Am Heart Assoc* [265]

The goal of this study was actually assessment of crew configurations (physician-staffed HEMS had better outcomes). From an overall HEMS outcome perspective, the relevant study data were those identifying a mean time from EKG to PCI of under 120 minutes for the entire set of nearly 400 cases.

Almawiri (2017) Mortality benefit of primary transportation to a PCI-capable center persists through an eight-year follow-up in patients with STEMI; *J Interv Cardiol* [266]

This study's contribution was to demonstrate extended-assessment benefit for rapidly moving STEMI patients to primary PCI. Although HEMS was highlighted as playing an important role in getting patients quickly to PCI, there was no explicit comparison of "HEMS *vs.* GEMS" primary transport. The main applicability of this work to the HEMS debate, is its clear affirmation of benefits of saving time before primary PCI.

Funder (2018) Helicopter *vs.* ground transportation of patients bound for primary percutaneous coronary intervention; *Acta Anaesthesiol Scand* [267]

While statistical significance was found for time of diagnostic EKG to PCI center arrival (71 *vs.* 78 minutes), significance was not reached for the point estimates of HEMS benefit for mortality (OR 0.82, 95% CI 0.44-1.51) or involuntary retirement rate (IRR 0.68, 95% CI 0.15-3.23). The authors' discussion includes problems with extrapolation to other geographies (the study was not characterized by geographic barriers to GEMS), small sample size, and confounding by indication (*i.e.* residual confounding due to HEMS cases' being higher acuity in unmeasured fashion). The authors conclude that the only way to learn whether HEMS is useful in Denmark, is to execute a large RCT.

Ishikura (2021) The evaluation of HEMS with a physician for AMI in Japan; *Air Med J* [268]

This time-focused study found that for transport distances exceeding 20 km, HEMS achieved significant time savings from call to arrival at angiography suite (8% time savings for 20-40 km transport distance; 23% time savings for transport distances >40 km).

Ishiyama (2021) Impact of helicopter transport on reperfusion times and long-term outcomes in acute myocardial infarction patients in rural areas: a report from the Mie acute coronary syndrome registry; *Air Med J* [269]

The authors set call-to-balloon time savings as their a priori primary endpoint: HEMS saved 8% for scene and 14% for interfacility transports. Transport distances were slightly longer (but not significantly so) for HEMS as compared to GEMS. Two-year major cardiac and cerebrovascular events (MACCE) were a secondary endpoint; MACCE occurred in HEMS at only half the rate of GEMS for both scene and interfacility transports, but the differences were not statistically significant.

Nishigoori (2022) HEMS for patients with acute coronary syndrome: selection validity and impact on clinical outcomes; *Heart and Vessels* [270]

Using propensity-score techniques to adjust for the (higher) HEMS acuity, the authors employed survival analysis and found that HEMS-transported PPCI cases had significantly lower 2-year mortality than GEMS cases (6.3% *vs.* 14.9%, $p = .019$ by log-rank). This was attributed not only to prehospital time savings, but also to time savings upon arriving at the PCI center: hospital arrival to balloon time was 54 minutes for HEMS *vs.* 69 minutes for GEMS.

Mork (2022) Use of helicopters to reduce health care system delay in patients with STEMI admitted to an invasive center; *Am J Cardiol* [271]

The authors used time as their primary endpoint, referencing standard estimates that 10% relative mortality is achieved with each hour of time savings for primary percutaneous coronary intervention (PPCI). Both scene and interfacility transports for PPCI were assessed. HEMS was found to save clinically significant times at the assessed distances: 75 km (14 minutes' HEMS time savings), 100 km (16 minutes HEMS time savings), 125 km (20 minutes' HEMS time savings), and 170 km (29 minutes' HEMS time savings).

Schoenfeld (2024) Longitudinal assessment of a single referring-receiving hospital pair to assess air versus ground elapsed time from transport request to arrival at cardiac catheterization laboratory; *Air Med J* [77]

Using a multi-year assessment of a single pair of referring-receiving hospitals, the authors demonstrated that even for short-distance transports (<8 miles by air), HEMS may often save a clinically important amount of time in STEMI cases undergoing interfacility transport for primary PCI. Half of the patients who were transported by GEMS would have saved at least 15 minutes had they undergoing HEMS transport. The median time savings of 32 minutes corresponded to a potential 25% reduction in mortality (based on the cardiology literature tie-in between time savings and improved outcome for primary PCI).

Obstetric & Neonatal

The diagnostic categories of obstetrics and neonatal are considered together, since studies occasionally report outcomes for both mother and infant. In both groups, the logistics emphasis includes maintaining stability and minimizing out-of-hospital time; speed of transport (*i.e.* earlier arrival at the receiving center) may be less important.

Elliott (1982) Helicopter transportation of patients with obstetric emergencies in an urban area; *Am J Obstet Gynecol* [44]

As compared to post-delivery transport, antenatal transport improves outcomes, so there is a case for obstetric HEMS flights if patients would otherwise have to deliver at community hospitals. In southern California, HEMS saved substantial time (by avoiding traffic congestion), and neonatal outcomes for HEMS-transported patients were as good as outcomes for cases presenting primarily to the tertiary center. Availability of HEMS increased chances of delivery at the maternal-fetal center: in 25/100 cases the referring physician indicated that if HEMS were not available they'd not have allowed laboring patients to travel by GEMS and would have instead delivered patients at the community hospital.

Pieper (1994) The transport of neonates to an ICU; *S Afr Med J* [272]

The authors executed a descriptive analysis of air and ground neonatal transfers, concluding that HEMS was a critical part of regionalized neonatal critical care. While the study is limited by inability to focus on HEMS' particular contribution, the authors make a solid case for HEMS as a part of a successful regionalized neonatal network.

Berge (2005) Helicopter transport of sick neonates: A 14-year population-based study; *Acta Anesthesiol Scand* [135]

A large-scale, population-based, descriptive analysis of 256 neonatal transports in central Norway found neonatal mortality of the HEMS cohort to be similar to that of non-transported neonates cared for at the tertiary center. Results included findings of occasional performance of life-saving interventions. The authors reported that physiologic parameters associated with oxygenation, ventilation, and circulation all improved during the HEMS transport time frame.

Hon (2006) Air versus ground transportation of artificially ventilated neonates: Comparative differences in selected cardiopulmonary parameters; *Pediatr Emerg Care* [110]

There is no difference between air or ground transport (by the same team, into Miami Children's Hospital) with respect to intra-transport need for cardiopulmonary interventions; there was also no difference in risk of intratransport development of hypocapnia or hypercapnia. In essence, the study showed HEMS is not associated with inherent and unmanageable physiologic risks (*e.g.* due to altitude changes).

Ohara (2019) Safety and usefulness of emergency maternal transport using helicopter; *J Obstet Gynaecol Res* [79]

Japan has limited tertiary care facilities for maternal-fetal medicine, so maternal (prenatal) transport by air is an important part of regionalized care. The study assessed 26 obstetric HEMS transfers. Using actual air transport times, and estimated ground transport times, the authors calculated HEMS use was associated with savings of 101 minutes' out-of-hospital time (median flight time, 24 minutes; median estimated GEMS time, 125 minutes).

Kumagai (2011) Changes in maternal and child health outcomes after introduction of a helicopter into perinatal transportation in Japan; *Matern Child Health* [273]

Decreases in neonatal/perinatal mortalities in 2004-2006 (post-HEMS establishment) compared to 2000-2002 were greater in the area newly covered by HEMS, as compared to a "control" area that did not have a logistic need for HEMS. Further assessment of the system was performed seven years later (see below).

Alvarado-Socarras (2016) Hospital survival upon discharge of ill neonates transported by ground or air ambulance to a tertiary center; *J Pediatr (Rio J)* [274]

HEMS achieved equal adjusted neonatal survival to GEMS, despite HEMS cases coming from far greater distances (238 km *vs.* 11 km).

Kumagai (2018) Wakatama Medical University Hospital perinatal helicopter ambulance service: a 14-year review; *Pediatrics International* [275]

In a follow-up to previous work (see above), the authors assessed an extended period of both maternal and neonatal outcomes in their rural Japanese area. While focused statistical analysis was limited, the conclusion was that HEMS was an important contributor to regional outcomes improvements. The authors noted for two regions assessed, in one HEMS executed in 30 minutes, transports that would require two hours; in another region HEMS executed in an hour, transports that would require four hours.

Nawrocki (2019) Interfacility transport of the pregnant patient: a 5-year retrospective review of a single critical care transport program; *Prehosp Emerg Care* [276]

In what was essentially a report of transport safety, the authors examined 1,223 obstetrics transports by air and ground, and found no intratransport deliveries and only rare (6%, mostly hemodynamic) serious issues. The very low incidence of clinical serious events (*e.g.* zero intratransport delivery rate) represented a limitation on any HEMS *vs.* GEMS comparisons.

Neurology & Neurosurgery

As a time-critical set of illnesses, neurological conditions are among the most likely to benefit from time savings that can potentially be accrued with air transport. The evolving literature, particularly in the field of stroke, is characterized by a focus on logistics that parallels the evidence base exploring HEMS uses for PCI patients.

Chalela (1999) Safety of air medical transportation after tissue plasminogen activator administration in acute ischemic stroke; *Stroke* [277]

This was primarily a "safety study," demonstrating HEMS transport of post-lysis stroke patients did not result in worsened outcome (*e.g.* from vibration-induced hemorrhage).

Conroy (1999) Helicopter transfer offers benefit to patients with acute stroke; *Stroke* [99]

While the title may overstate the results – there was no demonstration of outcomes improvement as compared to a GEMS cohort – the authors make an excellent point about the minimal "packaging" needed for stroke cases. If time savings is the endpoint of focus, stroke cases represent a group for whom HEMS' logistics advantages may be truly important (depending on what therapy will be offered at receiving centers).

Silliman (2003) Use of a field-to-stroke center helicopter transport program to extend thrombolytic therapy to rural residents; *Stroke* [74]

In rural southeastern USA, HEMS scene response for suspected stroke was found to be appropriately deployed and not overused (stroke was ultimately diagnosed at the receiving center in 76% of cases). During the study period, stroke transports comprised 4% of HEMS volume but HEMS strokes accounted for 23% of receiving-center lysis cases. With proper prehospital provider education and judicious triage, HEMS can extend the reach of a stroke center along the lines of the trauma care model.

Walcott (2011) Interfacility helicopter ambulance transport of neurosurgical patients: Observations, utilization, and outcomes from a quaternary care hospital; *PloS One* [278]

This retrospective review assessed trauma, cerebrovascular, tumor, and other neurosurgical HEMS interfacility transports into the Massachusetts General Hospital (the study group includes colleagues of this monograph's author). The approach of retrospective calculation of ground transport times using GoogleMaps is well-executed and since validated (see discussion elsewhere in this monograph). Although the study lacked any GEMS comparison group, the findings (*e.g.* lack of need for urgent intervention in a third of cases) were sufficient to support a conclusion regarding need for triage improvement.

Olson (2012) Does HEMS transfer offer benefit to patients with stroke? *Stroke* [279]

Air transported post-lysis stroke cases arrived at the receiving stroke center 15 minutes faster than those going by GEMS, but the time savings has questionable clinical significance. Once the stroke patient has been lysed, presuming there are no plans for further definitive treatment (*i.e.* mechanical neurointervention) the medical priorities (*e.g.* blood pressure control,) don't dictate a need for routine HEMS deployment.

Reiner-Deitmeyer (2011) Helicopter transport of stroke patients and its influence on thrombolysis rates: Data from the Austrian Stroke Unit Registry; *Stroke* [20]

In studies of transport for stroke, one endpoint is whether patients actually receive thrombolytic therapy. The implication is that transport must be effected in such fashion as to get patients to stroke centers within the intervention window. Using data from their national stroke registry, this study's authors found that as compared to GEMS, HEMS transports from either scenes or referring hospitals allowed for higher thrombolysis rates. Scene HEMS response was associated with the highest chances of patients' receiving thrombolytics within the pre-defined preferred time frame of 90 minutes from symptom onset.

Hesselfeldt (2014) Is air transport of stroke patients faster than ground transport? A prospective controlled study; *Emerg Med J* [22]

Time savings is an appropriate surrogate endpoint for transport studies of some patient groups (including cases of stroke). The authors examined strokes going by GEMS (with transport time >30 minutes) or HEMS to a regional stroke center. Results including 265 GEMS and 65 HEMS cases identified longer average transport distances (83 *vs.* 67) for HEMS and commensurately longer times for air transports. Outcomes were similar and it appeared HEMS saved minimal time. The authors reasonably concluded that expedited GEMS transport of stroke to lysis centers is preferable to HEMS if the latter does not save time.

Gupta (2016) Severe hemiparesis as a prehospital tool to triage stroke severity: a pilot study to assess diagnostic accuracy and treatment times; *J Neurointerv Surg* [280]

These Georgians assessed use of hemiparesis to trigger helicopter transport in their center's rural catchment area in the southeastern USA. Of the patients transported directly from the scene with suspected stroke, 60% had stroke diagnosed and time-critical acute therapy (lysis or neurointerventional care) was used in 47%. The median first medical contact to groin puncture was 101 minutes (faster than if HEMS had not been used). The authors concluded that use of hemiparesis as a prehospital screening tool for HEMS scene dispatch could be effective in speeding therapeutic interventions and outcomes in patients with stroke.

Hui (2017) Helistroke: neurointerventionalist helicopter transport for interventional stroke treatment; *J Neurointerv Surg* [281]

Following on the principle of using HEMS to transport physicians to patients, this proof-of-concept report outlined a case in which time interval from decision to treat and groin puncture was 43 minutes. The authors from Johns Hopkins Medical Center make a case for (ischemic) stroke care systems to include capability for helicopters to quickly transport neurointerventionalists to appropriately equipped community hospitals where rapid treatment can then occur.

Ishihara (2017) Safety and time course of drip-and-ship in treatment of acute ischemic stroke; *J Stroke Cerebrovasc Dis* [282]

Perhaps best considered in the context of Olson (see above), this group monitored blood pressure control in post-lysis stroke cases. HEMS benefit was suggested by a finding that mean blood pressure change was lower (<5 mmHg) in HEMS patients than GEMS cases (12.2 mmHg).

Ishikawa (2017) A comparison between evacuation from the scene and interhospital transportation using a helicopter for subarachnoid hemorrhage; *Am J Emerg Med* [283]

This safety study focused on patients who ultimately were diagnosed with subarachnoid hemorrhage. Investigators compared outcomes of HEMS scene-transported cases going directly to tertiary care *vs.* outcomes of cases GEMS-transported to nearby community hospitals before undergoing secondary HEMS transport to tertiary care. The authors found the HEMS cases were higher-acuity, but had similar survival and no apparent risk of intratransport deterioration or worsened physiology as a result of HEMS bypass of closer facilities. The authors concluded that HEMS potentially had a role for scene responses to suspected subarachnoid hemorrhage.

Weyhenmeyer (2018) Effects of distance and transport method on intervention and mortality in aneurysmal subarachnoid hemorrhage; *J Neurosurg* [284]

Distance from tertiary center was identified as a major contributor to outcome in this analysis. HEMS cases had worse outcome than GEMS cases, but the HEMS cases both came from farther away, and (by multiple assessment parameters) were of substantially higher acuity.

Ueno (2019) Helicopter transport for patients with cerebral infarction in rural Japan; *J Stroke Cerebrovasc* [128]

In following the lead of some earlier trauma and cardiac-care systems literature, the authors reported that HEMS was useful in their system in that it allowed further-away cases to get to tertiary care in the same time frame as closer-in patients.

Almallouhi (2020) Outcomes of interfacility helicopter transportation in acute stroke care; *Neurol Clin Prac* [285]

In an analysis adjusting for multiple potential confounders, HEMS' faster transport time (60 minutes HEMS *vs.* 84 minutes GEMS, $p < .001$) resulted in significantly improved outcome by Modified Rankin <3: OR 4.7 (95% CI 2.2-10.4, $p < .001$).

Lee (2020) Comparative study on the outcome of stroke patients transferred by doctor helicopters and ground ambulances in South Korea; *Emerg Med Int* [286]

In this assessment of patients transported from scenes, with transport distance of at least 50 km, helicopter-transported patients arrived at the stroke center earlier (3 hours post-onset, GEMS 4.2 hours post-onset) and had significantly ($p = .001$) higher survival (96% versus 83%). HEMS cost was $3500 per transport. GEMS was less expensive (at $260 per transport) but the authors concluded HEMS was cost-effective

Coughlan (2021) Secondary transfer of emergency stroke patients eligible for mechanical thrombectomy by air in rural England: economic evaluation and considerations; *Emerg Med J* [287]

This was an economic modeling analysis, based on a case of 75 year-old patient requiring interfacility transport for mechanical thrombectomy. The model found that, if HEMS saves one hour in time to arrival at neurointerventional care – presuming arrival was within 6 hours – the incremental cost-effectiveness was GBP28,000 per quality-adjusted life-year (QALY). The modeling found that HEMS' cost-effectiveness was most sensitive to two factors: rapid transport and avoidance of futile secondary transfers (*i.e.* transports for which neurointerventional care was not a practical option).

Kunte (2021) Total transfer time for ground *vs.* air transport for interhospital and scene transfers of acute stroke patients; *J Stroke Cerebrovasc Dis* [288]

The most compelling results from this relatively small study dealt with its main focus, of time intervals in stroke transfer. The logistics conclusion was that HEMS was warranted for stroke cases (requiring neurointervention) for interfacility distances exceeding 40 miles, and scene transfers exceeding 28 miles. The authors noted the study was underpowered to assess the four groups (air and ground, scene and interfacility) for mortality; the results of no mortality difference were thus limited.

Florez-Perdomo (2022) Effects of helicopter transportation of acute ischemic stroke patients on mortality and functional outcomes: a systematic review and meta-analysis; *Air Med J* [157]

While the heterogeneity marker was quite high (*I*-squared over 90%), the authors found in their review of eight studies, that HEMS for stroke doubled the odds of good functional outcome (OR 2.0, 95% CI 1.8-2.3, p <.001). HEMS was not associated with improvement in mortality (OR 0.7, 95% CI 0.6-1.1, p = .10).

Sioutas (2023) The impact of weather and mode of transport on outcomes of patients with acute ischemic stroke undergoing mechanical thrombectomy; *Neurosurgery* [289]

This study focused on weather but also reported on HEMS and stroke outcome. HEMS was not statistically significantly associated with either outcome improvement or decrease in the major complication of symptomatic intracranial hemorrhage. Point estimates for these endpoints were favorable for HEMS, but CIs were wide and p values did not come near the .05 cutoff; for functional outcome HEMS OR was 1.45 (95% CI 0.57-3.70, p = .441) and for symptomatic intracranial hemorrhage the HEMS OR was .55 (95% CI .13-2.42, p = .428).

Urdaneta (2023) Air medical transport for acute ischemic stroke patients; *Air Med J* [290]

In an assessment of scene and interfacility transports to stroke centers, this study used the endpoint of patients' receiving standard-of-care thrombolytic therapy. HEMS associated with increased chances of receiving thrombolysis (OR 2.57, 95% CI 2.38-2.78).

Vuorinen (2024) A hybrid strategy using an ambulance and a helicopter to convey thrombectomy candidates to definitive care: A prospective observational study; *BMC Emerg Med* [78]

The study examined time savings (from referring hospital to stroke center) associated with hybrid transfers – HEMS met patients *en route* via GEMS and completed the transport by air. HEMS use saved 25 minutes, judged to be a clinically significant time interval in these cases (who were transported for thrombectomy).

Bhatt (2024) Acquisition of prehospital stroke severity scale is associated with shorter door-to-puncture times in patients with prehospital notifications transported directly to a thrombectomy center; *J Neurointerv Surg* [70]

In the authors' system (in Pittsburgh) prehospital stroke scales are dictated by protocol for GEMS and HEMS cases. HEMS crews' doubling of stroke scale execution (RR 2.1, 95% CI 1.7-2.6) was associated with a speeding-up of door-to-puncture time of eight minutes.

Koneru (2024) "Chopperlysis:" The effect of helicopter transport on reperfusion and outcomes in large-vessel occlusion strokes; *Interv Neurorad* [291]

The study of patients undergoing stroke transport, many after thrombolytic therapy, found that spontaneous reperfusion was significantly more likely in those transported by helicopter. HEMS cases spontaneously reperfused in 11.8% of transports; 0% of GEMS cases spontaneously reperfused. The NNT for HEMS *vs.* GEMS transport based on this risk difference is 8 (95% CI 6-14).

Vascular

The major-vessel HEMS diagnosis that arises most often in HEMS transport is aortic pathology, for which savings of time can be important. There are some series assessing HEMS transport of non-traumatic aortic disease, but data tend to be limited in both overall number (power to discern outcomes differences) and ability to adjust for acuity. As much as time savings, intra-transport care (*e.g.* hemodynamic management) may be important. [292-294]

Kent (1989) Helicopter transport of ruptured abdominal aortic aneurysms; *Ala Med* [295]

This was one of the earliest descriptions of the "direct-to-OR" transport for non-trauma diagnostic groups. This type of expedited care, though difficult to assess statistically, seems likely to occasionally benefit patients since there's not much that can be done outside of the OR.

Shewakramani (2007) Air transport of patients with ruptured aortic aneurysms directly into operating rooms; *Prehosp Emerg Care* [80]

It's feasible and occasionally useful for HEMS crews to sometimes bypass receiving hospital EDs in order to bring cases directly into the operating room. The ready access of referring hospitals to CT scans translated to 100% accuracy in correctly identifying patients with ruptured AAA.

Knobloch (2009) HEMS *vs.* EMS transfer for acute aortic dissection Type A; *Air Med J* [294]

In a series that included both scene and interfacility transports, HEMS had no apparent benefit for scene transports (mortality and transport distances were similar for air and ground groups). For interfacility transports, the finding of similar mortality despite much longer transport distance (HEMS 110 km, GEMS 41 km) supported a possibility that HEMS allowed for time savings. The time savings is potentially important, as the authors quote the classic 1% mortality increase per each hour from symptom onset to operative intervention.

Rose (2019) Ground same intratransport efficacy as air for acute aortic diseases; *Air Med J* [293]

In a series that included both aortic dissection and AAA, findings included equality of HEMS/GEMS mortality as well as most components of hemodynamic management as measured at receiving center arrival; there was no assessment of intra-transport hemodynamics.

Ishikawa (2024) Role of helicopter transfer and cloud-type imaging for acute Type A aortic dissection; *Thorac Cardiovasc Surg* [296]

In a series that included both aortic dissection and AAA, findings included equality of HEMS/GEMS mortality as well as most components of hemodynamic management as measured at receiving center arrival; there was no assessment of intra-transport hemodynamics.

Section 4: Potential HEMS benefits supported by evidence

The array of potential benefits perceived with HEMS is illustrated in a New Zealand survey of requesters of air transport. In half of the cases, time was the main factor for HEMS activation. In a third, geographic access was key. For the remaining cases, flight crew expertise was the aim of those calling for HEMS.[297]

This section of the monograph attempts to bring together the evidence addressing the myriad possible HEMS benefits. Any conclusions are necessarily preliminary, given the non-definitive nature of existing data. However, HEMS is in wide use today, all over the world. Decisions about if and how HEMS is to deployed must therefore be made now, even in the setting of a suboptimal evidence base.

Mortality improvement as an endpoint

Overview

Studies that directly assess HEMS *vs.* GEMS outcomes using the endpoint of mortality are covered in this section. As noted elsewhere, most of the data that directly measure mortality as a function of transport modality are in the trauma literature. For non-injured patients, particularly those with stroke or STEMI, there are some preliminary data.

Trauma

Historically, the concentration of the HEMS evidence base on trauma translated into emphasis on the endpoint of survival. Studies tended to use registry-based methods (*e.g.* TRISS) best suited for a mortality endpoint.

Unfortunately, methodological heterogeneity in the HEMS trauma literature renders MA difficult, if not impossible.[11] Studies including all trauma transports are quite different from investigations including only cases with a certain ISS cutoff, and the ISS issue is compounded by different investigators' employment of varying ISS cutoffs to define study groups.

Analyses focusing on various subgroups (*e.g.* TBI, pediatrics) comprise their own subsets of the HEMS trauma literature. These studies' findings (*e.g.* influence of ETI on outcome) may not be appropriate for extrapolation to the broader group of all injured patients.

An additional challenge in the collective summary of the HEMS trauma literature is that some of the best studies assess use of HEMS as part of a wider trauma system; it can be difficult to parse HEMS' incremental effect (if any) from the systemwide factors.[144,179,298]

With the above *caveats* in mind, the preponderance of the literature as outlined above supports a conclusion in favor of mortality benefit for HEMS use in trauma. While the weight of the evidence addresses scene HEMS use there are sufficient data supporting interfacility HEMS benefit to justify inclusion of these patients in the general group of injured cases in whom HEMS may be useful. At the minimum benefit range, particularly for the general population of injured children, the proportional mortality reduction is as low as a few percent. For the broader population of trauma cases as currently triaged to HEMS, air transport's mortality reduction varies with particular population characteristics but is likely in the range of 10-30%. A rough estimate for the range of *W* is 1 to 10.

Given the above, the phrase "there is controversy regarding HEMS benefits," ubiquitous in HEMS trauma studies' introduction sections, is most applicable to questions about *degree* of benefit. Although the available evidence base supports a conclusion that there is mortality benefit with HEMS as currently deployed – in other words, HEMS as dispatched today, using suboptimal triage – there is much work to be done in the realm of triage; this subject is addressed later in the monograph.

Non-trauma

Trauma-centered HEMS literature may tend to focus on mortality with less information on mechanisms underlying putative survival effect, but non-trauma HEMS evidence has the opposite problem of emphasizing endpoints other than survival. The abundant, if mixed-quality, data addressing HEMS outcomes in non-trauma include few studies directly examining transport mode and its effect on survival. The literature that does exist is largely restricted to safety studies and demonstrations of survival equivalence for patients distant from tertiary care.

The first category of non-trauma outcomes studies is the safety study. These analyses address whether there is increased mortality due to physiologic dangers (*e.g.* vibrations, altitude) inherent in HEMS' in-flight setting. The conclusion based on available information is that there is no reason to suspect such risks. For widely disparate populations ranging from neonates to post-lysis stroke, aortic dissection, and STEMI, HEMS transport is not associated with concerning physiologic derangement or increase in mortality.[97,110,277,296,299] There do remain some questions requiring further study about both noise and vibrations attendant to HEMS in neonatal transport. Two studies[300,301] have suggested that these parameters may exceed desirable levels, but authors also point out previous studies[302] demonstrating the problem may be equal (or worse) with GEMS transport.

Besides the safety studies, the other mortality-related endpoint for HEMS transport of non-trauma is demonstration of equivalence in outcomes for patients distant from tertiary care, as compared to those presenting primarily to tertiary centers. These types of studies are in essence aiming to show that HEMS extends the reach of specialty care centers, allowing those at geographically distant locations to benefit from the same survival benefits as those patients who live close to high-level care. Data suggest HEMS can successfully extend specialty-center survival benefit to a variety of non-trauma diagnostic groups including neonates, high-risk gravida, and those with STEMI.[44,134,135]

The final category of non-trauma studies of HEMS' mortality impact, studies assessing mortality as part of a composite endpoint, includes few data. Perhaps the best example of this category is the AIR PAMI trial, in which STEMI cases transported for primary PCI had a six-fold improvement as compared to non-transported cases (lysed at referring hospitals). The AIR PAMI transport cohort's improved outcome occurred as measured by a composite outcome that included survival.[69] This is a less-commonly encountered endpoint in the non-trauma literature, and even AIR PAMI (despite its name) assessed a largely ground-transported interfacility cohort. There is thus insufficient available information to draw even preliminary conclusions regarding HEMS' impact on composite endpoints that include survival.

For non-trauma populations, the dearth of direct assessments of HEMS' survival influence will not be resolved until there is a reliable method to adjust for differential acuity in HEMS *vs.* GEMS cohorts. In the meantime, HEMS' non-trauma literature offers just a few limited mortality conclusions:

1) HEMS is not associated with unmanageable in-flight medical risks that decrease survival,
2) HEMS can extend the survival benefit associated with tertiary care to geographically distant patients, and
3) The best case for mortality benefit associated with HEMS transport of non-trauma cases lies in consideration of non-mortality endpoints closely linked to survival. These endpoints are addressed in the next subsection.

Clinical outcomes other than survival

Overview

When mortality studies are lacking, non-mortality endpoints provide the next-best endpoint set in an examination of HEMS benefits. Even in the trauma population, for which there are data directly addressing mortality effect of transport mode, non-mortality endpoints can provide useful and complementary information (*e.g.* by suggesting mechanisms for HEMS survival benefit). Some non-mortality clinical endpoints are well-accepted as independent outcomes measures that could justify HEMS use.[21]

When assessment of HEMS' clinical effect is restricted to mortality analysis, a potentially important part of the transport-mode outcome picture is excluded. In the realm of trauma, for example, those considering the weight of the evidence in favor of HEMS' improvement of mortality have concluded that if HEMS improves mortality there are likely considerable non-mortality outcome gains as well.[195] Thus there are sound reasons to consider what non-mortality benefits may be achieved with use of HEMS.

Functional survival

Within the group of patients whose survival is effected by HEMS, one important question regards functional outcome. If HEMS is saving lives only to increase neurologically non-functional survivors then argument in favor of air transport is reversed. Findings from large-scale trauma studies have been judged to "refute the hypothesis that only the most severely injured patients with a low quality of life benefit from helicopter trauma team" deployment. [184]

More recent trauma studies have also specifically demonstrated improvements in functional outcome (*e.g.* discharge to home).[28,111,188] Non-mortality clinical outcomes have also been specified in the HEMS STEMI literature.[69]

Functional survival is also clearly linked to the logistics (time-savings) endpoint to be subsequently discussed for stroke transport.[52]

Airway management

Prehospital airway management, specifically ETI, is a complex subject. Performance of ETI is not universally accepted as an outcome for HEMS studies. Some investigators failing to find HEMS benefit have theorized that flight crews' higher propensity to perform ETI actually worsens outcome.[259] Such reasoning is likely flawed, at least in some settings, given data demonstrating outcomes detriment from prehospital ETI apply to GEMS (not HEMS) airway management. Because of the importance of airway management in acute care (failed ETI is a well-known cause of preventable death),[303] and because of the disparity in apparent impact of prehospital ETI when performed by HEMS as compared to GEMS, further attention to the subject is warranted here.

This subsection addresses four major findings regarding prehospital ETI. The overarching lesson from the evidence is that with HEMS *vs.* GEMS, ETI is more likely, success rates are higher, and peri-ETI oxygenation, ventilation, and hemodynamics are more stable. The preponderance of available evidence supports the conclusion of individual researchers and groups such as the Oxford Centre of Evidence Based Medicine, that airway management is one of the major pathways by which HEMS improves outcomes.[304] Even in critically injured subgroups such as those in trauma arrest, HEMS is significantly more likely than GEMS to provide ETI (and ETI is associated with increased chance of return of spontaneous circulation).[305] The reasons for ETI as a mediator of HEMS' improved outcome are four-fold:

1) <u>Even after adjustment for acuity and other factors, HEMS is more likely to perform ETI than GEMS.</u> In one rural trauma setting, ETI was performed in 81% of HEMS and virtually never in GEMS.[176] Even in more urban settings (Germany) in which GEMS crews included physicians, ETI was 33% more likely in HEMS *vs.* GEMS cases (the difference in airway management was deemed a likely mechanism for the study's finding of markedly improved trauma survival with HEMS).[189] Others in Europe studying HEMS and GEMS in settings where both modalities were physician-attended have also identified frequent ETI in the HEMS cohort.[196,200]
2) <u>Compared to GEMS crews, flight teams have higher 1st-attempt and overall success rates for ETI.</u> For both adults and children, HEMS crews demonstrate ETI success rates that rival those achieved in EDs, whereas there are lesser success rates with GEMS ETI.[27,28,59,306] It seems likely that poor results from GEMS ETI are related to providers' procedural opportunities (*i.e.* lesser numbers and thus less experience) and differences in initial and ongoing training opportunities. Experience differences are highlighted by authors of studies demonstrating ongoing high ETI success rates for HEMS that is often (but not always) physician-staffed. Some illustrative reports include the following:
    - In 2014, a 16-month experience of a U.K. physician-based flight crew newly introduced to a rural trauma catchment found a 100% ETI success rate.[307]
    - Another 2014 report covering five years of airway management by a physician-crewed Dutch HEMS service compared HEMS and GEMS ETI success in the same patients, for whom HEMS administered ETI drugs and then GEMS attempted one ETI pass before HEMS crews took over. The Dutch found 1st-attempt ETI success significantly higher for HEMS (85% *vs.* 46%).[166]
    - In 2015, an Australian group reported 100% ETI success rates by their paramedic-staffed HEMS crew, for both adult and pediatric patients.[308]
    - Two years after the above study, another Australian group reported in a group of pediatric cases (n = 82 cases over 64 months), an ETI success rate of 100% with 1st-attempt success in 91%.[309]
    - A five-country European research group combined with Australian investigators in 2015 to report HEMS physician ETI 1st-attempt success rate of 86%, overall ETI success rate of 98.8%, and successful airway establishment in 100% of cases.[310]
    - In a 2016 report, Swiss physician-staffed HEMS ETIs were characterized by 1st-attempt success in 96.4% of cases and overall ETI success rates were 99.5%.[311]
    - Another 2016 Swiss study analyzed 425 pediatric ETI cases, reporting 1st-attempt ETI success of over 95% with nearly 99% overall ETI success.[312]
3) <u>In TBI, there is evidence suggesting GEMS ETI worsens outcome while HEMS ETI improves outcome.</u> There are many studies identifying improved TBI outcome for HEMS as compared to GEMS.[203,313] Studies assessing HEMS *vs.* GEMS ETI performance and TBI outcome have been executed worldwide, with similar results:

- Prehospital ETI in Pennsylvania worsened TBI outcome when performed by GEMS, but HEMS performance of the procedure improved survival.[28]
- The same findings – worsened outcome with GEMS ETI and improved survival with HEMS ETI – have been reported from California.[188]
- Studies of peri-ETI physiology in patients subject to secondary brain injury have suggested that as compared to HEMS, GEMS airway management is much more likely to be characterized by hypoxemia, hypocapnia, or hypotension.[63,314,315]

4) Even when GEMS performs ETI, HEMS' post-ETI ventilation practices improve outcomes (particularly for TBI cases). In a California analysis of patients undergoing prehospital ETI (mostly by GEMS), subsequent transport by HEMS (*vs.* GEMS) was associated with 40% improved likelihood of discharge to home or rehabilitation facility; intratransport ventilatory practices were judged responsible.[155]

Physiologic stabilizing therapy other than airway management

While airway management is perhaps the easiest prehospital procedural indicator to track, other stabilizing therapies can be just as important either singly or in combination. For example, prehospital stabilization was mentioned as a mediator of overall outcomes improvement in three European studies that reported these comparisons as a supplement to their primary endpoint (mortality).[196,200] In these analyses comparing physician-staffed HEMS to physician-staffed GEMS units, the HEMS crews were significantly more likely to execute prehospital interventions such as thoracostomy or blood transfusion. For the highest-severity trauma cases – those with traumatic arrest – HEMS has been demonstrated to be useful in administering therapies (*e.g.* blood transfusion, difficult IV access, thoracostomy) that improve likelihood of return of spontaneous circulation.[305,316] Others have also remarked on the higher likelihood of appropriate fluid resuscitation or thoracostomy. In a 2024 report that noted tranexamic acid (TXA) survival benefit drops by 10% for each 15-minutes' delay in its administration, Gulickx[317] reported that for patients with trauma or non-trauma severe hemorrhage, HEMS was 4.4 times more likely to administer TXA (OR 4.4, 95% CI 3.0-6.3).

Given the importance of hemodynamics as a mediator of secondary brain injury, the TBI literature occasionally includes measures of HEMS *vs.* GEMS blood pressure management. Findings of improved prehospital perfusion pressure have been reported by studies that showed HEMS' favorable TBI impact in Italy and Austria.[111]

Pain management

After being neglected for too long as a priority in acute-care and prehospital medicine, the subject of analgesia now receives due attention. Commentators have written that pain care is a valid outcomes endpoint for assessing prehospital care, and that HEMS' analgesia practice is often much more diligent than that of GEMS. [318-320]patients with isolated fractures, for example, reported analgesia rates range from 1.8-12.5% for GEMS while HEMS reports describe analgesia rates above 90%.[54] Similar findings of better pain relief have been reported for HEMS *vs.* GEMS transport of cardiac patients.[55]

It is easy to argue that good pain care *could* be brought to bear by GEMS, but the existing evidence on what *is* done, is currently consistent with a HEMS pain management benefit. It seems unlikely that better analgesia practice will ever be a sole reason justifying HEMS dispatch, and there are occasional studies[293] finding equally effective pain relief for GEMS and HEMS cases. Overall, it is fair to conclude that pain care constitutes an important part of a multifaceted non-mortality benefit package that is likely obtained with HEMS.

Logistics and systems-level benefits

Overview

Logistics variables such as time savings have long been employed as surrogate endpoints. For trauma, the notion of the "golden hour" underpins the logistics case for HEMS[304,321] and a growing evidence base has arisen for time criticality of some non-trauma conditions. This subsection of the monograph considers access and time-related endpoints from HEMS outcomes studies. The endpoints to be addressed include time savings for ALS arrival to patients, streamlining of time from scenes or referring hospitals to tertiary care, and minimization of out-of-hospital (transit) time.

HEMS as a mechanism for broad coverage with timely advanced care

Particularly in rural or isolated areas, HEMS may represent the best means to get ALS to patients within a reasonable time frame.[322-324] A German logistics analysis found that a single HEMS unit can cost-effectively cover an area that would otherwise require six GEMS units.[325] An American prehospital expert, calculating a similar result (that a single HEMS aircraft can cover roughly the same geographic area of seven GEMS ambulances), has written: "This kind of coverage, in many areas of the country, provides advanced care where it is not otherwise available."[27]

The survival benefit of HEMS-associated faster "time to treatment" (*i.e.* by HEMS crews) has long been noted in systems throughout the world.[324,326-328] Expert reviewers, citing both HEMS evidence and also studies finding trauma mortality increasing with prehospital GEMS response delays, identify rapid access to experienced providers as a mechanism by which HEMS scene response improves injury outcomes.[91,111,304] Many have found HEMS' rapid movement of advanced care to the injured improves outcome even when there is no savings of overall prehospital time.[23,73,186,324]

In some remote regions, HEMS provides the only timely access to care at the ALS level (or higher).[324] Even at scenes when GEMS ALS is on site, HEMS crews' added experience can be valuable. Many procedures executed by HEMS with demonstrated positive impact on outcome (*e.g.* ETI) are also within the purview of GEMS ALS providers but the HEMS crews are more likely to execute the procedures with clinical effectiveness.[28,73,111,189]

In fact, GEMS ALS crews at scenes often defer procedures such as ETI to arrival of the HEMS crews who are perceived as more experienced.[16] The HEMS benefit of quickly getting seasoned crews to patients is also reported as beneficial for interfacility transports, when patients are at small hospitals where non-specialist ED physicians often have less experience with high-acuity cases.[27,75,83]

The added clinical experience usually present with HEMS crews is often complemented by a broader scope of practice as compared to GEMS. Extended practice capabilities and aggressive early stabilization (*e.g.* blood transfusion, antibiotics for open fractures, thoracostomy and even rare thoracotomy) have been advanced as justifications for HEMS in regions with limited GEMS capabilities.[111,198,329,330]

HEMS crews' advanced-care benefits are not restricted to executing procedures in trauma patients. Flight crews have administered critical-care therapies such as antivenom, TXA, or stroke thrombolysis[331-333] HEMS transport is for many rural areas the only mechanism for interfacility movement of patients with complex medical devices such as intra-aortic balloon pumps.[334]

The final aspect of HEMS' benefit in providing ALS coverage comes into play when an area with sparse GEMS ALS coverage must transport a patient to distant tertiary care. Such transports leave the local system with inadequate ALS response capability. HEMS can either provide ALS back-up for the area that's lost its in-transit GEMS unit or – more commonly, although less desirably – HEMS can simply execute the transport to prevent regional stripping of ALS coverage.[241]

Getting patients to hospitals faster: Timing endpoints and the case for time savings as a surrogate outcome

The idea of HEMS utilization to expedite care for patients with time-critical injury and illness is not new. HEMS can potentially save time when used to take patients from scenes to tertiary care (perhaps with bypass of nearby less-capable hospitals), or from referring hospitals to higher-level centers.

When time savings involves comparing scene or interfacility transports of HEMS *vs.* GEMS' execution of the same transport leg, logistics calculations are usually straightforward. When HEMS is used to bypass local facilities in favor of moving patients directly to tertiary care (*e.g.* trauma centers or PCI suites), there are system-level logistics benefits but time savings are not easily calculated since GEMS would have gone to a local facility.

In laying groundwork for importance of HEMS' contributions to survival as related to time savings, it is useful to have reliable metrics allowing extrapolation of a given time savings to a given mortality improvement (*i.e.* "savings of *x* minutes translates into survival improvement of *y* lives"). No such linear relationship exists for the population of injured patients. However, there are data supporting extrapolation of time savings for STEMI patients undergoing transport for PCI, and for stroke patients undergoing transport for neurointerventional procedures or thrombolytic therapy. Therefore, while there is little argument over the general desirability of time savings in trauma, the equations relating time savings to discrete outcome increments relate to STEMI and stroke transports.

For cardiac patient transports, getting STEMIs to primary PCI is the treatment of choice – improvements occur in both mortality and non-mortality outcomes such as reinfarction and stroke – if PCI can be reached within a therapeutic window. One goal of prehospital systems is the transport of STEMI patients to primary PCI within 90 minutes of EKG diagnosis. However, the traditional 90-minute window is not absolute; earlier is better even with PCI times below 90 minutes. Above 90 minutes, and up to 150 minutes, each 15-minutes' PCI time savings gains 6.3 lives per 1,000 PCI cases; there is benefit to time savings throughout a door-to-balloon PCI range of 45-225 minutes (*i.e.* up to 3¾ hours).[120,121] Considered another way, a meta-analysis from the cardiology literature estimates that for every 30 minutes' time savings to primary PCI (for patients undergoing PCI within three hours of presentation), mortality is reduced 25%.[335]

In stroke, each hour of stroke ischemia results in neuronal damage approximating 3.6 years of normal aging and worsens mortality by about 16%.[52] Considered in smaller time increments, savings of each 15 minutes in stroke lysis improves survival by 4%.[52] Meta-analysis of available literature (in 2024) estimated that for each hour of time savings to endovascular therapy, the odds of functional independence (modified Rankin Score of 0-2) increase by 25% for those treated within 4.5 hours, and 22% for those treated in the window of 4.5-6 hours after symptom onset.[336]

Time savings: HEMS vs. GEMS transport from scenes to tertiary centers

The scene trauma response literature includes frequent references to the possibility of time savings as a mediator of HEMS' outcome improvement,[28,202] but there are surprisingly few trauma data directly demonstrating improved scene-case survival solely due to HEMS' being faster.

Improved mortality associated with HEMS trauma transport is commonly attributed in part to direct transport to high-level trauma care and HEMS' ability to extend the reach of a trauma center. It is not simply time savings that's responsible for better outcomes; it's the fact that there is bypass of hospitals lacking expertise, to get injured patients to trauma centers.

One additional facet of scene HEMS response and time savings is the contention that, even when HEMS doesn't result in overall prehospital time savings, the improved out-of-hospital stabilization saves time at receiving centers. Some research finds that since procedures such as IV placement and ETI have been done in the field, trauma center work-up (*e.g.* cranial CT imaging, urgent surgery) can proceed more quickly after patient arrival at the tertiary hospital.[111,337]

The system-based impact of logistics on trauma mortality has been argued in a *JAMA* study which found that HEMS was an important means of extending trauma center access since it represented the only mechanism by which 27% of the USA population had timely (<1 hour) Level 1 or 2 trauma center access. [338] The fact that HEMS provides the only timely access to high-level trauma care is particularly noteworthy, since trauma center care results in a distinct outcomes benefit as compared to other levels of trauma care.[338]

Systems-based conclusions similar to those for trauma, have been applied to thermal injury. While there is not necessarily a "golden hour" for burn patients, early burn center care improves outcome and HEMS is the sole mechanism by which millions in the USA can access burn centers within 2 hours of injury.[339] (It must be acknowledged that there is no shortage of burns studies that conclude HEMS is substantially overused for thermal injury.)[241,340]

Non-trauma cases comprise an additional facet of the evidence base assessing HEMS' scene-run time savings benefits. The timing advantage of moving patients directly from scenes to definitive care, often bypassing local facilities with less capability, is particularly important for stroke and STEMI. Just as the previously noted *JAMA* publications outlined systems-based access enabled by HEMS, there are similar findings for HEMS' ability to provide access to advanced STEMI and stroke care. HEMS presence is responsible for substantial increases in proportions of Americans with timely (<1 hour) access to stroke thrombolysis (from 81% to 97%) and endovascular intervention (from 56% to 85%).[341]

The principle of HEMS non-trauma scene response utility is illustrated in such case reports as one from Ohio, in which HEMS responded to a rural scene where GEMS diagnosed STEMI. HEMS took the patient to a specialty-hospital PCI lab in less time than it would have taken GEMS to transport the case to a non-PCI center. [342] For STEMI, as in other time-critical conditions, there is some argument for bypassing community hospitals in favor of direct transport to larger, higher-volume centers with more capabilities for primary PCI.[124]

Calculations pertinent to the PCI time-savings discussion come from one study that assessed interfacility HEMS transports for primary PCI that occurred from referring hospitals that had initially received those patients by GEMS. The researchers modeled the time savings that would have been accrued if, instead of transporting patients from the cardiac scenes to local non-PCI facilities, GEMS would have instead called HEMS for transport directly to PCI centers. Calculations determined that HEMS dispatch to the cardiac scenes would have saved 48 minutes from initial medical contact to PCI.[343]

HEMS scene response for STEMI cases going to PCI has been reported in case series. A Massachusetts study confirmed the utility of simultaneous HEMS dispatch and PCI lab notification (with bypass of the receiving center ED) to save 10-20 minutes in STEMIs transported from the scene.[81] Scene responses also comprised a part of the study set for a Danish study finding 20-30 minutes' time savings for HEMS *vs.* GEMS transports of over 55 miles.[344]

For stroke patients, time savings is an accepted endpoint[22] and HEMS has been identified as maximizing the arrival of patients to stroke centers within interventional windows. In Austria, for example, stroke patients who were scene-transported by HEMS directly to tertiary care were more likely to arrive at stroke centers within a pre-specified 90-minute window than the other two groups assessed (those transported by GEMS to stroke centers, or transported by GEMS to community hospitals with subsequent HEMS transport to stroke centers).[20] Similar extension of stroke center reach has been reported in the USA.[74,280,345]

The endpoint of HEMS time savings for both trauma and non-trauma scene transports is inextricably linked to the systems question of when patients should bypass local hospitals in favor of tertiary center care. Use of HEMS as a mechanism to bypass community hospitals is not without potential objection from both the bypassed hospitals (financial reasons) and the receiving centers (patient overload). The issue is complicated because it is only partially a transport vehicle question; the bigger picture revolves around system decisions regarding which clinical services are offered at which hospitals.

Time savings: HEMS vs. GEMS transport from referring hospitals to tertiary centers

Interfacility timing endpoints address whether there is time gained by use of HEMS *vs.* GEMS in the execution of transport from referring hospitals to specialty centers. For trauma cases, HEMS' speed in moving patients from non-trauma center hospitals to tertiary care is a long-recognized system component contributing to improved mortality.[242] On a related note, loss of HEMS services increases trauma mortality in patients presenting to non-Level I centers.[144] For non-trauma cases, particularly STEMI and stroke patients, HEMS has also been found to offer clinically significant time savings for interfacility transport.[262,346-348] The use of air medical resources to rapidly move patients to specialized centers is logical given dicta that "time is myocardium" and "time is brain." Substantial time savings in median transport time (from 1.7 to 1.3 hours) has also been identified in a Mayo Clinic study of HEMS transport for patients with severe sepsis.[349]

Time savings with HEMS should never be assumed. Neither should it be assumed that there's no time savings with HEMS when GEMS units are stationed at or near referring hospitals. A study from the University of Wisconsin[350] reported transport times from their network of twenty referring hospitals (many with on-site GEMS) and found that for all hospitals, the *average* HEMS total transport time was at least as good as the *best* ground transport time (time savings for the twenty facilities ranged from 10-45 minutes). Schoenfeld's results from Boston provide similar evidence highlighting the risk of making assumptions about relative transport times for HEMS and GEMS; HEMS' longest transport time for a single referring-receiving hospital pair was at least 15 minutes faster than actual GEMS transport times for half of STEMI transports.[77]

In time-critical STEMI cases moving from referring hospitals to PCI centers, there are data establishing the utility of HEMS in regional cardiac systems. In Cincinnati, investigators found that a series of HEMS interfacility STEMI transports rarely got patients to PCI within 90 minutes of initial presentation,[351] but the door-to-balloon median (131 minutes) and interquartile range (114 to 158 minutes) fell well within the accepted window for time-savings benefit. A Cleveland Clinic report, also using a 90-minute window as an endpoint, described integration of HEMS into a system's referral streamlining approach (*e.g.* HEMS autolaunch, bypass of receiving-center ED) and tripled the proportion of STEMIs reaching PCI within the cutoff.[352]

The longer 120-minute PCI time window supported by the cardiology literature served as one of the endpoints in a Pennsylvania analysis. There, investigators instituted a streamlined HEMS transport program for community hospitals to get patients into receiving center PCI, and tracked the proportions of patients with time intervals from community hospital arrival to PCI wire-crossing that fell under pre-specified endpoints of 90 and 120 minutes. For both time frames, the proportions of patients meeting the timing endpoints increased significantly (under 90 minutes, from 0% to 24%; under 120 minutes, from 2% to 67%).[262]

Instead of examining numbers of cases arriving at PCI within a certain time window, some investigators have simply attempted to quantify expected time savings accrued with HEMS use. In locations as disparate as Denmark and Japan, estimates for STEMI time savings with HEMS *vs.* GEMS PCI transport fall in the range of 20-30 minutes.[344,353,354]

As a final logistics endpoint for HEMS in PCI, there are data indicating that community hospital diagnostic or therapeutic PCI programs are often safe only when there is HEMS back-up to transport cases to tertiary care when there is need for urgent further intervention.[355,356] When considering these reports of HEMS integration into a cardiac care system, the HEMS benefit is neither easy to measure nor fair to ignore.

Interfacility transport time savings with HEMS have also been reported for stroke. An Austrian Stroke Registry analysis of likelihood of interfacility-transported stroke patients' receiving thrombolysis (an endpoint selected to reflect timely transport) found significantly higher treatment rates in HEMS *vs.* GEMS cases.[20]

Time savings: Reduced in-transit (out-of-hospital) time for interfacility transports of unstable cases

As an additional facet to the time issue, the issue of out-of-hospital time (for interfacility transports) should be considered separately from the subject of pre-trauma center time. Even if a HEMS service takes longer than local ground units to respond to a community hospital patient requiring transport to a tertiary care center, the actual time spent in patient transport is much less for HEMS patients and this parameter is sometimes critical. In one trauma study, for instance, even though the overall time characteristics of HEMS were not significantly better than ground EMS, the actual out-of-hospital time saved by HEMS use averaged 20 minutes (58 minutes for HEMS *vs.* 78 minutes for ground transport).[321]

In some patients – especially those who are in tenuous condition or who may require difficult interventions in the event of deterioration – minimization of time spent in the relatively uncontrolled out-of-hospital transport environment is a major goal. As an example, in some areas high-risk obstetric patients are often transported by air (helicopter or fixed-wing) to minimize out-of-hospital times and decrease chances of intratransport delivery. In Japan, for instance, reduction in out-of-hospital times averaged over 100 minutes for high-risk obstetric patients transported by helicopter as compared to ground; the reduction in out-of-hospital times was theorized by the authors to contribute to favorable outcomes in their transported population.[79] A group from Los Angeles also found significant time savings with HEMS obstetric transports. More importantly, the Californians reported that a quarter of the obstetrics cases that were successfully air-transported to optimal delivery conditions at maternal-fetal medical centers would have stayed to deliver at referring hospitals if HEMS had been unavailable.[44]

HEMS benefits in disaster and mass casualty incidents

The helicopter offers advantages of being flexible with respect to receiving center; aircraft speed and range can bring distant hospitals into play if local facilities are overloaded. This has obvious benefit in unusual circumstances such as disasters.[89,357]

The versatility of rotor-wing aircraft can translate into unique utility. For example, in the case where a medical expert or team needs to be transported to the patient, the speed and logistical capabilities of the helicopter may be useful. This was the case in the 2005 London subway bombing mass casualty incident, during which London HEMS flew at least 25 missions involving transport of medical teams to injury scenes (Personal communication, Dr. David Baker of the UK's Health Protection Agency, June 2007.) Others have also discussed the fact that HEMS flexibility translates into multiple potential uses during disaster and mass casualty incidents.[357-361]

Conclusions regarding HEMS benefits

HEMS potential benefits as discussed in the literature include improved survival, better functional outcomes, and favorable impacts on physiologic and procedural endpoints. There are also logistics and systems-based benefits that include some factors easily linked to patient survival (*e.g.* faster time to PCI) and other factors more difficult to precisely define (*e.g.* provision of needed back-up for rural GEMS).

The outlining of the literature's discussion of possible HEMS benefits should not be interpreted as a blanket endorsement of all of the iterated potential advantages of air transport. The case for individual endpoints should be considered in light of the evidence most applicable to a given setting. Whether the case for a particular outcome advantage has been successfully made is a point of judgment, but understanding the nature of the endpoints and the state of current evidence should inform that judgment.

In formulating opinions regarding HEMS' benefits, a natural next step is to ask "Is it worth the cost?" The next section introduces the complex subject of juxtaposing HEMS costs and benefits.

Section 5: HEMS cost-benefit assessment

Calculating HEMS costs and benefits in the absence of precise data

The lack of agreement as to degree, or even existence, of HEMS' benefits is an obvious impediment to calculating air transport's cost-benefit ratio. One review from 2010 assessed 13 HEMS cost-benefit studies and reported that in five of the analyses there was no HEMS benefit (and thus no cost-benefit); in the other eight studies HEMS cost-benefit was roughly $3000 per life-year saved for trauma and $12,000 per life-year saved for non-trauma. Perhaps equally interesting was the width of the range reported in the literature for annual HEMS costs: $116,000 to $5.6 million.[362] It is not uncommon to see phrasing such as "HEMS is 10- to 15-fold the cost of GEMS."[25]

It's not just the vehicle cost side of the equation that lacks clarity. Ascertaining the true, all-encompassing cost differential between air transport and alternatives is not always straightforward for a variety of reasons such as how to calculate crew costs (*e.g.* for HEMS crews that also work in the ED during their shifts). The inescapable conclusion is that precise cost-benefit calculations for HEMS remain elusive.

Even if there is more uncertainty than would be desirable in HEMS' cost-benefit mathematics, the assessments must still be attempted. In the USA alone, there are hundreds of thousands of HEMS missions annually. Such a prominent part of the healthcare system cannot be free of economic scrutiny, even if the available information is not ideal.

The data that are available, strongly suggest that – at least when viewed retrospectively – HEMS is often used for cases that don't benefit. Some authors report that in their regions, there are no HEMS-use guidelines at all. [185]Others report that there's widespread variation in compliance with dispatch guidelines even when such criteria have been promulgated by EMS regions.[363] It's thus not surprising that there are frequent reports of HEMS use for minimally acute patients for whom there was no benefit.[259,364,365] Such overuse is not limited to the USA, with systems in developing regions such as Brazil reporting overuse of HEMS in the range of 1 in 5 cases being non-indicated.[366]

Proponents of HEMS interpret the evidence base as demonstrating that air medical transport optimizes outcomes for both scene cases and interfacility-transported patients with a broad range of conditions. Critics tend to disagree with HEMS proponents on the question of degree of outcomes benefit, but even the most ardent HEMS critics usually concede HEMS appears useful in occasional cases. Thus, the true debate isn't over the question of whether HEMS has any associated benefit; the disagreement is over the ratio of costs to benefits accrued. This section assesses the existing evidence weighing HEMS' costs against benefits.

Definitions and principles underpinning HEMS economics studies

Placing a dollar value on morbidity and survival improvement is complicated, involving mathematics, assumptions, and even nomenclature that can be daunting at first sight. There are difficulties in such basic decisions as assigning value to human life. This section's discussion is meant to be no more than a superficial introduction to the concepts and their application in HEMS.

The definitions of economic study endpoints can be confusing. This monograph's author – who claims no expertise in this arena – learned in graduate school that *cost-benefit* analysis measures outcomes in dollars (or some other currency units), *cost-effectiveness* analysis uses a non-dollar outcome (*e.g.* lives saved).

The cost-effectiveness study is sometimes referred to as the "real-world" economics analysis. After one performs a cost-benefit calculation, the next step is to compare the relative cost-effectiveness of a number of options, to determine which accrues the most benefit for a given amount of cost. This is an important step in the HEMS topic, because some of the cases in which HEMS may have the most benefit (*e.g.* isolated geographical conditions) are characterized by both high cost for HEMS and high differential cost-effectiveness if HEMS is compared to alternative transport modalities. Patients at scenes or referring hospitals, who will undergo attended transport to a hospital, must have some form of EMS. Therefore, cost-benefit analysis of HEMS should not be considered in a vacuum; instead, real-world calculations should consider the differential costs of HEMS *vs.* non-HEMS alternatives (*e.g.* GEMS, boat, snowmobile-and-sled).

In cost-effectiveness analyses, a final option against which HEMS transport costs and benefits should be weighed is the option of no transport at all. This option would have been selected in a quarter of obstetrics cases in one Los

Angeles series, in which HEMS unavailability would have resulted in delivery of high-risk cases at community hospitals without advanced maternal-fetal medicine capabilities. [44]The adjudication of costs and benefits of HEMS in such cases should include the monetary expenses as well as medical-outcome "costs" of patients for whom the only non-HEMS option was the no-transport option.

A third metric in health economics is the Quality-adjusted life-year (QALY), which is assessed in *cost-utility* studies. Use of QALYs is intended to adjust for various levels of functional survival. Death is given a value of 0, and perfect health a value of 1, with varying degrees of health assigned intermediate values. It can be tricky to assign a level of 0 to 1 to a given quality of life – some investigators use negative numbers for some conditions – but the QALY unit remains a broadly accepted metric.

Although these terms and approaches are often found in textbooks, many HEMS studies don't rigidly adhere to the strict definitions.[40] In general, this monograph will trade precision for consistency, using the term "cost-benefit" in non-technical application. However, readers of the economic outcomes literature are cautioned to carefully consider a given study's specific outcome metric in the framing of that study's results.

Complexity increases when one attempts to account for the bigger picture of costs and benefits. Saving a life doesn't accrue any benefits if the patient who has been saved is in a vegetative state. Also, from a utilitarian perspective it may be more "beneficial" (in QALYs) to save a 9-year-old *vs.* saving a 90-year-old.

Imprecision in even the best available HEMS cost-effectiveness studies may result in underestimation of HEMS benefit. Acknowledged by study authors themselves, such shortcomings are related to assumptions and excluded information regarding both HEMS' costs and benefits. For example, one of the most rigorous health-economics studies[40] of HEMS trauma scene response failed to consider at least four major benefits – previously addressed in this monograph – that could be accrued with HEMS: 1) morbidity and other non-mortality clinical benefits, 2) provision of ALS-level coverage in areas that would otherwise lack such coverage, 3) prevention of regional loss of GEMS ALS coverage during long transports that would have been executed by GEMS is HEMS were not used, and 4) direct transport of scene trauma patients to trauma centers rather than having GEMS take those patients to nearby non-specialty centers. This key information is largely absent in many – even the best – of the HEMS cost- benefit studies.[40]

Another consideration when assessing vehicle costs of HEMS is the concept that some regions are forced by geography (*e.g.* rural areas, service regions with terrain such as mountains or islands) to procure and operate air transport services.[263,367] As early as 1983, for instance, Jurkovich identified HEMS as an important contributor to improved survival in seriously injured skiers.[368] More recent work focusing on scene response for skiers and snowboarders (*i.e.* groups in geographically isolated areas) has also found that HEMS is associated with improved outcome (survival OR 8.6).[245]

In cases where HEMS is needed for a particular subpopulation, justification of the system's resource commitment on air transport is based on system issues. When this is the case, there may be less incremental cost (*i.e.* more favorable cost-benefit) for a given HEMS deployment. Once the HEMS service is bought and paid-for (for one subgroup), it may be fair to judge that less mission-specific benefit is necessary to justify dispatch in the broader set of cases.

Capital equipment is not the only cost arena that can be tricky in cost-benefit calculations. Since different HEMS programs operate on different staffing and operational models, personnel costs may differ. For instance, in some cases the HEMS crew salaries are "covered" under a hospital's cost center, since the HEMS crew serves as extra help in the ED or elsewhere (*e.g.* as the hospital's "IV team" for difficult-access patients). How should HEMS crew costs be calculated in these situations? This discussion makes no pretense at having the answers to either equipment or personnel cost calculation questions, but it should be obvious that the issues are sufficiently complex that one cannot simply say "helicopters are far more expensive than ground ambulances."

When professional economists assess the HEMS cost literature, they have found the evidence base's methodology lacking in rigor.[369] Even a brief read of the mathematically intensive economic analysis[369] executed as a (German) exemplar for other programs' cost analysis, renders it clear that the issues pertinent to cost calculations are neither simple nor fixed. The Germans, for example, found that the cost of a single primary mission was roughly $750 (US dollars), but this calculation depended on number of hours/day of operation (12), number of annual scene and interfacility missions (1200 and 92, respectively), and mission complexity. The usefulness of the German calculations was not so much their result, as their methodology.

The "acceptable" threshold for healthcare interventions is not universally agreed. Health policy and medical experts writing in the field tend to place it between $35,000 and $100,000.[40,370-372]

Evidence assessing overall (trauma and non-trauma) HEMS program cost-benefit

This subsection examines conclusions of authors reporting HEMS cost-benefit on a program-wide level (*i.e.* all patients of all diagnoses undergoing HEMS transport). The evidence base is not rich, but there are some pertinent studies. In this subsection and those that follow, monetary units have been converted to $US.

One of the earliest detailed assessments of HEMS' overall costs and benefits was a 1991 study assessing one year of transports (scene and interfacility, all diagnoses) in rural Norway.[159] The authors used a panel review to ascertain potential HEMS benefit and found such benefit in 15% of scene and 33% of interfacility missions. At a cost of approximately $1 million, the 13 lives saved were determined to come at a per-life cost of about $75,000. QALYs were not calculated, and the authors concluded that HEMS was too expensive (money should be invested in local systems of care).

A few years after the Norway report, another panel-review study from the U.K. found virtually no HEMS benefit (and obviously unacceptable cost-benefit). [370]The independent analysis of HEMS' cost and benefit data conducted at the Canadian Institute of Health Economics concluded that "air medical services appear to be expensive on a single-case basis but not at a system level."[9]

Scandinavia continues to provide useful data informing cost-benefit assessment. Convinced by health economics data (cost-benefit ratio of 1:5.9), Norway set (and achieved) a national goal of having 90% of the population reachable by HEMS within 45 minutes. [373] In a 2002 study, calculations for a rural HEMS service providing scene responses in Finland yielded an estimate of $30,000 per beneficial mission.[324]Two decades later,[374] an overall assessment of the national Finnish HEMS service calculated a cost per QALY of $60,000 (well within accepted standards). A Swedish HEMS analysis assessing an interfacility HEMS unit determined that while fixed-wing vehicles were most cost-effective once distances exceeded 300 km (186 miles), at shorter transports HEMS was preferred from an overall cost-benefit perspective.[375] A Danish group failed to find quality-of-life benefits from HEMS stroke transport, but concluded that their broad confidence intervals indicated low power to detect a HEMS benefit.[376]

The USA provides data addressing cost-effectiveness of HEMS *vs.* similarly expert GEMS crews spread over a New England region covered by one HEMS unit. The authors concluded that even if one could *fiat* HEMS-crews' experience and expertise across a large group of widely dispersed GEMS crews, cost-benefit calculations still favored HEMS.[24]

Perhaps the most important point to consider in these overarching cost-benefit assessments, is that they are executed using sets of actual HEMS transports that occur in a world of acknowledged triage imprecision. As will be noted subsequently in this monograph, triage is an imperfect science so it's important to consider the lack of ideal specificity seen with current HEMS dispatch criteria. Any refinements in triage and associated improvements in HEMS use appropriateness, can only improve air transport's cost-benefit.

Evidence assessing cost-benefit of HEMS *vs.* GEMS for trauma transports

The weight of HEMS outcomes data addresses transported of the injured, so it is not surprising that the weight of diagnosis-specific economic evidence evaluates HEMS use for trauma. Data from around the world support a contention that HEMS has favorable cost-benefit for response to injury scenes.[195,371,377,378] This may be simply because patients are transported directly to scenes to trauma centers where more expert care translates into improved outcomes (and thus more favorable HEMS cost-benefit).

It's possible that some HEMS scene response cost-benefit arises from cost savings via eliminating the community hospital stop in a patient's pathway from injury scene to trauma center. It has been long-known that there are substantial costs incurred transporting patients to a lower-level hospital before secondary transport to a trauma center. Studies from nearly two decades ago found that the extra hospital stop adds at least $700 to per-patient transport expenditure.[377] Similar preventable costs occur due to repetition of laboratory and radiology evaluation at referring and receiving hospitals.[379] Expenses have doubtless increased over the years, so monetary costs of an intermediate stop at community hospitals should be considered important.

Dutch traumatologists and health-economists have assessed HEMS' cost-effectiveness in their system of scene response. The calculated cost/QALY range for HEMS supported the authors' conclusion that air medical transport was at least as cost-effective as well-accepted procedures such as heart, lung, or liver transplants (which had reported cost/QALY of $50,000-$100,000).[371]

In New South Wales, Australians found that HEMS scene response was associated with cost per life-year saved of

$72,000 for all trauma patients. The cost per life-year saved was an even more favorable $37,000 for patients with ISS exceeding 12, and $36,000 was the cost per life-year saved for TBI cases.[378]

The Australians' focus on TBI cases was echoed by findings in the USA, where it was noted that HEMS' favorable impact on TBI would have important ramifications for major cost-savings in arenas such as long-term rehabilitation.[152]

Non-mortality benefits to HEMS trauma scene response have been judged worthy of consideration.[195] There is occasional evidence addressing economic endpoints such as days off of work; HEMS has been determined in one study to reduce government-subsidized time off of work.[50] At this point, the evidence is sufficient only to conclude that limitation of cost-benefit analysis to mortality endpoints likely underestimates HEMS' favorability.[195]

One factor that can influence cost-benefit analysis is the practice of autolaunch. While the term can mean different triggers for HEMS in different areas, the practice of helicopter dispatch based on minimal criteria has potential both for increased benefit and increased cost. On the benefit side of the equation, autolaunch can reduce by nearly 75%, the transport radius at which HEMS becomes faster than GEMS.[380] The benefits come at a significant cost, though. In Minnesota, where lay passersby can activate HEMS (*i.e.* before law enforcement or first-responder arrival), autolaunch was judged cost-beneficial but the mission completion rate was just 21%.[27]

It is noteworthy that some of the same investigators who have identified major need for improvement in triage, have also found (in the same population in whom suboptimal triage was being applied) that HEMS was indeed cost-effective.[371] Health-economics analysts comprise an important part of the chorus asking for better triage. [40]However, rigorous assessments of cost-benefit in the current era of flawed triage have found scene trauma HEMS to be cost-effective (using the target of $100,000 per life-year saved) at a *W* threshold of 1.3, which is quite consistent with the outcomes benefits suggested by the preponderance of both the scene and interfacility HEMS trauma transport literature.[5,21,40]

Evidence assessing cost-benefit of HEMS *vs.* GEMS for non-trauma transports

Cost-benefit for non-trauma transports is limited by the lack of precise point estimates for benefits. Some of the non-trauma literature is suggestive of favorable cost-benefit, via time savings or other mechanisms, but the measures are either indirect or difficult to measure. The high-risk obstetrics transport literature is emblematic. In considering outcomes of both mother and newborn, high-risk deliveries best occur at maternal-fetal medicine centers. Currently available evidence suggests HEMS use occasionally enables these deliveries to occur at tertiary care centers instead of community hospitals; this is clearly cost-beneficial but not in an easily quantifiable fashion.[44]

Episodic examples of non-trauma cost-benefit aside, the two diagnostic groups with the most robust evidence basis for HEMS cost-benefit calculations are STEMIs (transported for PCI) and strokes (transported for thrombolysis or neurointerventional therapy). For each of these groups there is time-windowed therapy and broadly accepted linkage between faster access to definitive care and improved outcomes.

Assessment of costs and benefits in a sufficiently rigorous fashion to allow precise calculations is challenging. Some of the early cost-benefit work in stroke focused on different assumptions about time savings, speed, and costs. Silbergleit found that HEMS transport of acute stroke patients for tertiary care lysis cost $35,000 for each incremental favorable outcome; the cost per QALY was $3700 (ranging up to $50,000 depending on model assumptions).[381] Cost-effectiveness was sensitive to the effectiveness of thrombolysis but minimally sensitive to most other input values.

The work of Silbergleit was complemented nearly two decades later, by results from the UK. English investigators assuming a time savings of one hour for neurointervention (thrombectomy) calculated HEMS' cost at $35,000 per QALY.[287] Similar cost-effectiveness has been calculated in a South Korean study, based on both time savings and mortality reduction.[286] A 2024 analysis from Finland reported that assuring air medical accessibility for stroke patients was one of the most important contributors to overall HEMS cost-effectiveness.[374]

With regard to meta-analysis, for stroke some have concluded that the quality of evidence (assessed as recently as 2021) does not yet allow for pooled effect estimation.[14] Thus researchers have used surrogate methods to assess presence and degree of HEMS benefit for stroke.

One method to calculate cost-benefit in STEMI or stroke HEMS transports is to count those HEMS cases receiving time-windowed therapy, which would not have been eligible for such therapy had they gone by GEMS. This has been executed for both STEMI and stroke populations. One multicenter HEMS STEMI investigation, CCT CORE's HEARTS study, reported a NNT of 3: for every 3 STEMIs transported by HEMS *vs.* GEMS, one additional patient underwent PCI within a predefined endpoint of 90 minutes.[264] Another analysis of over a hundred STEMI cases evacuated off of a

Baltic island reported what was essentially a NNT of 1; HEMS was the sole transport modality allowing achievement of within-window PCI.[263]

Obviously, cost-benefit calculations related to logistics are dependent on situational specifics. Examining the broader picture of transports in Norway, one group concluded that HEMS incorporation into a regional STEMI system extended PCI cost-benefit over a much broader geographic area.[382] Similar findings have been reported in the USA, where health economists determined that centralizing PCI and establishing well-developed transport networks (including HEMS) was more cost-effective than spreading PCI capabilities across multiple smaller hospitals.[334]

The cost-benefit considerations include a word of warning highlighted by HEMS systems modelers in Norway. Calculations in that country assessed rapid HEMS response (< 15 minutes) for 99% *vs.* 100% of the national population. Findings included that 1% increment in coverage (from 99% to 100%) would require 26 additional HEMS bases. Such costs would be considered impractical by policymakers aiming to achieve neutral cost-benefit.[383]

Conclusions regarding HEMS cost-benefit

Readers should keep in mind that in the absence of benefit, cost-benefit will not be present. Investigators who find no HEMS benefit will not pursue cost-benefit calculations. This truism is doubtless partially responsible for the largely one-sided nature of the HEMS cost-benefit literature.

Regardless of which direction the existing evidence points with respect to HEMS cost-benefit, the subject is far more complex than its presentation here. The data presented in this section are intended only to familiarize the reader with basic concepts, and to provide tools that might be useful in reading cost-benefit analyses.

It is hoped that the data presented will allow the reader to view the recurring HEMS-study opening statement – “helicopter transport is expensive” – from a rational standpoint. HEMS is undoubtedly a costly and resource-intensive service. However, the question as to whether HEMS is “too expensive” requires judicious weighing of costs and benefits of HEMS as compared to alternatives of either GEMS or no transport at all. Common sense and available data support the conclusion that the best cost-benefit for HEMS will be achieved by a rational, evidence-driven transport triage process including both HEMS and GEMS.[384]

Section 6: Optimizing HEMS utilization

Definitions and principles underpinning HEMS utilization appropriateness

It's often written that HEMS should be used only when appropriate. While correct, this truism doesn't provide much practical guidance for healthcare providers facing a right-now decision as to transport mode for their patient.

Unfortunately, there are few specific, practical, validated criteria for HEMS *vs.* GEMS transport decision-making. This fact is nearly always elided in the seemingly endless stream of retrospective "HEMS appropriateness" studies using *a posteriori* methodology to classify many air-transported patients as GEMS-eligible. Such reviews are accurate, but these after-the-fact HEMS appropriateness categorizations do little to advance triage science.

This section considers the inextricably related topics of triage and HEMS utilization appropriateness. First, a few definitions should be clarified as to their use in this monograph. Some terms as applied to HEMS triage have similar meanings, and this means they are occasionally used interchangeably in a fashion that can be confusing.

- *HEMS triage* refers to decision-making regarding choice of transport modality. In this monograph, the term applies to the vehicle decision-making that occurs either at a scene or at a referring hospital.
- *Overtriage* occurs when the use of HEMS for a patient is associated with no outcomes benefit (to either the patient or the system). Overtriage is inherent in HEMS dispatch, just as it is inherent in execution of many medical decisions (*e.g.* sometimes an appropriately ordered CT scan comes back normal).
- *Overutilization* occurs when there is overtriage that is avoidable. No triage guidelines are perfect, so cases overtriaged to HEMS could still be *appropriate utilization*; this is the case if HEMS triage is defensible in light of applicable dispatch guidelines and information that was contemporaneously available to triagers.

Trauma triage and HEMS appropriateness for injured patients

Framing the issue

Determination as to which injured patients need HEMS for scene missions is a theoretically straightforward two-step process. First, decide if the patient needs a trauma center. Then, after deciding the patient needs a trauma center, decide if the case warrants HEMS response for some combination of flight crew skills and logistics.

Unfortunately, the conceptual simplicity of HEMS triage does not translate to practical simplicity. On-the-spot decisions made at trauma scenes can be rendered difficult by time pressures and myriad unknowns. Understandable bias in favor of erring on the side of overtriage must be balanced against using HEMS for trivially injured patients who walk out of the hospital within hours of arrival.

This monograph does not intend to delve too deeply into the complex and sometimes frustrating science of trauma triage. However, since general trauma triage is inextricable from HEMS trauma triage, some attention must be given the triage issue. It is not rational to expect HEMS triage to be any more precise than triage to trauma centers: if it's not known with any precision whether a patient needs to go to a trauma center, it certainly cannot be known with precision whether that patient needs HEMS.

Overtriage to trauma centers: performance of currently used criteria

There is broad recognition that the various currently used triage approaches are in need of improvement. [9]Years after the CDC's Field Triage meetings a *JAMA* report of HEMS mortality benefit in its study population of cases with major trauma (ISS >15) highlighted the ongoing triage problem of identifying those major-trauma patients: "To date, the development and use of effective pre-hospital triage tools that can identify adults with a high ISS have remained elusive."[195]

There is no known combination of anatomic, physiologic, and mechanism criteria that reliably identifies patients needing high-level care while eliminating overtriage. It is well known that limiting triage decisions to anatomic and physiologic variables results in dangerous and inappropriate levels of undertriage, rendering prehospital provider judgment (including assessment of injury mechanism) a necessary criterion.[385] On the other hand, it is just as clear that incorporation of these additional triage criteria inevitably leads to more cases of overtriage.[303,386]

The difficulties with triage mean there must be room for situational judgment with trauma scene triage as well as secondary triage at community hospitals (where physicians are determining which cases need to go to trauma centers). The goal for trauma center triage has long been based on an American College of Surgeons (ACS) position that an undertriage rate of 5-10% is considered unavoidable and may be associated with overtriage exceeding 30%; authors have continued to state general goals of 5% (maximum) undertriage with 25-35% undertriage.[387]

Phrased in a different fashion, the ACS' benchmark for undertriage requires trauma center triage criteria sensitivity of 90-95%. Investigators around the world have found that to achieve such sensitivity, overtriage often exceeds the ACS' estimate of 30-50%. [385] An Irish group, for instance, concluded that appropriate HEMS scene triage in their system was associated with an unavoidable (and acceptable) 25% rate of discharge from the receiving ED.[388] Studies from the USA are also illustrative.

In one USA cohort, limitation of trauma center triage to anatomic and physiologic criteria yielded a sensitivity (87%) that didn't quite reach the ACS goal, and yet still resulted in an 80% overtriage rate.[389] Similar results were found in a 2013 analysis of multiple different triage models' performance in the western USA. In order to reach the prespecified goal of 95% sensitivity, even the best model had poor specificity (81% overtriage) with triage precision being even worse for geriatric trauma.[390] The report showed that frustratingly little progress had been made in the decades since demonstration of the fact that following a strict set of ACS triage criteria could achieve excellent 97% sensitivity, but at a cost of an 82% overtriage rate.[391]

Some of the USA's most rigorous trauma center triage analyses are based on data from New York State's population-based trauma registry. Heart rate (HR) is but one of many interesting and instructional points made by those registry data. HR is an obviously non-specific measure, but it was included in the state's final triage model since abnormal HR (<50 or >120) was the *only* criterion present for 26% of cases requiring major operative intervention.[392]

In addition to its findings that need to optimize sensitivity dictated a need for trauma center triage rules to include non-specific criteria such as HR, the New York data also addressed the question: Can trauma center triage be based solely on anatomic and physiologic criteria? The answer was "no", since restricting trauma center destination decisions to these factors failed to identify 43% of cases needing urgent operation.[392]

Overall analysis of the New York data revealed that, to improve trauma triage sensitivity from 85% to 95%, each additional "true-positive" case identified by loosening triage criteria would come at a cost of approximately 100 unnecessary (overtriaged) patients.[392] Not surprisingly, experts from New York concluded that the suboptimal performance of triage criteria translated into a need to accept overtriage.[392]

If overtriage is unavoidable, what level of overtriage is acceptable? As previously noted, the ACS acknowledges that overtriage is unavoidably associated with maintaining desired triage sensitivity. The high end of the ACS range (*i.e.* 50%) is commonly cited, but there is no universally agreed benchmark and many experts report that overtriage rates can range to 90%.[385] On the low end, trauma systems identifying particularly low levels of overtriage have expressed concern that the low overtriage rate is reflecting substantial *under*triage.[393]

The promise of technology is currently being applied to HEMS triage, with results that are preliminary yet which provide hope. In a 2025 assessment of machine learning for prediction of need for lifesaving interventions, the AMPT group from University of Pittsburgh achieved desirable levels of negative predictive value – 95.3% - but there was still work to be done for sensitivity (which was 26.8%).[394]

Triage of trauma cases to HEMS transport: Challenges and evidence

If half of the patients directed to trauma centers are overtriaged, it is hardly surprising that many trauma cases airlifted to trauma centers are overtriaged. Of course, most patients who need trauma center care don't need a helicopter to get there and there's no controversy around the fact that currently used HEMS triage criteria often dispatch aircraft for cases that don't benefit from HEMS. The difficulty, of course, is the application of available evidence to support specific changes to triage guidelines so HEMS triage criteria maintain sensitivity without undue overtriage.[303]

Tackling the question of whether HEMS triage was indicated requires an answer to the question: "Did HEMS benefit the patient?" If triage appropriateness is defined as being present when patients had high likelihood of receiving benefit from HEMS deployment, then assigning appropriateness judgments relies on some assessment of the probability of HEMS bringing benefit in a given case. (As mentioned earlier, there are cases in which system issues rather than patient-centered benefits can justify HEMS use; such system benefits are addressed elsewhere in this monograph.)

Adjudication as to whether patients benefited from HEMS can be individualized by transport, by asking questions such as "did HEMS crews provide life-saving therapy?" or "did the patient need urgent operative intervention?" These questions are straightforward sometimes, but not always. Who decides what therapy was life-saving, or what operations were urgent? Is every ETI life-saving? Is every operation within 24 hours urgent enough to warrant HEMS?

The inherent subjectivity in assessing case-by-case HEMS transports for triage appropriateness has led many investigators to use ISS cutoffs to define appropriate HEMS use. While ISS has disadvantages, the scores are assigned in objective fashion (*i.e.* with no reason for bias towards higher or lower scoring based on transport mode). Furthermore, the HEMS outcomes evidence base itself tends to use ISS cutoffs to define groups benefiting from HEMS transport. The use of ISS to define cases for which HEMS is indicated is therefore objective, common, and as much evidence-based as any other method for adjudicating HEMS appropriateness.

ISS use for defining HEMS triage appropriateness does have a few problems. The most important is that ISS can only be used for *post hoc* appropriateness assignments. The challenge of defining triage criteria that will predict high ISS remains. The second problem with using ISS cutoffs to define HEMS appropriateness is the determination of which cutoff to use; the HEMS outcomes literature supports different cutoffs.

The large-scale *JAMA* investigation and other studies such as the previously referenced Australian study used an ISS cutoff of 15 to define "major" injury.[195,385] Many others also use the ISS >15 cutoff; an example study from 2014 reports a Dutch finding of 5.3 lives saved per 100 dispatches with the denominator consisting of cases with ISS >15.[205] However, there are many data demonstrating that HEMS improves outcomes in a group constituted by patients with lower ISS cutoffs. Some representative evidence includes the following:

- A Canadian population-based study demonstrated definitive improvement (*W* 8.8 air versus ground) with HEMS use for patients with ISS scores ≥12.[83]
- The same cutoff of ISS ≥12 was used by another Canadian group in 2016, in a study finding HEMS-associated *W* advantage of 6.6.[129]
- A cutoff one point higher (ISS >12) than the Canadians used, was demonstrated to define HEMS cost-effectiveness in a 2012 Australian study.[378]
- Germans have used large trauma registry databases to lower the ISS cutoff defining HEMS benefit even lower, to ≥9. After an initial (2013) report in which HEMS was found to bring a 25% mortality reduction for cases with ISS ≥9,[200] the Germans followed up with a larger study of over 50,000 cases (a third of which came by HEMS) confirming HEMS improved survival for the set of injured cases with ISS ≥9. [209]In fact, a 2016 German analysis found that HEMS was *most* beneficial relative to ground transport, for the ISS group 9-15 (OR for survival, 0.66).[209]

In light of the above findings, setting an ISS >15 cutoff to define HEMS will fail to identify all patients for whom the available evidence firmly suggests outcomes improvement and cost-effective HEMS use. Even if the ISS is chosen as an objective well-proven measure of injury acuity to define HEMS triage appropriateness, there remains the question as to where the cutoff should be set.

Triage of trauma cases to HEMS transport: Current status and implementable goals

The difficulty of establishing ideal triage criteria does not obviate the need for regional trauma systems to generate guidelines both for determining destination and transport mode. Having any set of rationally designed criteria is preferable to having no guidelines at all, since the latter situation invariably results in substantial HEMS overutilization.[185]

For regions aiming to optimize use of trauma center and HEMS resources, the first step is to establish triage criteria addressing hospital destination and transport mode. While the current science limitations mean no triage criteria are ideal, recent years have seen publications that can be used as bases for a region's implementation of improved HEMS trauma triage.[260,395] The NAEMSP HEMS dispatch criteria (www.naemsp.org) provide a good starting point for regional HEMS-use guidelines. For scene trauma, the Air Medical Prehospital Triage (AMPT) score described by Brown seems particularly useful: in an analysis of over 2 million NTDB cases AMPT's HEMS-triaged group had HEMS-associated mortality benefit of 28% whereas those AMPT triaged to GEMS (many of whom actually went by HEMS) had no HEMS benefit.[396] Further work by Brown has validated the AMPT in a statewide database.[395]

One little-discussed aspect of HEMS triage imprecision is undertriage. Undertriage risks increased morbidity and mortality in the trauma population. In fact, in developing trauma systems the appropriate concern for overtriage is balanced by data that have prompted major concern for HEMS undertriage (in South Africa, for instance).[397] Even in well-developed trauma systems (*e.g.* Germany), investigators confirming HEMS' survival impact have expressed concern about underutilization of the resource.[201] Investigators have found that it is difficult to predict (when retrospectively assessing, for instance, penetrating scene trauma cases) which of the patients will need HEMS-level interventions to survive.[398]

HEMS trauma undertriage is also an issue in the USA. In an era of increasing non-availability of surgical subspecialty coverage for trauma, HEMS may play an increasing role in quickly evacuating patient (from scenes or community hospitals) where they simply cannot get the interventions they need.[399] These region-specific parameters should be incorporated into a trauma system's HEMS triage criteria.

If design of HEMS trauma triage guidelines is one implementable goal, another such goal is the assurance that region-specific guidelines are actually followed. Whatever difficulties lie in design of HEMS trauma triage criteria, once those criteria have been designed and agreed within a region, they should be followed. Unfortunately, within trauma systems around the world there is broad variability in compliance with region-specific HEMS dispatch guidelines.[363,400] Fortunately, efforts such as work in North Carolina have demonstrated that HEMS overuse can be reduced by institution of active reviews and plans to improve compliance with air transport use guidelines.[401]

HEMS triage imprecision is certainly not limited to prehospital providers: physicians at referring hospitals are not consistently able to execute better triage than EMS crews at trauma scenes. Recent assessment of over 10,000 injured patients undergoing initial evaluation at 43 referring hospitals in Oregon found that even after adjusting for patient and logistics characteristics, there was substantial heterogeneity between different institutions' transfer practices.[390] Analysis of particular diagnoses (*e.g.* spinal trauma) provides further evidence that secondary transfer of these cases is often inappropriate.[402] The message is not that referring physicians are particularly poor at triage. Rather, the point is that triage is difficult and imprecise both at the trauma scene and the community hospital – physicians are not significantly better triagers than prehospital providers.[390,399]

The HEMS trauma triage discussion can conclude on a positive note. In addition to the constant evolution of the science of trauma triage, there are additional grounds for optimism in the fact that existing literature frequently demonstrates HEMS outcomes improvement with current (imprecisely triaged) helicopter deployment.

One point for optimism lies in the fact that often, it is the same investigators who demonstrate both a need for triage improvement and overall HEMS-associated mortality benefit.[16,253,255,258,303,363] On a nationwide scale, a national trauma registry analysis of over a quarter of a million trauma transports – triaged in imperfect systems around the USA – clearly demonstrated HEMS patients' higher acuity as well as a 22% mortality reduction with HEMS scene trauma response.[191] This large-scale study reported other findings of note with regard to HEMS cases across the country, that should be interpreted as a reason for optimism in light of the well-known problem of imprecise triage:

- Rate of discharge within 24 hours was much lower (<15%) than previously speculated.
- Almost half of cases required ICU admission; 20% were on ventilators, for an average of seven days.
- Nearly a fifth of patients underwent urgent operative intervention.
- Average ISS was at least 15 for cases with pre-trauma center transport time under 2 hours.
- The authors concluded that "On a national level, patients being selected for HEMS are appropriately sicker and are more likely to use trauma center resources than those transported by ground ambulance."[191]

The above points include an important logistics finding, that when patients were grouped by prehospital time, the average ISS of HEMS transports did not fall below 15 until total prehospital times exceeded 2 hours. The time-distance calculations that inform HEMS triage comprise an important part of transport mode decision-making; approaches to these calculations are addressed in a later section of this monograph.

One reasonable conclusion from the evidence outlined in this subsection is that trauma triage needs improvement and that until such improvement occurs, HEMS triage will continue to be suboptimally specific. The lack of perfection in triage criteria, while no excuse for cases of obvious HEMS overuse, should be remembered by those quick to criticize aircraft dispatch by looking at cases after the fact.

Triage of HEMS for non-trauma missions

Apart from its use for geographical or systems-related indications (*e.g.* remote-access ALS coverage), HEMS triage for non-trauma diagnoses can be even more case-specific than helicopter dispatch for trauma. Whereas the aircraft may be useful for diagnoses such as aortic aneurysm or high-risk obstetrics, it's certainly not necessary to activate HEMS for all cases of aortic disease or pregnancy. Even for stroke and STEMI, the two non-trauma diagnoses for which there is clear potential for time-savings benefit, HEMS is only appropriate when it will save significant time in a patient receiving windowed therapy. As is the case with trauma triage (noted above), available evidence suggests that when HEMS stroke overtriage is assessed, about half the cases come from scene (ground EMS triage) and the other half from physicians (interfacility transports).[403] There is little reason to believe that (with proper training) ground EMS cannot perform HEMS stroke triage at an accuracy approximating that of physician-directed interfacility stroke transfers.

Non-trauma triage decisions in STEMI and stroke cases should thus be guided by the discussion from the previous section addressing HEMS' influence on time-related endpoints and those outcomes (*e.g.* savings of at least 15 minutes is arguably a solid reason to triage to HEMS for patients being transported for primary PCI or time-windowed stroke care).

As much or more so than is the case for trauma cases, in non-trauma populations there is need to accept some degree of HEMS overtriage due to the relative paucity of high-quality guiding evidence.[9,16] As of this time, the best available consideration in guiding non-trauma patient triage to HEMS is that provided by groups such as the NAEMSP (see next section); still, these guidelines should be considered as the starting point for HEMS non-trauma triage criteria.

Every patient scenario is different, but HEMS use for many non-trauma cases is based largely on the concept of time savings. This monograph has already outlined the evidence basis for at least two large non-trauma patient groups (stroke and STEMI) demonstrating morbidity and mortality benefits from reducing time to definitive care by as little as 15 minutes. If it is true that time savings are associated with improved outcomes in some patients, the next step in triage to HEMS is to determine which situational logistics are predictive of a clinically significant time savings. The next section addresses logistics considerations that can inform decisions about HEMS triage for non-trauma (as well as trauma).

HEMS triage: *Logistics considerations*

Although occasionally HEMS use is driven by lack of GEMS access (*e.g.* islands, mountains),[404] logistics in HEMS triage is usually approached in terms of mileage or time cutoffs. Using these types of cutoffs can potentially objectify HEMS triage, restricting aircraft dispatch to cases with favorable logistics. This section of the monograph outlines evidence on various time and distance cutoffs.

An important *caveat* to reading the HEMS logistics literature is that the usual endpoint, arrival at receiving hospital, presumes that no HEMS benefits occur from earlier arrival of skilled flight crews. This may or may not be the case for non-trauma patients (*e.g.* STEMIs, strokes) with primarily time-critical transport needs (although there is evidence that points to scene-time prolongation as being associated with improved physiology even in the non-injured).[405] For trauma, however, the restriction of HEMS triage to logistics considerations ignores decades of evidence showing HEMS outcome benefit even in the absence of time-savings benefit.[73,112,191] With this limitation in mind, it is still useful to consider logistics that can inform HEMS triage. An overriding recommendation is to consider the local situation and available (non-HEMS) resources; one group, for instance, has found high-speed train travel a logistically and clinically viable alternative in an area with little ground or air ambulance availability.[406]

Mileage cutoffs for HEMS triage

There are those who posit that specific distance considerations should be the major trigger for HEMS dispatch. This subsection considers mileage-based triggers for HEMS use.

The very idea of using distance as an isolated determinant of HEMS appropriateness is introduced with caution. Time of day and traffic can be paramount determinants. It is noted, for instance, that Schoenfeld[77] in Boston found that even with a transport (linear) distance of <8 miles, HEMS saved at least 15 minutes' (average, 32 minutes) in half of STEMI cases undergoing interfacility transport for primary PCI; this corresponds to an outcomes improvement as high as 25% with HEMS use. It is prudent to avoid assumptions based solely on distance, that HEMS will be either faster or slower than alternative transport modes.

Much of this subject area's evidence base uses an endpoint of total elapsed time from transport initiation to tertiary facility arrival. Studies set the receiving hospital as the center of a circle and calculate the radius at which HEMS becomes faster than GEMS in getting patients to the circle's center. Representative findings from these studies, which include both scene and interfacility mission types, include the following:

- In a largely rural setting of upstate New York, GIS software was used to generate a radius from a trauma center at which HEMS use reduced pre-trauma center times. Helicopter transport was found to speed pre-hospital time (by a mean of 13 minutes) at distances of 6-15 miles from the trauma center.[407]
- In a Southern California trauma system employing autolaunch, HEMS becomes faster than GEMS at 10 miles' distance from the trauma center. (With standard "no-autolaunch" dispatch, HEMS wasn't faster at getting patients to trauma centers until transport distance reached 45 miles.)[380]
- A population-based study of trauma cases in Pennsylvania found that mortality improvement from HEMS' proximity to trauma scenes became statistically significant once distances from trauma centers reached 11 miles.[82]
- A 2016 analysis of the USA's NTDB finds that HEMS is associated with a significant survival increase when HEMS transport distances reach 14.3 miles (interestingly, the highest percentage of survival benefit was found for the close-in transports and HEMS benefit disappeared altogether when transport distance exceeded 71 miles).[23]
- Neurosurgical patients in Korea were found to arrive at the hospital faster by HEMS at transport distances exceeding 31 miles (50 km).[408]
- In Australia, it was determined HEMS saved time to trauma centers when transport distances exceeded 62 miles (100 km).[409]
- At the high end of the mileage spectrum, a Swedish group attempted to determine when transport distances were so far that fixed-wing was preferable to HEMS. Their study concluded that airplanes became more cost-effective at transport distances exceeding 186 miles (300 km).[375]
- Also at the higher end of the distance range, investigators in rural states have pointed out that for some long-distance flights (the discussion context was rural transports with an average distance of nearly 100 miles) air transport is a practical necessity for maintaining local GEMS coverage.[259]

Given the above, it is clear that some region-specific mapping and planning will be in order for those trying to determine guiding mileages for their own area's vehicle triage. Mathematical modeling has been shown to be quite useful to inform HEMS placement.[410]

Planners should be mindful that endpoint selection (*i.e.* flight crew arrival at patients or patient arrival at tertiary care) can greatly influence determinations of distances at which HEMS may be indicated. Another component to distance and HEMS asset placement is the determination as to whether the emphasized endpoint is population coverage or response time.[411]

One approach that may be useful in various trauma systems is that taken in Pennsylvania, where fatal motor vehicle crash sites were mapped and HEMS locations plotted to optimize system utilization. The Pennsylvanians calculated that logistics-guided HEMS placement at two remote sites of frequent trauma would achieve a relative mortality reduction of 12.3%.[412]

As a final consideration for distance as a driver for HEMS placement, planners should keep in mind that in many cases the helicopter is not responding from the receiving hospital but from a separate location. When remote aircraft placement is the case, systems allocation of HEMS resources may need to use a different geometrical model (elliptical isochromes) to determine the optimum site for air medical resources.[413]

Transport-time criteria for HEMS deployment

Since any distance-based triage parameter is largely a surrogate for time, it is sensible to consider whether time can itself be used as a triage criterion. The previously noted *caveat* regarding where the time endpoint should be measured – HEMS crew arrival at patient *vs.* patient arrival at tertiary care – comes into play when considering time goals. A Norwegian group has published logistics analyses based upon time from call to HEMS crew arrival at the patient (they used 30- and 45-minute cutoffs). [410]Most, however, tend to use the time from the patient's location to the receiving center. Regardless of the definition, time in some form plays a role in most HEMS activations. This monograph subsection highlights some proposed time-based criteria and related issues.

Considering trauma cases first, time-based criteria are mentioned in many studies and consensus statements. In the USA's interagency government panel on HEMS dispatch, the consensus conclusion was that aircraft should be dispatched to trauma scenes based on time savings for patients who met the CDC's Field Triage guidelines' anatomic or physiologic criteria for trauma center care.[414] Specific benchmarks for defining "significant time savings" in trauma HEMS dispatch are found in publications such as the following:

- In the USA, a nationwide NTDB analysis of half-dozen years of trauma cases concluded that HEMS improved outcome over GEMS when prehospital transport times were in the range of 6-30 minutes; the greatest HEMS benefit (80% increase in survival odds) was seen with GEMS transport times in the range of 16-20 minutes.[23]
- A Scottish group suggests that for head-injury cases, HEMS should be used when GEMS times exceed 30 minutes.[415]
- English investigators have proposed that scene HEMS response be reserved for suitably critical cases (*e.g.* patients with airway issues, shock, head or facial injury) for which ground transport to appropriate trauma centers would require more than 45 minutes.[416]

As compared the use of distance criteria, which can be clearly assessed and even mapped for a given region, time-based HEMS triage criteria are more subject to estimation error. Subjectivity comes into play both at the time of a given triage decision, and in after-the-fact utilization review. The use of HEMS in urban settings is particularly problematic, because distances involved are usually small, yet traffic considerations can create long ground transports. One obvious mistake in assessing urban HEMS use is the retrospective assignation, based upon estimation of travel times, of theoretical ground EMS times. This approach (as used by many investigators)[185,409] ignores the critical need to ascertain why HEMS was requested in a given circumstance – an ascertainment that is important since HEMS dispatch often occurs due to extraordinary traffic/travel situations unapparent on retrospective view.

Even for interfacility transports, which should seemingly be more predictable (since the "runs" are repeated frequently over time), close assessment of predicted *vs.* actual time savings can yield surprising results. Perhaps the best demonstration of this comes from logistics research based at the University of Wisconsin's 20-hospital network.[350] When assessing HEMS and GEMS transports into the tertiary center, investigators found that HEMS saved time for transports at all distances – for close-in hospitals HEMS saved just 10 minutes (potentially of clinical significance) whereas for other hospitals HEMS saved up to 45 minutes. The results were surprising because many of the referring facilities had GEMS based on-site for transports. Noting that theoretical immediate availability of GEMS units understandably did not always translate into rapid response, the Wisconsin group advised systems look carefully at actual (rather than presumed) travel times when setting up time-based HEMS triage.[350]

Unwanted surprises on time-related endpoints are not restricted to GEMS. For HEMS, one of the most common hidden time costs is incurred when referring and/or receiving hospital's HEMS landing sites are placed distant from clinical units. The lost time (not to mention the added transport leg) can be significant, as reported by findings from around the world:

- In an Ontario study in which referring and receiving hospitals lacked on-site helipads, HEMS did not appear to save time over GEMS when measured from the time of transport decision to trauma center arrival. The Canadians concluded that GEMS *vs.* HEMS transport times were often significantly influenced by non-distance factors such as helipad placement.[321]
- Research from the U.K. has also noted time loss due to remote helipad placement, incorporating into HEMS dispatch guidelines the adjudication as to whether the receiving hospital's helipad lies within a "trolley's push" of the ED.[416,417]
- Other Europeans (in Hungary) have concurred that HEMS' time benefits are reliably achieved only if referring and receiving hospitals have ready access to helipads.[418]
- The USA-based National Association of EMS Physicians is in agreement with the time-savings benefits of ready access to helipads.[419]

The information regarding helipad placement is but one of many factors other than pure distance, that can affect transport time. Estimated time benefits of HEMS must take into account *all* factors that can play into total time required for HEMS and GEMS transport; accurate assessment of potential transport-mode time differences can only be made with a comprehensive view of time issues.

Section 7: HEMS dispatch guidelines (ACEP, AMPA, NAEMSP)

Decades ago, this monograph's author collaborated to generate National Association of EMS Physicians (NAEMSP) guidelines for HEMS dispatch.[420] Those guidelines were essentially a cut-and-paste of the HEMS use guidelines then in use at the author's Massachusetts HEMS program (Boston MedFlight, expertly run by the late and much-missed Suzanne K. Wedel MD). The guidelines' provenance is mentioned as a nod to Dr. Wedel, and also to acknowledge that generation of HEMS guidelines is – given the many uncertainties as highlighted in this monograph – not as concrete a science as would be wished.

Potential shortcomings aside, the guidelines have recently (2021) been updated and are easily obtainable over the internet.[19] Given the ease of their accessibility online, they are no longer reproduced in this monograph (which is quite long enough without them).

As with previous guidelines, collaboration between multiple (USA-based) groups allowed the final product to benefit from many sources of expertise. The guidelines' updated version has been endorsed by at least three major groups in the USA: NAEMSP, the Air Medical Physician Association (AMPA), and the American College of Emergency Physicians (ACEP).

These guidelines serve as a reasonable starting point for regions working to develop their own HEMS dispatch criteria. Just as the adaptation of NAEMSP (or any) HEMS dispatch guidelines to regional needs is important, the success or failure of guidelines in optimizing use of air medical resources is dependent on a vigorous *a posteriori* utilization review process. The review process can identify both over- and undertriage, and guide modifications to regional criteria for HEMS use.

SECTION 8: SUMMARY AND REFERENCES

The preponderance of scientific evidence supports a conclusion that HEMS transport is a necessary and important component of many EMS systems. Benefits are accrued to patients, as well as healthcare regions.

Ongoing criticism of HEMS utilization is not without basis. Specifically, the inexact science of triage has been, and continues to be, a major hindrance to efforts at optimally deploying helicopter transport resources. While researchers should maintain efforts directed toward more accurate identification of situations in which HEMS is likely to be helpful, regions in which air transport is used should also work to insure that triage guidelines exist – and that they're followed.

Ongoing efforts in clinical HEMS investigation should include focus on specific instances in which air medical response may be associated with improvements in mortality, morbidity, or other endpoints (including cost savings). Specific attention should be paid not only to costs of HEMS, but to differential costs of air medical versus alternative transport (*e.g.* by ground critical care teams).

Fortunately, although HEMS utilization in the USA and abroad is associated with overtriage, data indicate sufficiently favorable cost-effectiveness to continue HEMS use while the science of out-of-hospital care improves. With the *caveat* that safety remains the highest priority, ongoing investigational focus on cost-beneficial care should improve HEMS utilization and incorporation of air transport into healthcare systems.

References

1. Thomas SH, Cheema F, Cumming M, Wedel SK, Thomson D. Nontrauma helicopter emergency medical services transport: annotated review of selected outcomes-related literature. Prehospital emergency care : official journal of the National Association of EMS Physicians and the National Association of State EMS Directors 2002;6(2):242-55. (In eng).
2. Thomas SH, Cheema F, Wedel SK, Thomson D. Trauma helicopter emergency medical services transport: annotated review of selected outcomes-related literature. Prehospital emergency care : official journal of the National Association of EMS Physicians and the National Association of State EMS Directors 2002;6(3):359-71. (In eng).
3. Thomas SH. Helicopter emergency medical services transport outcomes literature: annotated review of articles published 2000-2003. Prehospital emergency care : official journal of the National Association of EMS Physicians and the National Association of State EMS Directors 2004;8(3):322-33. (In eng).
4. Thomas SH. Helicopter EMS transport outcomes literature: annotated review of articles published 2004-2006. Prehospital emergency care : official journal of the National Association of EMS Physicians and the National Association of State EMS Directors 2007;11(4):477-88. (In eng). DOI: 10.1080/10903120701537097.
5. Brown BS, Pogue KA, Williams E, et al. Helicopter EMS Transport Outcomes Literature: Annotated Review of Articles Published 2007-2011. Emergency medicine international 2012;2012:876703. DOI: 10.1155/2012/876703.
6. Lee EJ, Arthur AO, Thomas SH. Helicopter EMS outcomes literature: Annotated review of articles published 2012-2013. Br J Medicine Medical Res 2014;4:3620-3649.
7. Thomas SH, Blumen I. Helicopter Emergency Medical Services Literature 2014 to 2016: Lessons and Perspectives, Part 1-Helicopter Transport for Trauma. Air medical journal 2018;37(1):54-63. DOI: 10.1016/j.amj.2017.10.006.
8. Thomas SH, Blumen I. Helicopter Emergency Medical Services Literature 2014 to 2016: Lessons and Perspectives, Part 2-Nontrauma Transports and General Issues. Air medical journal 2018;37(2):126-130. DOI: 10.1016/j.amj.2017.10.005.
9. Moga C, Harstall C. Air ambulance transportation with capabilities to provide advanced life support. Institute for Health Economics (Edmonton) 2008:1-122.
10. Garner AA, Mann KP, Fearnside M, Poynter E, Gebski V. The Head Injury Retrieval Trial (HIRT): a single-centre randomised controlled trial of physician prehospital management of severe blunt head injury compared with management by paramedics only. Emergency medicine journal : EMJ 2015;32(11):869-75. (In eng). DOI: 10.1136/emermed-2014-204390.
11. Galvagno SM, Jr., Sikorski R, Hirshon JM, et al. Helicopter emergency medical services for adults with major trauma. The Cochrane database of systematic reviews 2015(12):Cd009228. (In eng). DOI: 10.1002/14651858.CD009228.pub3.
12. Moore L, Champion H, Tardif PA, et al. Impact of Trauma System Structure on Injury Outcomes: A Systematic Review and Meta-Analysis. World journal of surgery 2018;42(5):1327-1339. DOI: 10.1007/s00268-017-4292-0.
13. Schiller J, McCormack JE, Tarsia V, et al. The effect of adding a second helicopter on trauma-related mortality in a county-based trauma system. Prehospital emergency care : official journal of the National Association of EMS Physicians and the National Association of State EMS Directors 2009;13(4):437-43. (In eng). DOI: 10.1080/10903120903144825.
14. Tal S, Mor S. The impact of helicopter emergency medical service on acute ischemic stroke patients: A systematic review. The American journal of emergency medicine 2021;42:178-187. DOI: 10.1016/j.ajem.2020.02.021.
15. Risgaard B, Draegert C, Baekgaard JS, Steinmetz J, Rasmussen LS. Impact of Physician-staffed Helicopters on Pre-hospital Patient Outcomes: A systematic review. Acta anaesthesiologica Scandinavica 2020;64(5):691-704. DOI: 10.1111/aas.13547.
16. Ringburg AN, Thomas SH, Steyerberg EW, van Lieshout EM, Patka P, Schipper IB. Lives saved by helicopter emergency medical services: an overview of literature. Air medical journal 2009;28(6):298-302. (In eng). DOI: 10.1016/j.amj.2009.03.007.
17. Abe T, Takahashi O, Saitoh D, Tokuda Y. Association between helicopter with physician versus ground

emergency medical services and survival of adults with major trauma in Japan. Critical care (London, England) 2014;18(4):R146. (In eng). DOI: 10.1186/cc13981.

18. Brown JB, Gestring ML, Stassen NA, et al. Geographic Variation in Outcome Benefits of Helicopter Transport for Trauma in the United States: A Retrospective Cohort Study. Annals of surgery 2016;263(2):406-12. (In eng). DOI: 10.1097/sla.0000000000001047.
19. Lyng JW, Braithwaite S, Abraham H, et al. Appropriate Air Medical Services Utilization and Recommendations for Integration of Air Medical Services Resources into the EMS System of Care: A Joint Position Statement and Resource Document of NAEMSP, ACEP, and AMPA. Prehospital emergency care : official journal of the National Association of EMS Physicians and the National Association of State EMS Directors 2021;25(6):854-873. DOI: 10.1080/10903127.2021.1967534.
20. Reiner-Deitemyer V, Teuschl Y, Matz K, et al. Helicopter transport of stroke patients and its influence on thrombolysis rates: data from the Austrian Stroke Unit Registry. Stroke 2011;42(5):1295-300. (In eng). DOI: 10.1161/strokeaha.110.604710.
21. Thomas SH, Arthur AO. Helicopter EMS: Research Endpoints and Potential Benefits. Emergency medicine international 2012;2012:698562. (In eng). DOI: 10.1155/2012/698562.
22. Hesselfeldt R, Gyllenborg J, Steinmetz J, Do HQ, Hejselbaek J, Rasmussen LS. Is air transport of stroke patients faster than ground transport? A prospective controlled observational study. Emergency medicine journal : EMJ 2014;31(4):268-72. (In eng). DOI: 10.1136/emermed-2012-202270.
23. Brown JB, Gestring ML, Guyette FX, et al. Helicopter transport improves survival following injury in the absence of a time-saving advantage. Surgery 2016;159(3):947-59. (In eng). DOI: 10.1016/j.surg.2015.09.015.
24. Bruhn JD, Williams KA, Aghababian R. True costs of air medical vs. ground ambulance systems. Air medical journal 1993;12(8):262-8. (In eng). DOI: 10.1016/s1067-991x(05)80311-6.
25. Dominguez OH, Grigorian A, Lekawa M, et al. Helicopter Transport Has Decreased Over Time and Transport From Scene or Hospital Matters. Air Med J. 20200420 ed2020:283-290.
26. Silver DS, Sperry JL, Beiriger J, et al. Association Between Emergency Medical Service Agency Volume and Mortality in Trauma Patients. Annals of surgery 2024;279(1):160-166. DOI: 10.1097/SLA.0000000000006087.
27. Hankins DG. Air medical transport of trauma patients. Prehospital emergency care : official journal of the National Association of EMS Physicians and the National Association of State EMS Directors 2006;10(3):324-7. DOI: 10.1080/10903120600728748.
28. Wang HE, Peitzman AB, Cassidy LD, Adelson PD, Yealy DM. Out-of-hospital endotracheal intubation and outcome after traumatic brain injury. Annals of emergency medicine 2004;44(5):439-50. (In eng). DOI: 10.1016/s0196064404004160.
29. Cudnik MT, Newgard CD, Wang H, Bangs C, Herrington Rt. Distance impacts mortality in trauma patients with an intubation attempt. Prehospital emergency care : official journal of the National Association of EMS Physicians and the National Association of State EMS Directors 2008;12(4):459-66. DOI: 10.1080/10903120802290745.
30. Patel SC, Murphy S, Penfil S, Romeo D, Hertzog JH. Impact of Interfacility Transport Method and Specialty Teams on Outcomes of Pediatric Trauma Patients. Pediatric emergency care 2018;34(7):467-472. DOI: 10.1097/PEC.0000000000001167.
31. Low RB, Dunne MJ, Blumen IJ, Tagney G. Factors associated with the safety of EMS helicopters. The American journal of emergency medicine 1991;9(2):103-6. (In eng).
32. Holland J, Cooksley DG. Safety of helicopter aeromedical transport in Australia: a retrospective study. The Medical journal of Australia 2005;182(1):17-9. (In eng).
33. Hinkelbein J, Dambier M, Viergutz T, Genzwurker H. A 6-year analysis of German emergency medical services helicopter crashes. The Journal of trauma 2008;64(1):204-10. (In eng). DOI: 10.1097/01.ta.0000239256.28393.e2.
34. Aschenbrenner U, Neppl S, Ahollinger F, et al. [Air rescue missions at night: Data analysis of primary and secondary missions by the DRF air rescue service in 2014]. Der Unfallchirurg 2015;118(6):549-63. (In ger). DOI: 10.1007/s00113-015-0016-9.
35. Peters JH, van Wageningen B, Hoogerwerf N, Biert J. Helicopter emergency medical service patient transport safe at night? Air medical journal 2014;33(6):296-8. (In eng). DOI: 10.1016/j.amj.2014.07.021.
36. Lutman D, Montgomery M, Ramnarayan P, Petros A. Ambulance and aeromedical accident rates during

emergency retrieval in Great Britain. Emergency medicine journal : EMJ 2008;25(5):301-2. (In eng). DOI: 10.1136/emj.2007.046557.
37. Chesters A, Grieve PH, Hodgetts TJ. A 26-year comparative review of United Kingdom helicopter emergency medical services crashes and serious incidents. The journal of trauma and acute care surgery 2014;76(4):1055-60. (In eng). DOI: 10.1097/ta.0000000000000170.
38. Bellini C, Risso FM, Sannia A, Campone F, Traggiai C, Ramenghi LA. A retrospective analysis of the occurrence of accidents during 20 years of neonatal transport in Liguria region, Italy. European journal of emergency medicine : official journal of the European Society for Emergency Medicine 2017;24(1):71-75. (In eng). DOI: 10.1097/mej.0000000000000385.
39. Boyd DD, Macchiarella ND. Occupant Injury Severity and Accident Causes in Helicopter Emergency Medical Services (1983-2014). Aerospace medicine and human performance 2016;87(1):26-31. (In eng). DOI: 10.3357/amhp.4446.2016.
40. Delgado MK, Staudenmayer KL, Wang NE, et al. Cost-effectiveness of helicopter versus ground emergency medical services for trauma scene transport in the United States. Annals of emergency medicine 2013;62(4):351-364.e19. (In eng). DOI: 10.1016/j.annemergmed.2013.02.025.
41. Hartmann K, Lubin J, Boehmer S, Amin S, Flamm A. Ground versus air: Which mode of EMS transportation is more likely to crash. Air medical journal 2022.
42. Sanddal ND, Albert S, Hansen JD, Kupas DF. Contributing factors and issues associated with rural ambulance crashes: literature review and annotated bibliography. Prehospital emergency care : official journal of the National Association of EMS Physicians and the National Association of State EMS Directors 2008;12(2):257-67. DOI: 10.1080/10903120801907661.
43. Wang HE, Fairbanks RJ, Shah MN, Abo BN, Yealy DM. Tort claims and adverse events in emergency medical services. Annals of emergency medicine 2008;52(3):256-62. DOI: 10.1016/j.annemergmed.2008.02.011.
44. Elliott JP, O'Keeffe DF, Freeman RK. Helicopter transportation of patients with obstetric emergencies in an urban area. American journal of obstetrics and gynecology 1982;143(2):157-62. (In eng).
45. Baxt WG, Moody P. The impact of advanced prehospital emergency care on the mortality of severely brain-injured patients. The Journal of trauma 1987;27(4):365-9. (In eng).
46. Pakkanen T, Kamarainen A, Huhtala H, et al. Physician-staffed helicopter emergency medical service has a beneficial impact on the incidence of prehospital hypoxia and secured airways on patients with severe traumatic brain injury. Scandinavian journal of trauma, resuscitation and emergency medicine 2017;25(1):94. (In eng). DOI: 10.1186/s13049-017-0438-1.
47. Weinlich M, Martus P, Blau MB, et al. Competitive advantage gained from the use of helicopter emergency medical services (HEMS) for trauma patients: Evaluation of 1724 patients. Injury 2019;50(5):1028-1035. DOI: 10.1016/j.injury.2018.12.018.
48. Davis DP, Dunford JV, Ochs M, Park K, Hoyt DB. The use of quantitative end-tidal capnometry to avoid inadvertent severe hyperventilation in patients with head injury after paramedic rapid sequence intubation. The Journal of trauma 2004;56(4):808-14. (In eng).
49. Lenartova L, Janciak I, Wilbacher I, Rusnak M, Mauritz W. Severe traumatic brain injury in Austria III: prehospital status and treatment. Wiener klinische Wochenschrift 2007;119(1-2):35-45. (In eng). DOI: 10.1007/s00508-006-0762-3.
50. Funder KS, Rasmussen LS, Lohse N, Siersma V, Hesselfeldt R, Steinmetz J. Long-term follow-up of trauma patients before and after implementation of a physician-staffed helicopter: A prospective observational study. Injury 2016;47(1):7-13. (In eng). DOI: 10.1016/j.injury.2015.10.032.
51. Ciaraglia A, Lumbard D, Murala A, et al. Comparison of helicopter and ground transportation in pediatric trauma patients. Pediatr Res 2024;95(1):188-192. DOI: 10.1038/s41390-023-02761-5.
52. Saver JL, Fonarow GC, Smith EE, et al. Time to treatment with intravenous tissue plasminogen activator and outcome from acute ischemic stroke. Jama 2013;309(23):2480-8. DOI: 10.1001/jama.2013.6959.
53. Sterner RC, Brooks NP. Interfacility Ambulance Versus Helicopter Transport of Traumatic Spinal Cord Injury Patients: Outcomes, Observations, and Utilization. Wisc Med J 2024;123(2):88-94. (Article) (In English) (https://www.scopus.com/inward/record.uri?eid=2-s2.0-85192585077&partnerID=40&md5=3f6252a59e469df7b3871c77802b8e3d).
54. Thomas SH, Rago O, Harrison T, Biddinger PD, Wedel SK. Fentanyl trauma analgesia use in air medical scene

transports. The Journal of emergency medicine 2005;29(2):179-87. (In eng). DOI: 10.1016/j.jemermed.2005.02.007.
55. Berns KS, Hankins DG, Zietlow SP. Comparison of air and ground transport of cardiac patients. Air medical journal 2001;20(6):33-6. (In eng).
56. Sonne A, Wulffeld S, Steinmetz J, Rasmussen LS, Hesselfeldt R. Prehospital interventions before and after implementation of a physician-staffed helicopter. Danish medical journal 2017;64(10) (In eng).
57. Harrison TH, Thomas SH, Wedel SK. Success rates of pediatric intubation by a non-physician-staffed critical care transport service. Pediatric emergency care 2004;20(2):101-7. (In eng).
58. Thomas SH, Harrison T, Wedel SK. Flight crew airway management in four settings: a six-year review. Prehospital emergency care : official journal of the National Association of EMS Physicians and the National Association of State EMS Directors 1999;3(4):310-5. (In eng).
59. Tollefsen WW, Brown CA, 3rd, Cox KL, Walls RM. Two hundred sixty pediatric emergency airway encounters by air transport personnel: a report of the air transport emergency airway management (NEAR VI: "A-TEAM") project. Pediatric emergency care 2013;29(9):963-8. (In eng). DOI: 10.1097/PEC.0b013e3182a219ea.
60. Peters J, Beekers C, Eijk R, Edwards M, Hoogerwerf N. Evaluation of Dutch Helicopter Emergency Medical Services in transporting children. Air medical journal 2014;33(3):112-4. (In eng). DOI: 10.1016/j.amj.2014.02.005.
61. Garner AA, Bennett N, Weatherall A, Lee A. Physician-staffed helicopter emergency medical services augment ground ambulance paediatric airway management in urban areas: a retrospective cohort study. Emergency medicine journal : EMJ 2019;36(11):678-683. DOI: 10.1136/emermed-2019-208421.
62. Moors XRJ, Rijs K, Den Hartog D, Stolker RJ. Pediatric out-of-hospital cardiopulmonary resuscitation by helicopter emergency medical service, does it has added value compared to regular emergency medical service? European journal of trauma and emergency surgery : official publication of the European Trauma Society 2018;44(3):407-410. DOI: 10.1007/s00068-017-0815-5.
63. Thomas SH, Orf J, Wedel SK, Conn AK. Hyperventilation in traumatic brain injury patients: inconsistency between consensus guidelines and clinical practice. The Journal of trauma 2002;52(1):47-52; discussion 52-3. (In eng).
64. Orf J, Thomas SH, Ahmed W, et al. Appropriateness of endotracheal tube size and insertion depth in children undergoing air medical transport. Pediatric emergency care 2000;16(5):321-7. (In eng).
65. Bossers SM, Verheul R, van Zwet EW, et al. Prehospital Intubation of Patients with Severe Traumatic Brain Injury: A Dutch Nationwide Trauma Registry Analysis. Prehospital emergency care : official journal of the National Association of EMS Physicians and the National Association of State EMS Directors 2023;27(5):662-668. DOI: 10.1080/10903127.2022.2119494.
66. Benhamed A, Fraticelli L, Claustre C, et al. Risk factors and mortality associated with undertriage after major trauma in a physician-led prehospital system: a retrospective multicentre cohort study. European journal of trauma and emergency surgery : official publication of the European Trauma Society 2023;49(4):1707-1715. DOI: 10.1007/s00068-022-02186-5.
67. MacDonald RD, Banks BA, Morrison M. Epidemiology of adverse events in air medical transport. Academic emergency medicine : official journal of the Society for Academic Emergency Medicine 2008;15(10):923-31. DOI: 10.1111/j.1553-2712.2008.00241.x.
68. Tollefsen WW, Chapman J, Frakes M, Gallagher M, Shear M, Thomas SH. Endotracheal tube cuff pressures in pediatric patients intubated before aeromedical transport. Pediatric emergency care 2010;26(5):361-3. (In eng). DOI: 10.1097/PEC.0b013e3181db224d.
69. Grines CL, Westerhausen DR, Jr., Grines LL, et al. A randomized trial of transfer for primary angioplasty versus on-site thrombolysis in patients with high-risk myocardial infarction: the Air Primary Angioplasty in Myocardial Infarction study. Journal of the American College of Cardiology 2002;39(11):1713-9. DOI: 10.1016/s0735-1097(02)01870-3.
70. Bhatt NR, Martin-Gill C, Al-Qudah A, et al. Acquisition of Prehospital Stroke Severity Scale is associated with shorter door-to-puncture times in patients with prehospital notifications transported directly to a thrombectomy center. Journal of neurointerventional surgery 2024 (Article) (In English). DOI: 10.1136/jnis-2024-022122.
71. Cuevas M, Frank M, Haacke W, Lüdke T. Prehospital care of anaphylactic reactions by the air rescue and ground-

based emergency services Dresden: An analysis of treatment and outcome. HNO 2024;72(9):611-618. (Article) (In German). DOI: 10.1007/s00106-024-01457-4.

72. Nasser AAH, Nederpelt C, El Hechi M, et al. Every minute counts: The impact of pre-hospital response time and scene time on mortality of penetrating trauma patients. American journal of surgery 2020;220(1):240-244. DOI: 10.1016/j.amjsurg.2019.11.018.

73. Baxt WG, Moody P. The impact of a rotorcraft aeromedical emergency care service on trauma mortality. Jama 1983;249(22):3047-51. (In eng).

74. Silliman SL, Quinn B, Huggett V, Merino JG. Use of a field-to-stroke center helicopter transport program to extend thrombolytic therapy to rural residents. Stroke 2003;34(3):729-33. (In eng). DOI: 10.1161/01.Str.0000056529.29515.B2.

75. Mommsen P, Bradt N, Zeckey C, et al. Comparison of helicopter and ground emergency medical service: a retrospective analysis of a German rescue helicopter base. Technology and health care : official journal of the European Society for Engineering and Medicine 2012;20(1):49-56. (In eng). DOI: 10.3233/thc-2011-0655.

76. Wheaton A, Fok PT, Holodinsky JK, Vanberkel P, Volders D, Kamal N. Optimal Transport Scenario With Rotary Air Transport for Access to Endovascular Therapy Considering Patient Outcomes and Cost: A Modeling Study. Front Neurol 2021;12:768381. DOI: 10.3389/fneur.2021.768381.

77. Schoenfeld D, Ho KKL, McCartin MP, et al. Longitudinal Assessment of a Single Referring-Receiving Hospital Pair to Assess Air Versus Ground Elapsed Time From Transport Request to Arrival at Cardiac Catheterization Laboratory: An Observational Cohort Study. Air medical journal 2024 (Article) (In English). DOI: 10.1016/j.amj.2024.11.007.

78. Vuorinen P, Setälä P, Ollikainen J, Hoppu S. A hybrid strategy using an ambulance and a helicopter to convey thrombectomy candidates to definite care: a prospective observational study. BMC emergency medicine 2024;24(1):17. (In eng). DOI: 10.1186/s12873-024-00931-0.

79. Ohara M, Shimizu Y, Satoh H, et al. Safety and usefulness of emergency maternal transport using helicopter. The journal of obstetrics and gynaecology research 2008;34(2):189-94. (In eng). DOI: 10.1111/j.1447-0756.2008.00756.x.

80. Shewakramani S, Thomas SH, Harrison TH, Gates JD. Air transport of patients with unstable aortic aneurysms directly into operating rooms. Prehospital emergency care : official journal of the National Association of EMS Physicians and the National Association of State EMS Directors 2007;11(3):337-42. (In eng). DOI: 10.1080/10903120701348024.

81. Thomas SH, Kociszewski C, Hyde RJ, Brennan PJ, Wedel SK. Prehospital electrocardiogram and early helicopter dispatch to expedite interfacility transfer for percutaneous coronary intervention. Critical pathways in cardiology 2006;5(3):155-9. (In eng). DOI: 10.1097/01.hpc.0000234809.93495.e3.

82. Rhinehart ZJ, Guyette FX, Sperry JL, et al. The association between air ambulance distribution and trauma mortality. Annals of surgery 2013;257(6):1147-53. (In eng). DOI: 10.1097/SLA.0b013e31827ee6b0.

83. Mitchell AD, Tallon JM, Sealy B. Air versus ground transport of major trauma patients to a tertiary trauma centre: a province-wide comparison using TRISS analysis. Canadian journal of surgery Journal canadien de chirurgie 2007;50(2):129-33. (In eng).

84. Varon J, Fromm RE, Jr., Marik P. Hearts in the air: the role of aeromedical transport. Chest 2003;124(5):1636-7. DOI: 10.1378/chest.124.5.1636.

85. Crocco TJ, Grotta JC, Jauch EC, et al. EMS management of acute stroke--prehospital triage (resource document to NAEMSP position statement). Prehospital emergency care : official journal of the National Association of EMS Physicians and the National Association of State EMS Directors 2007;11(3):313-7. DOI: 10.1080/10903120701347844.

86. Thomas SH, Schwamm LH, Lev MH. Case records of the Massachusetts General Hospital. Case 16-2006. A 72-year-old woman admitted to the emergency department because of a sudden change in mental status. N Engl J Med 2006;354(21):2263-71. DOI: 10.1056/NEJMcpc069007.

87. Reily DJ, Tollok E, Mallitz K, Hanson CW, 3rd, Fuchs BD. Successful aeromedical transport using inhaled prostacyclin for a patient with life-threatening hypoxemia. Chest 2004;125(4):1579-81. (In eng).

88. Robertson LC, McKinlay JA, Munro PT, Hearns S. Use of prothrombin complex concentrates: 4-year experience of a national aeromedical retrieval service servicing remote and rural areas. Emergency medicine journal : EMJ 2014;31(2):109-14. (In eng). DOI: 10.1136/emermed-2012-201967.

89. Assa A, Landau DA, Barenboim E, Goldstein L. Role of air-medical evacuation in mass-casualty incidents--a train collision experience. Prehospital and disaster medicine 2009;24(3):271-6. (In eng).
90. Ausserer J, Moritz E, Stroehle M, et al. Physician staffed helicopter emergency medical systems can provide advanced trauma life support in mountainous and remote areas. Injury 2017;48(1):20-25. (In eng). DOI: 10.1016/j.injury.2016.09.005.
91. Barbieri S, Feltracco P, Delantone M, et al. Helicopter rescue and prehospital care for drowning children: two summer season case studies. Minerva anestesiologica 2008;74(12):703-7. (In eng).
92. Johnsen AS, Fattah S, Sollid SJ, Rehn M. Utilisation of helicopter emergency medical services in the early medical response to major incidents: a systematic literature review. BMJ open 2016;6(2):e010307. (In eng). DOI: 10.1136/bmjopen-2015-010307.
93. Urdaneta LF, Sandberg MK, Cram AE, et al. Evaluation of an emergency air transport service as a component of a rural EMS system. The American surgeon 1984;50(4):183-8. (In eng).
94. Wills VL, Eno L, Walker C, Gani JS. Use of an ambulance-based helicopter retrieval service. The Australian and New Zealand journal of surgery 2000;70(7):506-10. (In eng).
95. Hotvedt R, Kristiansen IS, Forde OH, et al. Which groups of patients benefit from helicopter evacuation? Lancet (London, England) 1996;347(9012):1362-6. (In eng).
96. Hotvedt R, Kristiansen IS. Doctor-staffed ambulance helicopters: to what extent can the general practitioner replace the anaesthesiologist? The British journal of general practice : the journal of the Royal College of General Practitioners 2000;50(450):41-2. (In eng).
97. Fromm RE, Jr., Hoskins E, Cronin L, Pratt CM, Spencer WH, 3rd, Roberts R. Bleeding complications following initiation of thrombolytic therapy for acute myocardial infarction: a comparison of helicopter-transported and nontransported patients. Annals of emergency medicine 1991;20(8):892-5. (In eng).
98. Fromm RE, Jr., Taylor DH, Cronin L, McCallum WB, Levine RL. The incidence of pacemaker dysfunction during helicopter air medical transport. The American journal of emergency medicine 1992;10(4):333-5. (In eng).
99. Conroy MB, Rodriguez SU, Kimmel SE, Kasner SE. Helicopter transfer offers a potential benefit to patients with acute stroke. Stroke 1999;30(12):2580-4. (In eng).
100. Leira EC, Zaheer A, Schnell T, et al. Effect of helicopter transport on neurological outcomes in a mouse model of embolic stroke with reperfusion: AIR-MICE pilot study. International journal of stroke : official journal of the International Stroke Society 2015;10 Suppl A100:119-24. (In eng). DOI: 10.1111/ijs.12619.
101. Streijger F, Lee JH, Manouchehri N, et al. Responses of the Acutely Injured Spinal Cord to Vibration that Simulates Transport in Helicopters or Mine-Resistant Ambush-Protected Vehicles. Journal of neurotrauma 2016;33(24):2217-2226. (In eng). DOI: 10.1089/neu.2016.4456.
102. Carchietti E, Cecchi A, Valent F, Rammer R. Flight vibrations and bleeding in helicoptered patients with pelvic fracture. Air medical journal 2013;32(2):80-3. (In eng). DOI: 10.1016/j.amj.2012.06.012.
103. Knotts D, Arthur AO, Holder P, Herrington T, Thomas SH. Pneumothorax volume expansion in helicopter emergency medical services transport. Air medical journal 2013;32(3):138-43. (In eng). DOI: 10.1016/j.amj.2012.10.014.
104. Becher NA, Kierulf G, Bothwell S, Hills-Dunlap JL, Mandt M, Moulton SL. Interfacility Transport of Children with Traumatic Pneumothorax: Does Elevation Make a Difference? Journal of pediatric surgery 2024;59(2):316-319. DOI: 10.1016/j.jpedsurg.2023.10.022.
105. Chapman J, Pallin D, Ferrara L, et al. Endotracheal tube cuff pressures in patients intubated before transport. The American journal of emergency medicine 2009;27(8):980-2. (In eng). DOI: 10.1016/j.ajem.2008.07.025.
106. Orsborn J, Graham J, Moss M, Melguizo M, Nick T, Stroud M. Pediatric Endotracheal Tube Cuff Pressures During Aeromedical Transport. Pediatric emergency care 2016;32(1):20-2. (In eng). DOI: 10.1097/pec.0000000000000365.
107. Tennyson J, Ford-Webb T, Weisberg S, LeBlanc D. Endotracheal Tube Cuff Pressures in Patients Intubated Prior to Helicopter EMS Transport. The western journal of emergency medicine 2016;17(6):721-725. (In eng). DOI: 10.5811/westjem.2016.8.30639.
108. Delorenzo AJ, Shepherd M, Jennings PA. Endotracheal Cuff Pressure Changes During Helicopter Transport: A Systematic Review. Air medical journal 2017;36(2):81-84. (In eng). DOI: 10.1016/j.amj.2017.01.003.
109. Falla M, Hüfner K, Falk M, et al. Simulated Acute Hypobaric Hypoxia Effects on Cognition in Helicopter Emergency Medical Service Personnel – A Randomized, Controlled, Single-Blind, Crossover Trial. Human Factors

2024;66(2):404-423. DOI: 10.1177/00187208221086407.
110. Hon KL, Olsen H, Totapally B, Leung TF. Air versus ground transportation of artificially ventilated neonates: comparative differences in selected cardiopulmonary parameters. Pediatric emergency care 2006;22(2):107-12. (In eng). DOI: 10.1097/01.pec.0000199557.11605.c6.
111. Berlot G, La Fata C, Bacer B, et al. Influence of prehospital treatment on the outcome of patients with severe blunt traumatic brain injury: a single-centre study. European journal of emergency medicine : official journal of the European Society for Emergency Medicine 2009;16(6):312-7. (In eng). DOI: 10.1097/MEJ.0b013e32832d3aa1.
112. Ringburg AN, Spanjersberg WR, Frankema SP, Steyerberg EW, Patka P, Schipper IB. Helicopter emergency medical services (HEMS): impact on on-scene times. The Journal of trauma 2007;63(2):258-62. (In eng). DOI: 10.1097/01.ta.0000240449.23201.57.
113. Cocanour CS, Fischer RP, Ursic CM. Are scene flights for penetrating trauma justified? The Journal of trauma 1997;43(1):83-6; discussion 86-8. (In eng).
114. Heritage D, Griggs J, Barrett J, et al. Helicopter emergency medical services demonstrate reduced time to emergency anaesthesia in an undifferentiated trauma population: a retrospective observational analysis across three major trauma networks. Scandinavian journal of trauma, resuscitation and emergency medicine 2024;32(1):138. (In eng). DOI: 10.1186/s13049-024-01313-y.
115. Elkbuli A, Boserup B, Sen-Crowe B, Autrey C, McKenney M. Effects of mode and time of EMS transport on the rate and distribution of dead on arrival among trauma population transported to ACSCOT-verified trauma centers in the United States. The American journal of emergency medicine 2021;50:264-269. DOI: 10.1016/j.ajem.2021.08.035.
116. Lee D, Kawano K, Ishida S, et al. The impact of helicopter emergency medical services and craniocervical traction on the early reduction of cervical spine dislocation in a rural area of Japan. J Orthop Sci 2022;27(3):606-613. DOI: 10.1016/j.jos.2021.03.008.
117. De Trana L, Latronico S. [Transportation in a helicopter ambulance and resuscitation of patients with cervical spinal injuries. Our regional experience]. Minerva anestesiologica 1989;55(3):125-7. (In ita).
118. Phillips RT, Conaway C, Mullarkey D, Owen JL. One year's trauma mortality experience at Brooke Army Medical Center: is aeromedical transportation of trauma patients necessary? Military medicine 1999;164(5):361-5. (In eng).
119. Phillips M, Arthur AO, Chandwaney R, et al. Helicopter transport effectiveness of patients for primary percutaneous coronary intervention. Air medical journal 2013;32(3):144-52. (In eng). DOI: 10.1016/j.amj.2012.08.007.
120. Nallamothu BK, Bradley EH, Krumholz HM. Time to treatment in primary percutaneous coronary intervention. N Engl J Med 2007;357(16):1631-8. DOI: 10.1056/NEJMra065985.
121. Rathore SS, Curtis JP, Chen J, et al. Association of door-to-balloon time and mortality in patients admitted to hospital with ST elevation myocardial infarction: national cohort study. BMJ (Clinical research ed) 2009;338:b1807. DOI: 10.1136/bmj.b1807.
122. Scholz KH, Meyer T, Lengenfelder B, et al. Patient delay and benefit of timely reperfusion in ST-segment elevation myocardial infarction. Open Heart 2021;8(1). DOI: 10.1136/openhrt-2021-001650.
123. Park J, Choi KH, Lee JM, et al. Prognostic Implications of Door-to-Balloon Time and Onset-to-Door Time on Mortality in Patients With ST -Segment-Elevation Myocardial Infarction Treated With Primary Percutaneous Coronary Intervention. Journal of the American Heart Association 2019;8(9):e012188. DOI: 10.1161/JAHA.119.012188.
124. Moens D, Stipulante S, Donneau AF, et al. Air versus ground transport of patients with acute myocardial infarction: experience in a rural-based helicopter medical service. European journal of emergency medicine : official journal of the European Society for Emergency Medicine 2015;22(4):273-8. (In eng). DOI: 10.1097/mej.0000000000000149.
125. Hesselfeldt R, Pedersen F, Steinmetz J, et al. Implementation of a physician-staffed helicopter: impact on time to primary PCI. EuroIntervention : journal of EuroPCR in collaboration with the Working Group on Interventional Cardiology of the European Society of Cardiology 2013;9(4):477-83. (In eng). DOI: 10.4244/eijv9i4a77.
126. Knudsen L, Stengaard C, Hansen TM, Lassen JF, Terkelsen CJ. Earlier reperfusion in patients with ST-elevation

myocardial infarction by use of helicopter. Scandinavian journal of trauma, resuscitation and emergency medicine 2012;20:70. (In eng). DOI: 10.1186/1757-7241-20-70.
127. Konstantopoulos WM, Pliakas J, Hong C, et al. Helicopter emergency medical services and stroke care regionalization: measuring performance in a maturing system. The American journal of emergency medicine 2007;25(2):158-63. (In eng). DOI: 10.1016/j.ajem.2006.06.016.
128. Ueno T, Nishijima H, Hikichi H, et al. Helicopter Transport for Patients with Cerebral Infarction in Rural Japan. Journal of stroke and cerebrovascular diseases : the official journal of National Stroke Association 2019;28(9):2525-2529. DOI: 10.1016/j.jstrokecerebrovasdis.2019.06.010.
129. Buchanan IM, Coates A, Sne N. Does Mode of Transport Confer a Mortality Benefit in Trauma Patients? Characteristics and Outcomes at an Ontario Lead Trauma Hospital. Cjem 2016;18(5):363-9. (In eng). DOI: 10.1017/cem.2016.15.
130. Joosse P, Goslings JC, Luitse JS, Ponsen KJ. M-study; arguments for regional trauma databases. The Journal of trauma 2005;58(6):1272-6; discussion 1277. DOI: 10.1097/01.ta.0000169868.38625.b9.
131. Moors XRJ, Van Lieshout EMM, Verhofstad MHJ, Stolker RJ, Den Hartog D. A Physician-Based Helicopter Emergency Medical Services Was Associated With an Additional 2.5 Lives Saved per 100 Dispatches of Severely Injured Pediatric Patients. Air medical journal 2019;38(4):289-293. DOI: 10.1016/j.amj.2019.04.003.
132. Giannakopoulos GF, Kolodzinskyi MN, Christiaans HM, et al. Helicopter Emergency Medical Services save lives: outcome in a cohort of 1073 polytraumatized patients. European journal of emergency medicine : official journal of the European Society for Emergency Medicine 2013;20(2):79-85. (In eng). DOI: 10.1097/MEJ.0b013e328352ac9b.
133. Lee KH, Lee JI. Comparative Study on the Outcome of Trauma Patients Transferred by Doctor Helicopters and Ground Ambulance in South Korea. Disaster medicine and public health preparedness 2022;17:e290. DOI: 10.1017/dmp.2022.211.
134. Straumann E, Yoon S, Naegeli B, et al. Hospital transfer for primary coronary angioplasty in high risk patients with acute myocardial infarction. Heart (British Cardiac Society) 1999;82(4):415-9. (In eng).
135. Berge SD, Berg-Utby C, Skogvoll E. Helicopter transport of sick neonates: a 14-year population-based study. Acta anaesthesiologica Scandinavica 2005;49(7):999-1003. (In eng). DOI: 10.1111/j.1399-6576.2005.00712.x.
136. Moylan JA. Impact of helicopters on trauma care and clinical results. Annals of surgery 1988;208(6):673-8. (In eng).
137. Cunningham P, Rutledge R, Baker CC, Clancy TV. A comparison of the association of helicopter and ground ambulance transport with the outcome of injury in trauma patients transported from the scene. The Journal of trauma 1997;43(6):940-6. (In eng).
138. de Jongh MA, van Stel HF, Schrijvers AJ, Leenen LP, Verhofstad MH. The effect of Helicopter Emergency Medical Services on trauma patient mortality in the Netherlands. Injury 2012;43(9):1362-7. (In eng). DOI: 10.1016/j.injury.2012.01.009.
139. Stewart KE, Cowan LD, Thompson DM, Sacra JC, Albrecht R. Association of direct helicopter versus ground transport and in-hospital mortality in trauma patients: a propensity score analysis. Academic emergency medicine : official journal of the Society for Academic Emergency Medicine 2011;18(11):1208-16. (In eng). DOI: 10.1111/j.1553-2712.2011.01207.x.
140. Tsuchiya A, Tsutsumi Y, Yasunaga H. Outcomes after helicopter versus ground emergency medical services for major trauma--propensity score and instrumental variable analyses: a retrospective nationwide cohort study. Scandinavian journal of trauma, resuscitation and emergency medicine 2016;24(1):140. (In eng). DOI: 10.1186/s13049-016-0335-z.
141. Schoenfeld D, Thomas CE, McCartin M, Blumen I, Galvagno S, Thomas SH. Natural experiment outcomes studies in rotor-wing air medical transport: Systematic review and meta-analysis of before-and-after and helicopter-unavailable publications 1970-2022. Air medical journal 2023. DOI: 10.1016/j.amj.2023.11.005.
142. Chappell VL, Mileski WJ, Wolf SE, Gore DC. Impact of discontinuing a hospital-based air ambulance service on trauma patient outcomes. The Journal of trauma 2002;52(3):486-91. (In eng).
143. Borst GM, Davies SW, Waibel BH, et al. When birds can't fly: an analysis of interfacility ground transport using advanced life support when helicopter emergency medical service is unavailable. The journal of trauma and acute care surgery 2014;77(2):331-6; discussion 336-7. (In eng). DOI: 10.1097/ta.0000000000000295.
144. Mann NC, Pinkney KA, Price DD, et al. Injury mortality following the loss of air medical support for rural

interhospital transport. Academic emergency medicine : official journal of the Society for Academic Emergency Medicine 2002;9(7):694-8. (In eng).
145. McVey J, Petrie DA, Tallon JM. Air versus ground transport of the major trauma patient: a natural experiment. Prehospital emergency care : official journal of the National Association of EMS Physicians and the National Association of State EMS Directors 2010;14(1):45-50. (In eng). DOI: 10.3109/10903120903349788.
146. Hesselfeldt R, Steinmetz J, Jans H, et al. Impact of a physician-staffed helicopter on a regional trauma system: a prospective, controlled, observational study. Acta anaesthesiologica Scandinavica 2013;57(5):660-8. (In eng). DOI: 10.1111/aas.12052.
147. Flanigan M, Blatt A, Lombardo L, et al. Assessment of air medical coverage using the Atlas and Database of Air Medical Services and correlations with reduced highway fatality rates. Air medical journal 2005;24(4):151-63. DOI: 10.1016/j.amj.2005.05.001.
148. Mango N, Garthe E. Statewide tracking of crash victims' medical system utilization and outcomes. The Journal of trauma 2007;62(2):436-60. (In eng). DOI: 10.1097/01.ta.0000224616.04273.43.
149. Alstrup K, Rognas L, Sollid S, Johnsen SP, Valentin JB, Petersen JAK. Association of Helicopter vs Ground Emergency Medical Transportation With 1-Year Mortality in Denmark. JAMA Netw Open 2021;4(1):e2033318. DOI: 10.1001/jamanetworkopen.2020.33318.
150. Osteras O, Heltne JK, Tonsager K, Brattebo G. Outcomes after cancelled helicopter emergency medical service missions due to concurrencies: a retrospective cohort study. Acta anaesthesiologica Scandinavica 2018;62(1):116-124. (In eng). DOI: 10.1111/aas.13028.
151. Zink BJ, Maio RF. Out-of-hospital endotracheal intubation in traumatic brain injury: outcomes research provides us with an unexpected outcome. Annals of emergency medicine 2004;44(5):451-3. DOI: 10.1016/j.annemergmed.2004.05.001.
152. Davis DP, Peay J, Good B, et al. Air medical response to traumatic brain injury: a computer learning algorithm analysis. The Journal of trauma 2008;64(4):889-97. (In eng). DOI: 10.1097/TA.0b013e318148569a.
153. Athanasiou T, Krasopoulos G, Nambiar P, et al. Emergency thoracotomy in the pre-hospital setting: a procedure requiring clarification. European journal of cardio-thoracic surgery : official journal of the European Association for Cardio-thoracic Surgery 2004;26(2):377-86. (In eng). DOI: 10.1016/j.ejcts.2004.03.016.
154. Albrecht E, Taffe P, Yersin B, Schoettker P, Decosterd I, Hugli O. Undertreatment of acute pain (oligoanalgesia) and medical practice variation in prehospital analgesia of adult trauma patients: a 10 yr retrospective study. British journal of anaesthesia 2013;110(1):96-106. (In eng). DOI: 10.1093/bja/aes355.
155. Davis DP, Stern J, Sise MJ, Hoyt DB. A follow-up analysis of factors associated with head-injury mortality after paramedic rapid sequence intubation. The Journal of trauma 2005;59(2):486-90. (In eng).
156. Fritz CL, Thomas SA, Galvagno SM, Jr., Thomas SH. Survival Benefit of Helicopter Scene Response for Patients with an Injury Severity Score of at Least Nine: A Systematic Review and Meta-Analysis. Prehospital emergency care : official journal of the National Association of EMS Physicians and the National Association of State EMS Directors 2023:1-10. DOI: 10.1080/10903127.2023.2232453.
157. Florez-Perdomo WA, Garcia-Ballestas E, Konar SK, et al. Effect of Helicopter Transportation of Acute Ischemic Stroke Patients on Mortality and Functional Outcomes: A Systematic Review and Meta-Analysis. Air medical journal 2022;41(5):476-483. DOI: 10.1016/j.amj.2022.07.001.
158. Lavery MD, Aulakh A, Christian MD. Benefits of targeted deployment of physician-led interprofessional pre-hospital teams on the care of critically Ill and injured patients: a systematic review and meta-analysis. Scandinavian journal of trauma, resuscitation and emergency medicine 2025;33(1):1. DOI: 10.1186/s13049-024-01298-8.
159. Karper S, Stokstad I, Hjort PF, Indrebo T. [Ambulance helicopters in the mountains. An evaluation of the 1-year activity at the Dombas base]. Tidsskrift for den Norske laegeforening : tidsskrift for praktisk medicin, ny raekke 1991;111(2):221-4. (In nor).
160. Kee SS, Ramage CM, Mendel P, Bristow AS. Interhospital transfers by helicopter: the first 50 patients of the Careflight project. Journal of the Royal Society of Medicine 1992;85(1):29-31. (In eng).
161. Lindbeck GH, Groopman DS, Powers RD. Aeromedical evacuation of rural victims of nontraumatic cardiac arrest. Annals of emergency medicine 1993;22(8):1258-62. (In eng).
162. Arfken CL, Shapiro MJ, Bessey PQ, Littenberg B. Effectiveness of helicopter versus ground ambulance services for interfacility transport. The Journal of trauma 1998;45(4):785-90. (In eng).

163. Werman HA, Falcone RA, Shaner S, et al. Helicopter transport of patients to tertiary care centers after cardiac arrest. The American journal of emergency medicine 1999;17(2):130-4. (In eng).
164. Gerritse BM, Schalkwijk A, Pelzer BJ, Scheffer GJ, Draaisma JM. Advanced medical life support procedures in vitally compromised children by a helicopter emergency medical service. BMC emergency medicine 2010;10:6. (In eng). DOI: 10.1186/1471-227x-10-6.
165. Di Bartolomeo S, Gava P, Truhlar A, Sandberg M. Cross-sectional investigation of HEMS activities in Europe: a feasibility study. TheScientificWorldJournal 2014;2014:201570. (In eng). DOI: 10.1155/2014/201570.
166. Peters J, van Wageningen B, Hendriks I, et al. First-pass intubation success rate during rapid sequence induction of prehospital anaesthesia by physicians versus paramedics. European journal of emergency medicine : official journal of the European Society for Emergency Medicine 2015;22(6):391-4. (In eng). DOI: 10.1097/mej.0000000000000161.
167. Aiolfi A, Benjamin E, Recinos G, De Leon Castro A, Inaba K, Demetriades D. Air Versus Ground Transportation in Isolated Severe Head Trauma: A National Trauma Data Bank Study. The Journal of emergency medicine 2018;54(3):328-334. DOI: 10.1016/j.jemermed.2017.11.019.
168. Zakariassen E, Osteras O, Nystoyl DS, et al. Loss of life years due to unavailable helicopter emergency medical service: a single base study from a rural area of Norway. Scand J Prim Health Care 2019;37(2):233-241. DOI: 10.1080/02813432.2019.1608056.
169. Joseph AM, Horvat CM, Evans IV, Kuch BA, Kahn JM. Helicopter versus ground ambulance transport for interfacility transfer of critically ill children. The American journal of emergency medicine 2022;61:44-51. DOI: 10.1016/j.ajem.2022.08.032.
170. Wothe JK, Bergman ZR, Kalland KR, Peter LG, Lusczek ER, Brunsvold ME. Outcomes of Patients Undergoing Interfacility Extracorporeal Membrane Oxygenation Transfer Based on Cannulation Location and Mode of Transport. Crit Care Explor 2022;4(4):e0664. DOI: 10.1097/CCE.0000000000000664.
171. Olson C, Wothe J, Braaten J, et al. Outcomes of Interfacility VV-Extracorporeal Membrane Oxygenation Transfers: A Multicenter Study. ASAIO journal (American Society for Artificial Internal Organs : 1992) 2024;70(6):479-484. (In eng). DOI: 10.1097/mat.0000000000002133.
172. Baxt WG, Moody P, Cleveland HC, et al. Hospital-based rotorcraft aeromedical emergency care services and trauma mortality: a multicenter study. Annals of emergency medicine 1985;14(9):859-64. (In eng).
173. Urdaneta LF, Miller BK, Ringenberg BJ, Cram AE, Scott DH. Role of an emergency helicopter transport service in rural trauma. Archives of surgery (Chicago, Ill : 1960) 1987;122(9):992-6. (In eng).
174. Schiller WR, Knox R, Zinnecker H, et al. Effect of helicopter transport of trauma victims on survival in an urban trauma center. The Journal of trauma 1988;28(8):1127-34. (In eng).
175. Schwartz RJ, Jacobs LM, Juda RJ. A comparison of ground paramedics and aeromedical treatment of severe blunt trauma patients. Connecticut medicine 1990;54(12):660-2. (In eng).
176. Nardi G, Massarutti D, Muzzi R, et al. Impact of emergency medical helicopter service on mortality for trauma in north-east Italy. A regional prospective audit. European journal of emergency medicine : official journal of the European Society for Emergency Medicine 1994;1(2):69-77. (In eng).
177. Nicholl JP, Brazier JE, Snooks HA. Effects of London helicopter emergency medical service on survival after trauma. BMJ (Clinical research ed) 1995;311(6999):217-22. (In eng).
178. Celli P, Fruin A, Cervoni L. Severe head trauma. Review of the factors influencing the prognosis. Minerva chirurgica 1997;52(12):1467-80. (In eng).
179. Younge PA, Coats TJ, Gurney D, Kirk CJ. Interpretation of the Ws statistic: application to an integrated trauma system. The Journal of trauma 1997;43(3):511-5. (In eng).
180. Abbott D, Brauer K, Hutton K, Rosen P. Aggressive out-of-hospital treatment regimen for severe closed head injury in patients undergoing air medical transport. Air medical journal 1998;17(3):94-100. (In eng).
181. Brathwaite CE, Rosko M, McDowell R, Gallagher J, Proenca J, Spott MA. A critical analysis of on-scene helicopter transport on survival in a statewide trauma system. The Journal of trauma 1998;45(1):140-4; discussion 144-6. (In eng).
182. Jacobs LM, Gabram SG, Sztajnkrycer MD, Robinson KJ, Libby MC. Helicopter air medical transport: ten-year outcomes for trauma patients in a New England program. Connecticut medicine 1999;63(11):677-82. (In eng).
183. Di Bartolomeo S, Sanson G, Nardi G, Scian F, Michelutto V, Lattuada L. Effects of 2 patterns of prehospital care on the outcome of patients with severe head injury. Archives of surgery (Chicago, Ill : 1960) 2001;136(11):1293-

300. (In eng).
184. Oppe S, De Charro FT. The effect of medical care by a helicopter trauma team on the probability of survival and the quality of life of hospitalised victims. Accident; analysis and prevention 2001;33(1):129-38. (In eng).
185. Shatney CH, Homan SJ, Sherck JP, Ho CC. The utility of helicopter transport of trauma patients from the injury scene in an urban trauma system. The Journal of trauma 2002;53(5):817-22. (In eng). DOI: 10.1097/01.Ta.0000031100.02119.Fb.
186. Frankema SP, Ringburg AN, Steyerberg EW, Edwards MJ, Schipper IB, van Vugt AB. Beneficial effect of helicopter emergency medical services on survival of severely injured patients. The British journal of surgery 2004;91(11):1520-6. (In eng). DOI: 10.1002/bjs.4756.
187. Buntman AJ, Yeomans KA. The effect of air medical transport on survival after trauma in Johannesburg, South Africa. South African medical journal = Suid-Afrikaanse tydskrif vir geneeskunde 2002;92(10):807-11. (In eng).
188. Davis DP, Peay J, Serrano JA, et al. The impact of aeromedical response to patients with moderate to severe traumatic brain injury. Annals of emergency medicine 2005;46(2):115-22. (In eng). DOI: 10.1016/j.annemergmed.2005.01.024.
189. Frink M, Probst C, Hildebrand F, et al. [The influence of transportation mode on mortality in polytraumatized patients. An analysis based on the German Trauma Registry]. Der Unfallchirurg 2007;110(4):334-40. DOI: 10.1007/s00113-006-1222-2.
190. Talving P, Teixeira PG, Barmparas G, et al. Helicopter evacuation of trauma victims in Los Angeles: does it improve survival? World journal of surgery 2009;33(11):2469-76. (In eng). DOI: 10.1007/s00268-009-0185-1.
191. 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. The Journal of trauma 2010;69(5):1030-4; discussion 1034-6. (In eng). DOI: 10.1097/TA.0b013e3181f6f450.
192. Sullivent EE, Faul M, Wald MM. Reduced mortality in injured adults transported by helicopter emergency medical services. Prehospital emergency care : official journal of the National Association of EMS Physicians and the National Association of State EMS Directors 2011;15(3):295-302. (In eng). DOI: 10.3109/10903127.2011.569849.
193. Glance LG, Osler TM, Dick AW. Evaluating trauma center quality: does the choice of the severity-adjustment model make a difference? The Journal of trauma 2005;58(6):1265-71. DOI: 10.1097/01.ta.0000169429.58786.c6.
194. Bulger EM, Guffey D, Guyette FX, et al. Impact of prehospital mode of transport after severe injury: a multicenter evaluation from the Resuscitation Outcomes Consortium. The journal of trauma and acute care surgery 2012;72(3):567-73; discussion 573-5; quiz 803. (In eng). DOI: 10.1097/TA.0b013e31824baddf.
195. Galvagno SM, Jr., Haut ER, Zafar SN, et al. Association between helicopter vs ground emergency medical services and survival for adults with major trauma. Jama 2012;307(15):1602-10. (In eng). DOI: 10.1001/jama.2012.467.
196. Desmettre T, Yeguiayan JM, Coadou H, et al. Impact of emergency medical helicopter transport directly to a university hospital trauma center on mortality of severe blunt trauma patients until discharge. Critical care (London, England) 2012;16(5):R170. (In eng). DOI: 10.1186/cc11647.
197. Rose MK, Cummings GR, Rodning CB, Brevard SB, Gonzalez RP. Is helicopter evacuation effective in rural trauma transport? The American surgeon 2012;78(7):794-7. (In eng).
198. Ryb GE, Dischinger P, Cooper C, Kufera JA. Does helicopter transport improve outcomes independently of emergency medical system time? The journal of trauma and acute care surgery 2013;74(1):149-54; discussion 154-6. (In eng). DOI: 10.1097/TA.0b013e31827890cc.
199. Kleber C, Giesecke MT, Tsokos M, Haas NP, Buschmann CT. Trauma-related preventable deaths in Berlin 2010: need to change prehospital management strategies and trauma management education. World journal of surgery 2013;37(5):1154-61. (In eng). DOI: 10.1007/s00268-013-1964-2.
200. Andruszkow H, Lefering R, Frink M, et al. Survival benefit of helicopter emergency medical services compared to ground emergency medical services in traumatized patients. Critical care (London, England) 2013;17(3):R124. (In eng). DOI: 10.1186/cc12796.
201. Andruszkow H, Hildebrand F, Lefering R, Pape HC, Hoffmann R, Schweigkofler U. Ten years of helicopter emergency medical services in Germany: do we still need the helicopter rescue in multiple traumatised patients? Injury 2014;45 Suppl 3:S53-8. (In eng). DOI: 10.1016/j.injury.2014.08.018.

202. Missios S, Bekelis K. Transport mode to level I and II trauma centers and survival of pediatric patients with traumatic brain injury. Journal of neurotrauma 2014;31(14):1321-8. (In eng). DOI: 10.1089/neu.2014.3325.
203. Bekelis K, Missios S, Mackenzie TA. Prehospital helicopter transport and survival of patients with traumatic brain injury. Annals of surgery 2015;261(3):579-585. (In eng). DOI: 10.1097/sla.0000000000000672.
204. Greenberg SE, Ihejirika RC, Sathiyakumar V, et al. Ankle Fractures and Modality of Hospital Transport at a Single Level 1 Trauma Center: Does Transport by Helicopter or Ground Ambulance Influence the Incidence of Complications? The Journal of foot and ankle surgery : official publication of the American College of Foot and Ankle Surgeons 2015;54(5):826-9. (In eng). DOI: 10.1053/j.jfas.2014.12.041.
205. Den Hartog D, Romeo J, Ringburg AN, Verhofstad MH, Van Lieshout EM. Survival benefit of physician-staffed Helicopter Emergency Medical Services (HEMS) assistance for severely injured patients. Injury 2015;46(7):1281-6. (In eng). DOI: 10.1016/j.injury.2015.04.013.
206. Kim J, Heo Y, Lee JC, et al. Effective transport for trauma patients under current circumstances in Korea: a single institution analysis of treatment outcomes for trauma patients transported via the domestic 119 service. Journal of Korean medical science 2015;30(3):336-42. (In eng). DOI: 10.3346/jkms.2015.30.3.336.
207. Shaw JJ, Psoinos CM, Santry HP. It's All About Location, Location, Location: A New Perspective on Trauma Transport. Annals of surgery 2016;263(2):413-8. (In eng). DOI: 10.1097/sla.0000000000001265.
208. Ahmed N. Survival of Trauma Victims Transported by Helicopter Who Required Cardiopulmonary Resuscitation Within the First Hour of Hospital Arrival. Southern medical journal 2016;109(4):213-9. (In eng). DOI: 10.14423/smj.0000000000000434.
209. Andruszkow H, Schweigkofler U, Lefering R, et al. Impact of Helicopter Emergency Medical Service in Traumatized Patients: Which Patient Benefits Most? PloS one 2016;11(1):e0146897. (In eng). DOI: 10.1371/journal.pone.0146897.
210. Brown JB, Leeper CM, Sperry JL, et al. Helicopters and injured kids: Improved survival with scene air medical transport in the pediatric trauma population. The journal of trauma and acute care surgery 2016;80(5):702-10. (In eng). DOI: 10.1097/ta.0000000000000971.
211. Polites SF, Zielinski MD, Fahy AS, et al. Mortality following helicopter versus ground transport of injured children. Injury 2017;48(5):1000-1005. (In eng). DOI: 10.1016/j.injury.2016.12.010.
212. Englum BR, Rialon KL, Kim J, et al. Current use and outcomes of helicopter transport in pediatric trauma: a review of 18,291 transports. Journal of pediatric surgery 2017;52(1):140-144. (In eng). DOI: 10.1016/j.jpedsurg.2016.10.030.
213. Werman HA, Darbha S, Cudnik M, Caterino J. Do Trauma Patients Aged 55 and Older Benefit from Air Medical Transport? Prehospital emergency care : official journal of the National Association of EMS Physicians and the National Association of State EMS Directors 2017;21(4):461-465. (In eng). DOI: 10.1080/10903127.2016.1269223.
214. Zhu TH, Hollister L, Opoku D, Galvagno SM, Jr. Improved Survival for Rural Trauma Patients Transported by Helicopter to a Verified Trauma Center: A Propensity Score Analysis. Academic emergency medicine : official journal of the Society for Academic Emergency Medicine 2018;25(1):44-53. (In eng). DOI: 10.1111/acem.13307.
215. Farach SM, Walford NE, Bendure L, Amankwah EK, Danielson PD, Chandler NM. Helicopter Transport From the Scene of Injury: Are There Improved Outcomes for Pediatric Trauma Patients? Pediatric emergency care 2017 (In eng). DOI: 10.1097/pec.0000000000001190.
216. Chen X, Gestring ML, Rosengart MR, et al. Speed is not everything: Identifying patients who may benefit from helicopter transport despite faster ground transport. The journal of trauma and acute care surgery 2018;84(4):549-557. DOI: 10.1097/TA.0000000000001769.
217. Blasius FM, Horst K, Brokmann JC, et al. Helicopter Emergency Medical Service and Hospital Treatment Levels Affect Survival in Pediatric Trauma Patients. J Clin Med 2021;10(4). DOI: 10.3390/jcm10040837.
218. Hakakian D, Kong K, Bogdanovski DA, et al. Analysis of Transport to an American College of Surgeons Level I Trauma Center. Air medical journal 2019;38(2):95-99. DOI: 10.1016/j.amj.2018.11.013.
219. Michaels D, Pham H, Puckett Y, Dissanaike S. Helicopter versus ground ambulance: review of national database for outcomes in survival in transferred trauma patients in the USA. Trauma Surg Acute Care Open 2019;4(1):e000211. DOI: 10.1136/tsaco-2018-000211.
220. Ageron FX, Debaty G, Savary D, et al. Association of helicopter transportation and improved mortality for patients with major trauma in the northern French Alps trauma system: an observational study based on the

TRENAU registry. Scandinavian journal of trauma, resuscitation and emergency medicine 2020;28(1):35. DOI: 10.1186/s13049-020-00730-z.
221. Beaumont O, Lecky F, Bouamra O, et al. Helicopter and ground emergency medical services transportation to hospital after major trauma in England: a comparative cohort study. Trauma Surg Acute Care Open 2020;5(1):e000508. DOI: 10.1136/tsaco-2020-000508.
222. Enomoto Y, Tsuchiya A, Tsutsumi Y, et al. Association between physician-staffed helicopter versus ground emergency medical services and mortality for pediatric trauma patients: A retrospective nationwide cohort study. PloS one 2020;15(8):e0237192. DOI: 10.1371/journal.pone.0237192.
223. Nasser AAH, Khouli Y. The Impact of Prehospital Transport Mode on Mortality of Penetrating Trauma Patients. Air medical journal 2020;39(6):502-505. DOI: 10.1016/j.amj.2020.07.005.
224. Colnaric J, Bachir R, El Sayed MJ. Association Between Mode of Transportation and Outcomes of Adult Trauma Patients With Blunt Injury Across Different Prehospital Time Intervals in the United States: A Matched Cohort Study. The Journal of emergency medicine 2020;59(6):884-893. DOI: 10.1016/j.jemermed.2020.08.004.
225. Colnaric J, Bachir R, El Sayed M. Association Between Mode of Transportation and Outcomes in Penetrating Trauma Across Different Prehospital Time Intervals: A Matched Cohort Study. The Journal of emergency medicine 2021;60(4):460-470. DOI: 10.1016/j.jemermed.2020.11.043.
226. Ota S, Jitsuiki K, Muramatsu KI, et al. The utility of physician-staffed helicopters for managing individuals who experience severe isolated head trauma. Journal of rural medicine : JRM 2021;16(4):245-249. DOI: 10.2185/jrm.2021-016.
227. Kushida Y, Jitsuiki K, Muramatsu KI, et al. A comparison of physician-staffed helicopters and ground ambulances transport for the outcome of severe thoracic trauma patients. The American journal of emergency medicine 2021;45:358-360. DOI: 10.1016/j.ajem.2020.08.088.
228. Nabeta M, Murotani K, Kannae M, et al. Comparison of physician-staffed helicopter with ground-based emergency medical services for trauma patients. The American journal of emergency medicine 2021;45:75-79. DOI: 10.1016/j.ajem.2021.02.062.
229. Hosomi S, Kitamura T, Sobue T, Nakagawa Y, Ogura H, Shimazu T. Association of Pre-Hospital Helicopter Transport with Reduced Mortality in Traumatic Brain Injury in Japan: A Nationwide Retrospective Cohort Study. Journal of neurotrauma 2022;39(1-2):76-85. DOI: 10.1089/neu.2021.0181.
230. Duffens A, Grigorian A, de Virgilio C, et al. Association of Risk of Mortality in Pediatric Patients Transferred From Scene by Helicopter With Major But Not Minor Injuries. Pediatric emergency care 2022;38(1):e287-e291. DOI: 10.1097/PEC.0000000000002263.
231. Guinzburg A, Gelikas S, Tsur AM, et al. The association between helicopter emergency medical services and early casualty survival: a nationwide study. European journal of emergency medicine : official journal of the European Society for Emergency Medicine 2022. DOI: 10.1097/MEJ.0000000000000940.
232. Elkbuli A, Dowd B, Sanchez C, Shaikh S, Sutherland M, McKenney M. Emergency Medical Service Transport Time and Trauma Outcomes at an Urban Level 1 Trauma Center: Evaluation of Prehospital Emergency Medical Service Response. The American surgeon 2022;88(6):1090-1096. DOI: 10.1177/0003134820988827.
233. Amin D, Manhan AJ, Pak-Harvey E, Roser SM, Smith RN, Abramowicz S. Which Method of Transportation Is Associated With Better Outcomes for Patients With Firearm Injuries to the Head and Neck? J Oral Maxillofac Surg 2023;81(11):1383-1390. DOI: 10.1016/j.joms.2023.07.136.
234. Bou Saba G, Rahal R, Bachir R, El Sayed M. Factors associated with survival in adult trauma patients undergoing angiography with and without embolization across trauma centers in the United States. Emergency radiology 2023;30(1):1-10. DOI: 10.1007/s10140-022-02094-6.
235. Deeb AP, Teng CY, Peitzman AB, et al. Direct Trauma Center Access by Helicopter Emergency Medical Services is Associated With Improved Survival After Severe Injury. Annals of surgery 2023;278(4):e840-e847. DOI: 10.1097/SLA.0000000000005812.
236. Lapidus O, Rubenson Wahlin R, Backstrom D. Trauma patient transport to hospital using helicopter emergency medical services or road ambulance in Sweden: a comparison of survival and prehospital time intervals. Scandinavian journal of trauma, resuscitation and emergency medicine 2023;31(1):101. DOI: 10.1186/s13049-023-01168-9.
237. Zadorozny EV, Lin HS, Luther J, et al. Prehospital Time Following Traumatic Injury Is Independently Associated With the Need for In-Hospital Blood and Early Mortality for Specific Injury Types. Air medical journal

2024;43(1):47-54. DOI: 10.1016/j.amj.2023.09.013.
238. Bradford JM, Teixeira PG, DuBose J, et al. Temporal changes in the prehospital management of trauma patients: 2014–2021. American journal of surgery 2024;228:88-93. (Article) (In English). DOI: 10.1016/j.amjsurg.2023.08.001.
239. Moylan JA, Fitzpatrick KT, Beyer AJ, 3rd, Georgiade GS. Factors improving survival in multisystem trauma patients. Annals of surgery 1988;207(6):679-85. (In eng).
240. Boyd CR, Corse KM, Campbell RC. Emergency interhospital transport of the major trauma patient: air versus ground. The Journal of trauma 1989;29(6):789-93; discussion 793-4. (In eng).
241. Slater H, O'Mara MS, Goldfarb IW. Helicopter transportation of burn patients. Burns : journal of the International Society for Burn Injuries 2002;28(1):70-2. (In eng).
242. Brown JB, Stassen NA, Bankey PE, Sangosanya AT, Cheng JD, Gestring ML. Helicopters improve survival in seriously injured patients requiring interfacility transfer for definitive care. The Journal of trauma 2011;70(2):310-4. (In eng). DOI: 10.1097/TA.0b013e3182032b4f.
243. Kim OH, Roh YI, Kim HI, et al. Reduced Mortality in Severely Injured Patients Using Hospital-based Helicopter Emergency Medical Services in Interhospital Transport. Journal of Korean medical science 2017;32(7):1187-1194. (In eng). DOI: 10.3346/jkms.2017.32.7.1187.
244. Malekpour M, Younus JM, Jaap K, et al. Mode of Transport and Clinical Outcome in Rural Trauma: A Helicopter versus Ambulance Comparison. The American surgeon 2017;83(12):1413-1417. (In eng).
245. Sun H, Samra NS, Kalakoti P, et al. Impact of Prehospital Transportation on Survival in Skiers and Snowboarders with Traumatic Brain Injury. World neurosurgery 2017;104:909-918.e8. (In eng). DOI: 10.1016/j.wneu.2017.05.108.
246. Smith CA, Hardern RD, LeClerc S, Howes RJ. Prehospital analysis of northern trauma outcome measures: the PHANTOM study. Emergency medicine journal : EMJ 2019;36(4):213-218. DOI: 10.1136/emermed-2017-206848.
247. Stassen W, Alkzair S, Kurland L. Helicopter Emergency Medical Services in Trauma Does Not Influence Mortality in South Africa. Air medical journal 2020;39(6):479-483. DOI: 10.1016/j.amj.2020.08.004.
248. Ford D, Mills B, Ciccone N, Beatty S. Does Direct Helicopter Retrieval Improve Survival of Severely Injured Trauma Patients From Rural Western Australia? Air medical journal 2020;39(3):183-188. DOI: 10.1016/j.amj.2020.01.005.
249. Stewart K, Garwe T, Oluborode B, Sarwar Z, Albrecht RM. Association of Interfacility Helicopter versus Ground Ambulance Transport and in-Hospital Mortality among Trauma Patients. Prehospital emergency care : official journal of the National Association of EMS Physicians and the National Association of State EMS Directors 2021;25(5):620-628. DOI: 10.1080/10903127.2020.1817215.
250. Udekwu P, Stiles A, Tann K, McIntyre S, Roy S, Schiro S. Evaluation of statewide utilization of helicopter emergency medical services for interfacility transfer. The journal of trauma and acute care surgery 2021;91(3):496-500. DOI: 10.1097/TA.0000000000003309.
251. Patterson KN, Beyene TJ, Bergus K, Stafford J, Wurster L, Thakkar RK. Interfacility helicopter transport to a tertiary pediatric trauma center. Journal of pediatric surgery 2022;57(11):637-643. DOI: 10.1016/j.jpedsurg.2022.05.010.
252. Hosseinpour H, Magnotti LJ, Bhogadi SK, et al. Interfacility transfer of pediatric trauma patients to higher levels of care: The effect of transfer time and level of receiving trauma center. The journal of trauma and acute care surgery 2023;95(3):383-390. DOI: 10.1097/TA.0000000000003915.
253. Moront ML, Gotschall CS, Eichelberger MR. Helicopter transport of injured children: system effectiveness and triage criteria. Journal of pediatric surgery 1996;31(8):1183-6; discussion 1187-8. (In eng).
254. Kerr WA, Kerns TJ, Bissell RA. Differences in mortality rates among trauma patients transported by helicopter and ambulance in Maryland. Prehospital and disaster medicine 1999;14(3):159-64. (In eng).
255. Thomas SH, Harrison TH, Buras WR, Ahmed W, Cheema F, Wedel SK. Helicopter transport and blunt trauma mortality: a multicenter trial. The Journal of trauma 2002;52(1):136-45. (In eng).
256. Biewener A, Aschenbrenner U, Rammelt S, Grass R, Zwipp H. Impact of helicopter transport and hospital level on mortality of polytrauma patients. The Journal of trauma 2004;56(1):94-8. (In eng). DOI: 10.1097/01.Ta.0000061883.92194.50.
257. Larson JT, Dietrich AM, Abdessalam SF, Werman HA. Effective use of the air ambulance for pediatric trauma.

The Journal of trauma 2004;56(1):89-93. (In eng). DOI: 10.1097/01.Ta.0000061163.35582.A5.
258. Hannay RS, Wyrzykowski AD, Ball CG, Laupland K, Feliciano DV. Retrospective review of injury severity, interventions and outcomes among helicopter and nonhelicopter transport patients at a Level 1 urban trauma centre. Canadian journal of surgery Journal canadien de chirurgie 2014;57(1):49-54. (In eng).
259. Stewart CL, Metzger RR, Pyle L, Darmofal J, Scaife E, Moulton SL. Helicopter versus ground emergency medical services for the transportation of traumatically injured children. Journal of pediatric surgery 2015;50(2):347-52. (In eng). DOI: 10.1016/j.jpedsurg.2014.09.040.
260. Hirshon JM, Galvagno SM, Jr., Comer A, et al. Maryland's Helicopter Emergency Medical Services Experience From 2001 to 2011: System Improvements and Patients' Outcomes. Annals of emergency medicine 2016;67(3):332-340.e3. (In eng). DOI: 10.1016/j.annemergmed.2015.07.503.
261. AlThani H, ElMenyar A, Pillay Y, Mollazehi M, Mekkodathil A, Consunji R. Hospital Mortality Based on the Mode of Emergency Medical Services Transportation. Air medical journal 2017;36(4):188-192. (In eng). DOI: 10.1016/j.amj.2017.03.003.
262. Blankenship JC, Haldis TA, Wood GC, Skelding KA, Scott T, Menapace FJ. Rapid triage and transport of patients with ST-elevation myocardial infarction for percutaneous coronary intervention in a rural health system. The American journal of cardiology 2007;100(6):944-8. (In eng). DOI: 10.1016/j.amjcard.2007.04.031.
263. Schoos MM, Kelbaek H, Pedersen F, et al. Search and rescue helicopter-assisted transfer of ST-elevation myocardial infarction patients from an island in the Baltic Sea: results from over 100 rescue missions. Emergency medicine journal : EMJ 2014;31(11):920-5. (In eng). DOI: 10.1136/emermed-2013-202771.
264. Pathan S SJ, Qureshi I, Werman H, Reimer A, Brunko M, Alinier G, Irfan F, Thomas SH. Helicopter EMS and rapid transport for ST-elevation myocardial infarction: The HEARTS study. J Emerg Med Trauma Acute Care 2017;8:1-6. DOI: 10.5339/jemtac.2017.8.
265. Gunnarsson SI, Mitchell J, Busch MS, et al. Outcomes of Physician-Staffed Versus Non-Physician-Staffed Helicopter Transport for ST-Elevation Myocardial Infarction. Journal of the American Heart Association 2017;6(2) (In eng). DOI: 10.1161/jaha.116.004936.
266. Almawiri A, Jan V, Ziad A, Martin J, Josef S. Mortality benefit of primary transportation to a PCI-capable center persists through an eight-year follow-up in patients with ST-segment elevation myocardial infarction. Journal of interventional cardiology 2017;30(6):522-526. (In eng). DOI: 10.1111/joic.12419.
267. Funder KS, Rasmussen LS, Siersma V, et al. Helicopter vs. ground transportation of patients bound for primary percutaneous coronary intervention. Acta anaesthesiologica Scandinavica 2018;62(4):568-578. DOI: 10.1111/aas.13092.
268. Ishikura K, Nakagawa Y, Nakagawa Y, et al. The Evaluation of Helicopter Emergency Medical Services With a Physician for Acute Myocardial Infarction in Japan: A Registry-Based Study of Prognosis and Time Reduction. Air medical journal 2021;40(6):399-403. DOI: 10.1016/j.amj.2021.08.006.
269. Ishiyama M, Kurita T, Takasaki A, et al. Impact of Helicopter Transport on Reperfusion Times and Long-Term Outcomes in Acute Myocardial Infarction Patients in Rural Areas: A Report From the Mie Acute Coronary Syndrome Registry. Air medical journal 2021;40(5):337-343. DOI: 10.1016/j.amj.2021.05.001.
270. Nishigoori S, Kobayashi N, Shibata Y, et al. Helicopter emergency medical service for patients with acute coronary syndrome: selection validity and impact on clinical outcomes. Heart Vessels 2022;37(7):1125-1135. DOI: 10.1007/s00380-022-02022-1.
271. Mork SR, Botker MT, Hjort J, et al. Use of Helicopters to Reduce Health Care System Delay in Patients With ST-Elevation Myocardial Infarction Admitted to an Invasive Center. The American journal of cardiology 2022;171:7-14. DOI: 10.1016/j.amjcard.2022.01.042.
272. Pieper CH, Smith J, Kirsten GF, Malan P. The transport of neonates to an intensive care unit. South African medical journal = Suid-Afrikaanse tydskrif vir geneeskunde 1994;84(11 Suppl):801-3. (In eng).
273. Kumagai T, Higuchi R, Okutani T, Yagi S, Ikejima M, Minami S. Changes in maternal and child health outcomes after introduction of a helicopter into perinatal transportation in Japan. Maternal and child health journal 2011;15(2):255-9. DOI: 10.1007/s10995-010-0567-x.
274. Alvarado-Socarras JL, Idrovo AJ, Bermon A. Hospital survival upon discharge of ill-neonates transported by ground or air ambulance to a tertiary center. Jornal de pediatria 2016;92(3):276-82. (In eng). DOI: 10.1016/j.jped.2015.07.010.
275. Kumagai T, Riko M, Satoh M, et al. Wakayama Medical University Hospital perinatal helicopter ambulance

service: 14 year review. Pediatr Int 2018;60(1):63-66. DOI: 10.1111/ped.13439.
276. Nawrocki PS, Levy M, Tang N, Trautman S, Margolis A. Interfacility Transport of the Pregnant Patient: A 5-year Retrospective Review of a Single Critical Care Transport Program. Prehospital emergency care : official journal of the National Association of EMS Physicians and the National Association of State EMS Directors 2019;23(3):377-384. DOI: 10.1080/10903127.2018.1519005.
277. Chalela JA, Kasner SE, Jauch EC, Pancioli AM. Safety of air medical transportation after tissue plasminogen activator administration in acute ischemic stroke. Stroke 1999;30(11):2366-8. (In eng).
278. Walcott BP, Coumans JV, Mian MK, Nahed BV, Kahle KT. Interfacility helicopter ambulance transport of neurosurgical patients: observations, utilization, and outcomes from a quaternary level care hospital. PloS one 2011;6(10):e26216. (In eng). DOI: 10.1371/journal.pone.0026216.
279. Olson MD, Rabinstein AA. Does helicopter emergency medical service transfer offer benefit to patients with stroke? Stroke 2012;43(3):878-80. (In eng). DOI: 10.1161/strokeaha.111.640987.
280. Gupta R, Manuel M, Owada K, et al. Severe hemiparesis as a prehospital tool to triage stroke severity: a pilot study to assess diagnostic accuracy and treatment times. Journal of neurointerventional surgery 2016;8(8):775-7. (In eng). DOI: 10.1136/neurintsurg-2015-011940.
281. Hui FK, El Mekabaty A, Schultz J, et al. Helistroke: neurointerventionalist helicopter transport for interventional stroke treatment: proof of concept and rationale. Journal of neurointerventional surgery 2017 (In eng). DOI: 10.1136/neurintsurg-2017-013050.
282. Ishihara H, Oka F, Oku T, et al. Safety and Time Course of Drip-and-Ship in Treatment of Acute Ischemic Stroke. Journal of stroke and cerebrovascular diseases : the official journal of National Stroke Association 2017;26(11):2477-2481. (In eng). DOI: 10.1016/j.jstrokecerebrovasdis.2017.03.008.
283. Ishikawa K, Omori K, Takeuchi I, et al. A comparison between evacuation from the scene and interhospital transportation using a helicopter for subarachnoid hemorrhage. The American journal of emergency medicine 2017;35(4):543-547. (In eng). DOI: 10.1016/j.ajem.2016.12.007.
284. Weyhenmeyer J, Guandique CF, Leibold A, et al. Effects of distance and transport method on intervention and mortality in aneurysmal subarachnoid hemorrhage. Journal of neurosurgery 2018;128(2):490-498. DOI: 10.3171/2016.9.JNS16668.
285. Almallouhi E, Al Kasab S, Nahhas M, et al. Outcomes of interfacility helicopter transportation in acute stroke care. Neurol Clin Pract 2020;10(5):422-427. DOI: 10.1212/CPJ.0000000000000737.
286. Lee JI, Lee KH, Kim OH. Comparative Study on the Outcome of Stroke Patients Transferred by Doctor Helicopters and Ground Ambulances in South Korea: A Retrospective Controlled Study. Emergency medicine international 2020;2020:8493289. DOI: 10.1155/2020/8493289.
287. Coughlan D, McMeekin P, Flynn D, et al. Secondary transfer of emergency stroke patients eligible for mechanical thrombectomy by air in rural England: economic evaluation and considerations. Emergency medicine journal : EMJ 2021;38(1):33-39. DOI: 10.1136/emermed-2019-209039.
288. Kunte SA, Anderson D, Brown-Espaillat K, Froehler MT. Total Transfer Time for Ground vs. Air Transport for Interhospital and Scene Transfers of Acute Stroke Patients. Journal of stroke and cerebrovascular diseases : the official journal of National Stroke Association 2021;30(6):105704. DOI: 10.1016/j.jstrokecerebrovasdis.2021.105704.
289. Sioutas GS, Amllay A, Chen CJ, et al. The Impact of Weather and Mode of Transport on Outcomes of Patients With Acute Ischemic Stroke Undergoing Mechanical Thrombectomy. Neurosurgery 2023;93(1):144-155. DOI: 10.1227/neu.0000000000002391.
290. Urdaneta A, Fisk C, Tandel MD, Garcia A, Govindarajan P. Air Medical Transport for Acute Ischemic Stroke Patients: A Retrospective Cohort Study of National Trends Over an 8-Year Period. Air medical journal 2023;42(6):423-428. DOI: 10.1016/j.amj.2023.06.007.
291. Koneru M, Thon JM, Dubinski MJ, et al. "Chopperlysis": The effect of helicopter transport on reperfusion and outcomes in large vessel occlusion strokes. Interv Neuroradiol 2024:15910199241282721. DOI: 10.1177/15910199241282721.
292. Winsor G, Thomas SH, Biddinger PD, Wedel SK. Inadequate hemodynamic management in patients undergoing interfacility transfer for suspected aortic dissection. The American journal of emergency medicine 2005;23(1):24-9. DOI: 10.1016/j.ajem.2004.01.008.
293. Rose M, Newton C, Boualam B, et al. Ground Same Intratransport Efficacy as Air for Acute Aortic Diseases. Air

medical journal 2019;38(3):188-194. DOI: 10.1016/j.amj.2019.01.003.
294. Knobloch K, Dehn I, Khaladj N, Hagl C, Vogt PM, Haverich A. HEMS vs. EMS transfer for acute aortic dissection type A. Air medical journal 2009;28(3):146-53. (In eng). DOI: 10.1016/j.amj.2008.11.004.
295. Kent RB, 3rd, Newman LB, Johnson RC, Carraway RP. Helicopter transport of ruptured abdominal aortic aneurysms. Ala Med 1989;58(7):13-4. (https://www.ncbi.nlm.nih.gov/pubmed/2711955).
296. Ishikawa N, Narita M, Shirasaka T, et al. Role of Helicopter Transfer and Cloud-Type Imaging for Acute Type A Aortic Dissection. Thorac Cardiovasc Surg 2024;72(2):105-117. (In eng). DOI: 10.1055/a-2031-3763.
297. Gordon K, Swain A, Thirkell C, Bailey M, Greenberg D. The Wellington Life Flight Helicopter Emergency Medical Service (HEMS): a retrospective audit against new Ministry of Health criteria. The New Zealand medical journal 2014;127(1402):30-42. (In eng).
298. Schweigkofler U, Reimertz C, Lefering R, Hoffmann R. [Importance of air ambulances for the care of the severely injured]. Der Unfallchirurg 2015;118(3):240-4. (In ger). DOI: 10.1007/s00113-014-2566-7.
299. Valente ME, Sherif JA, Azen CG, Pham PK, Lowe CG. Cerebral Oxygenation and Acceleration in Pediatric and Neonatal Interfacility Transport. Air medical journal 2016;35(3):156-60. (In eng). DOI: 10.1016/j.amj.2016.01.006.
300. Bellini C, Minghetti D. Vibrations during helicopter neonatal transport. Acta Paediatr Int J Paediatr 2024;113(11):2481-2482. (Letter) (In English). DOI: 10.1111/apa.17372.
301. Solvik-Olsen T, Kåsin JI, Hagemo J, Heyerdahl F. Manikin study showed that neonates are exposed to high sound and vibration levels during helicopter incubator transports. Acta Paediatr Int J Paediatr 2024;113(11):2384-2390. (Article) (In English). DOI: 10.1111/apa.17326.
302. Bouchut JC, Van Lancker E, Chritin V, Gueugniaud PY. Physical stressors during neonatal transport: helicopter compared with ground ambulance. Air medical journal 2011;30(3):134-9. DOI: 10.1016/j.amj.2010.11.001.
303. Ringburg AN, de Ronde G, Thomas SH, van Lieshout EM, Patka P, Schipper IB. Validity of helicopter emergency medical services dispatch criteria for traumatic injuries: a systematic review. Prehospital emergency care : official journal of the National Association of EMS Physicians and the National Association of State EMS Directors 2009;13(1):28-36. (In eng). DOI: 10.1080/10903120802472012.
304. Butler DP, Anwar I, Willett K. Is it the H or the EMS in HEMS that has an impact on trauma patient mortality? A systematic review of the evidence. Emergency medicine journal : EMJ 2010;27(9):692-701. (In eng). DOI: 10.1136/emj.2009.087486.
305. Ter Avest E, Griggs J, Prentice C, Jeyanathan J, Lyon RM. Out-of-hospital cardiac arrest following trauma: What does a helicopter emergency medical service offer? Resuscitation 2019;135:73-79. DOI: 10.1016/j.resuscitation.2018.12.019.
306. Gausche M, Lewis RJ, Stratton SJ, et al. Effect of out-of-hospital pediatric endotracheal intubation on survival and neurological outcome: a controlled clinical trial. Jama 2000;283(6):783-90. DOI: 10.1001/jama.283.6.783.
307. Chesters A, Keefe N, Mauger J, Lockey D. Prehospital anaesthesia performed in a rural and suburban air ambulance service staffed by a physician and paramedic: a 16-month review of practice. Emergency medicine journal : EMJ 2014;31(1):65-8. (In eng). DOI: 10.1136/emermed-2012-201846.
308. Andrew E, de Wit A, Meadley B, Cox S, Bernard S, Smith K. Characteristics of Patients Transported by a Paramedic-staffed Helicopter Emergency Medical Service in Victoria, Australia. Prehospital emergency care : official journal of the National Association of EMS Physicians and the National Association of State EMS Directors 2015;19(3):416-24. (In eng). DOI: 10.3109/10903127.2014.995846.
309. Burns BJ, Watterson JB, Ware S, Regan L, Reid C. Analysis of Out-of-Hospital Pediatric Intubation by an Australian Helicopter Emergency Medical Service. Annals of emergency medicine 2017;70(6):773-782.e4. (In eng). DOI: 10.1016/j.annemergmed.2017.03.020.
310. Sunde GA, Heltne JK, Lockey D, et al. Airway management by physician-staffed Helicopter Emergency Medical Services - a prospective, multicentre, observational study of 2,327 patients. Scandinavian journal of trauma, resuscitation and emergency medicine 2015;23:57. (In eng). DOI: 10.1186/s13049-015-0136-9.
311. Piegeler T, Neth P, Schlaepfer M, et al. Advanced airway management in an anaesthesiologist-staffed Helicopter Emergency Medical Service (HEMS): A retrospective analysis of 1047 out-of-hospital intubations. Resuscitation 2016;105:66-9. (In eng). DOI: 10.1016/j.resuscitation.2016.04.020.
312. Schmidt AR, Ulrich L, Seifert B, Albrecht R, Spahn DR, Stein P. Ease and difficulty of pre-hospital airway management in 425 paediatric patients treated by a helicopter emergency medical service: a retrospective

analysis. Scandinavian journal of trauma, resuscitation and emergency medicine 2016;24:22. (In eng). DOI: 10.1186/s13049-016-0212-9.
313. Davis DP, Peay J, Sise MJ, et al. The impact of prehospital endotracheal intubation on outcome in moderate to severe traumatic brain injury. The Journal of trauma 2005;58(5):933-9. (In eng).
314. Helm M, Schuster R, Hauke J, Lampl L. Tight control of prehospital ventilation by capnography in major trauma victims. British journal of anaesthesia 2003;90(3):327-32. (In eng).
315. Bernard S, Smith K, Foster S, Hogan P, Patrick I. The use of rapid sequence intubation by ambulance paramedics for patients with severe head injury. Emergency medicine (Fremantle, WA) 2002;14(4):406-11. (In eng).
316. Di Bartolomeo S, Sanson G, Nardi G, Michelutto V, Scian F. HEMS vs. Ground-BLS care in traumatic cardiac arrest. Prehospital emergency care : official journal of the National Association of EMS Physicians and the National Association of State EMS Directors 2005;9(1):79-84. (In eng). DOI: 10.1080/10903120590891886.
317. Gulickx M, Lokerman RD, Waalwijk JF, et al. Pre-hospital tranexamic acid administration in patients with a severe hemorrhage: an evaluation after the implementation of tranexamic acid administration in the Dutch pre-hospital protocol. Eur J Trauma Emerg Surg 2024;50(1):139-147. (Article) (In English). DOI: 10.1007/s00068-023-02262-4.
318. Thomas SH, Shewakramani S. Prehospital trauma analgesia. The Journal of emergency medicine 2008;35(1):47-57. DOI: 10.1016/j.jemermed.2007.05.041.
319. DeVellis P, Thomas SH, Wedel SK, Stein JP, Vinci RJ. Prehospital fentanyl analgesia in air-transported pediatric trauma patients. Pediatric emergency care 1998;14(5):321-3. (In eng).
320. DeVellis P, Thomas SH, Wedel SK. Prehospital and emergency department analgesia for air-transported patients with fractures. Prehospital emergency care : official journal of the National Association of EMS Physicians and the National Association of State EMS Directors 1998;2(4):293-6. (In eng).
321. Karanicolas PJ, Bhatia P, Williamson J, et al. The fastest route between two points is not always a straight line: An analysis of air and land transfer of nonpenetrating trauma patients. The Journal of trauma 2006;61(2):396-403. (In eng). DOI: 10.1097/01.ta.0000222974.31728.2a.
322. Carpenter J, Thomas F. A 10-year analysis of 214 HEMS backcountry hoist rescues. Air medical journal 2013;32(2):98-101. (In eng). DOI: 10.1016/j.amj.2012.10.012.
323. Janssen DJ, Burns BJ. Experience of pre-hospital treatment of survivors of falls-related trauma by an Australian helicopter emergency medical service. Injury 2013;44(5):624-8. (In eng). DOI: 10.1016/j.injury.2012.04.012.
324. Kurola J, Wangel M, Uusaro A, Ruokonen E. Paramedic helicopter emergency service in rural Finland - do benefits justify the cost? Acta anaesthesiologica Scandinavica 2002;46(7):779-84. (In eng).
325. Lechleuthner A, Koestler W, Voigt M, Laufenberg P. Helicopters as part of a regional EMS system--a cost-effectiveness analysis for three EMS regions in Germany. European journal of emergency medicine : official journal of the European Society for Emergency Medicine 1994;1(4):159-66. (In eng).
326. Sanson G, Di Bartolomeo S, Nardi G, et al. Road traffic accidents with vehicular entrapment: incidence of major injuries and need for advanced life support. European journal of emergency medicine : official journal of the European Society for Emergency Medicine 1999;6(4):285-91. (In eng).
327. Imaizumi T, Hata N, Kobayashi N, et al. Early access to patients with life-threatening cardiovascular disease by an air ambulance service. Journal of Nippon Medical School = Nippon Ika Daigaku zasshi 2004;71(5):352-6. (In eng).
328. Raatiniemi L, Liisanantti J, Niemi S, et al. Short-term outcome and differences between rural and urban trauma patients treated by mobile intensive care units in Northern Finland: a retrospective analysis. Scandinavian journal of trauma, resuscitation and emergency medicine 2015;23:91. (In eng). DOI: 10.1186/s13049-015-0175-2.
329. Kupas DF, Miller DD. Out-of-hospital chest escharotomy: a case series and procedure review. Prehospital emergency care : official journal of the National Association of EMS Physicians and the National Association of State EMS Directors 2010;14(3):349-54. (In eng). DOI: 10.3109/10903121003770670.
330. Gunkel S, Konig M, Albrecht R, et al. [Deployment and efficacy of ground versus helicopter emergency service for severely injured patients. Analysis of a nationwide Swiss trauma center]. Der Unfallchirurg 2015;118(3):233-9. (In ger). DOI: 10.1007/s00113-014-2567-6.
331. Steuerwald MT, Gabbard SR, Beauchamp GA, Riddle MK, Otten EJ. Administration of CroFab Antivenom by a Helicopter Emergency Medical Service Team. Air medical journal 2016;35(6):371-373. (In eng). DOI:

10.1016/j.amj.2016.08.001.
332. Lambert R, Cabardis S, Valance J, Borge E, Ducasse JL, Arzalier JJ. [Fibrinolysis and acute stroke in maritime search and rescue medical evacuation]. Annales francaises d'anesthesie et de reanimation 2008;27(3):249-51. (In fre). DOI: 10.1016/j.annfar.2007.11.023.
333. Cornelius B. Air Medical Administration of Tranexamic Acid. Journal of trauma nursing : the official journal of the Society of Trauma Nurses 2017;24(1):30-33. (In eng). DOI: 10.1097/jtn.0000000000000259.
334. Burns B, Reid C, Habig K. Review of aeromedical intra-aortic balloon pump retrieval in New South Wales. European journal of emergency medicine : official journal of the European Society for Emergency Medicine 2013;20(1):23-6. (In eng). DOI: 10.1097/MEJ.0b013e32834fdcc9.
335. Price J, Rudman J, Schoenfeld D, et al. Survivorship With Incrementally Faster Times to Primary Percutaneous Coronary Intervention (SWIFT-PPCI): A Systematic Review and Meta-Analysis. The American journal of cardiology 2023;207:356-362. DOI: 10.1016/j.amjcard.2023.08.178.
336. Legere B, Mohamed A, Elsherif S, et al. Success with incrementally faster times to endovascular therapy (SWIFT-EVT): A systematic review and meta-analysis. J Stroke Cerebrovasc Dis 2024;33(11) (Article) (In English). DOI: 10.1016/j.jstrokecerebrovasdis.2024.107964.
337. Garner AA, Mann KP, Poynter E, et al. Prehospital response model and time to CT scan in blunt trauma patients; an exploratory analysis of data from the head injury retrieval trial. Scandinavian journal of trauma, resuscitation and emergency medicine 2015;23:28. (In eng). DOI: 10.1186/s13049-015-0107-1.
338. Branas CC, MacKenzie EJ, Williams JC, et al. Access to trauma centers in the United States. Jama 2005;293(21):2626-33. (In eng). DOI: 10.1001/jama.293.21.2626.
339. Klein MB, Kramer CB, Nelson J, Rivara FP, Gibran NS, Concannon T. Geographic access to burn center hospitals. Jama 2009;302(16):1774-81. (In eng). DOI: 10.1001/jama.2009.1548.
340. De Wing MD, Curry T, Stephenson E, Palmieri T, Greenhalgh DG. Cost-effective use of helicopters for the transportation of patients with burn injuries. The Journal of burn care & rehabilitation 2000;21(6):535-40. (In eng).
341. Adeoye O, Albright KC, Carr BG, et al. Geographic access to acute stroke care in the United States. Stroke 2014;45(10):3019-24. (In eng). DOI: 10.1161/strokeaha.114.006293.
342. Palmer C, McMullan J, Knight W, Gunderman M, Hinckley W. Helicopter scene response for a STEMI patient transported directly to the cardiac catheterization laboratory. Air medical journal 2011;30(6):289-92. (In eng). DOI: 10.1016/j.amj.2011.08.005.
343. McMullan JT, Hinckley W, Bentley J, et al. Ground emergency medical services requests for helicopter transfer of ST-segment elevation myocardial infarction patients decrease medical contact to balloon times in rural and suburban settings. Academic emergency medicine : official journal of the Society for Academic Emergency Medicine 2012;19(2):153-60. (In eng). DOI: 10.1111/j.1553-2712.2011.01273.x.
344. Clemmensen P, Schoos MM, Lindholm MG, et al. Pre-hospital diagnosis and transfer of patients with acute myocardial infarction--a decade long experience from one of Europe's largest STEMI networks. Journal of electrocardiology 2013;46(6):546-52. (In eng). DOI: 10.1016/j.jelectrocard.2013.07.004.
345. Hawk A, Marco C, Huang M, Chow B. Helicopter Scene Response for Stroke Patients: A 5-Year Experience. Air medical journal 2016;35(6):352-354. (In eng). DOI: 10.1016/j.amj.2016.05.007.
346. Leira EC, Lamb DL, Nugent AS, et al. Feasibility of acute clinical trials during aerial interhospital transfer. Stroke 2006;37(10):2504-7. (In eng). DOI: 10.1161/01.STR.0000239661.07675.9d.
347. Lukovits TG, Von Iderstine SL, Brozen R, Pippy M, Goddeau RP, McDermott ML. Interhospital helicopter transport for stroke. Air medical journal 2013;32(1):36-9. (In eng). DOI: 10.1016/j.amj.2012.04.002.
348. Soulek JJ, Arthur AO, Williams E, Schieche C, Banister N, Thomas SH. Geographic information software programs' accuracy for interfacility air transport distances and time. Air medical journal 2014;33(4):165-71. (In eng). DOI: 10.1016/j.amj.2014.03.002.
349. Kashyap R, Anderson PW, Vakil A, Russi CS, Cartin-Ceba R. A retrospective comparison of helicopter transport versus ground transport in patients with severe sepsis and septic shock. International journal of emergency medicine 2016;9(1):15. (In eng). DOI: 10.1186/s12245-016-0115-6.
350. Svenson JE, O'Connor JE, Lindsay MB. Is air transport faster? A comparison of air versus ground transport times for interfacility transfers in a regional referral system. Air medical journal 2006;25(4):170-2. (In eng). DOI: 10.1016/j.amj.2006.04.003.

351. McMullan JT, Hinckley W, Bentley J, et al. Reperfusion is delayed beyond guideline recommendations in patients requiring interhospital helicopter transfer for treatment of ST-segment elevation myocardial infarction. Annals of emergency medicine 2011;57(3):213-220.e1. (In eng). DOI: 10.1016/j.annemergmed.2010.08.031.
352. Reimer AP, Hustey FM, Kralovic D. Decreasing door-to-balloon times via a streamlined referral protocol for patients requiring transport. The American journal of emergency medicine 2013;31(3):499-503. DOI: 10.1016/j.ajem.2012.09.031.
353. Hata N, Kobayashi N, Imaizumi T, et al. Use of an air ambulance system improves time to treatment of patients with acute myocardial infarction. Internal medicine (Tokyo, Japan) 2006;45(2):45-50. (In eng).
354. Fjaeldstad A, Kirk MH, Knudsen L, Bjerring J, Christensen EF. Physician-staffed emergency helicopter reduces transportation time from alarm call to highly specialized centre. Danish medical journal 2013;60(7):A4666. (In eng).
355. Peterson LF, Peterson LR. The safety of performing diagnostic cardiac catheterizations in a mobile catheterization laboratory at primary care hospitals. Angiology 2004;55(5):499-506. (In eng). DOI: 10.1177/000331970405500505.
356. Frutkin AD, Mehta SK, Patel T, et al. Outcomes of 1,090 consecutive, elective, nonselected percutaneous coronary interventions at a community hospital without onsite cardiac surgery. The American journal of cardiology 2008;101(1):53-7. (In eng). DOI: 10.1016/j.amjcard.2007.07.047.
357. Thomas SH, Harrison T, Wedel SK, Thomas DP. Helicopter emergency medical services roles in disaster operations. Prehospital emergency care : official journal of the National Association of EMS Physicians and the National Association of State EMS Directors 2000;4(4):338-44. (In eng).
358. Bredmose PP, Grier G, Davies GE, Lockey DJ. Pre-hospital use of ketamine in paediatric trauma. Acta anaesthesiologica Scandinavica 2009;53(4):543-5. (In eng). DOI: 10.1111/j.1399-6576.2008.01852.x.
359. Liu X, Liu Y, Zhang L, et al. Mass aeromedical evacuation of patients in an emergency: experience following the 2010 Yushu earthquake. The Journal of emergency medicine 2013;45(6):865-71. (In eng). DOI: 10.1016/j.jemermed.2013.05.054.
360. Mair P, Frimmel C, Vergeiner G, et al. Emergency medical helicopter operations for avalanche accidents. Resuscitation 2013;84(4):492-5. (In eng). DOI: 10.1016/j.resuscitation.2012.09.010.
361. Matsumoto H, Motomura T, Hara Y, et al. Lessons learned from the aeromedical disaster relief activities following the great East Japan earthquake. Prehospital and disaster medicine 2013;28(2):166-9. (In eng). DOI: 10.1017/s1049023x12001835.
362. Taylor CB, Stevenson M, Jan S, Middleton PM, Fitzharris M, Myburgh JA. A systematic review of the costs and benefits of helicopter emergency medical services. Injury 2010;41(1):10-20. (In eng). DOI: 10.1016/j.injury.2009.09.030.
363. Tiamfook-Morgan TO, Kociszewski C, Browne C, Barclay D, Wedel SK, Thomas SH. Helicopter scene response: regional variation in compliance with air medical triage guidelines. Prehospital emergency care : official journal of the National Association of EMS Physicians and the National Association of State EMS Directors 2008;12(4):443-50. (In eng). DOI: 10.1080/10903120802290794.
364. Vercruysse GA, Friese RS, Khalil M, et al. Overuse of helicopter transport in the minimally injured: A health care system problem that should be corrected. The journal of trauma and acute care surgery 2015;78(3):510-5. (In eng). DOI: 10.1097/ta.0000000000000553.
365. Michailidou M, Goldstein SD, Salazar J, et al. Helicopter overtriage in pediatric trauma. Journal of pediatric surgery 2014;49(11):1673-7. (In eng). DOI: 10.1016/j.jpedsurg.2014.08.008.
366. Cardoso RG, Francischini CF, Ribera JM, Vanzetto R, Fraga GP. Helicopter emergency medical rescue for the traumatized: experience in the metropolitan region of Campinas, Brazil. Revista do Colegio Brasileiro de Cirurgioes 2014;41(4):236-44. (In eng
por).
367. Haagensen R, Sjoborg KA, Rossing A, Ingilae H, Markengbakken L, Steen PA. Long-range rescue helicopter missions in the Arctic. Prehospital and disaster medicine 2004;19(2):158-63. (In eng).
368. Jurkovich GJ, Pearce WH, Cleveland HC. Thoracic and abdominal injuries in skiers: the role of air evacuation. The Journal of trauma 1983;23(9):844-8. (In eng).
369. Roper J, Krohn M, Flessa S, Thies KC. Costing of helicopter emergency services- a strategic simulation based on

the example of a German rural region. Health Econ Rev 2020;10(1):34. DOI: 10.1186/s13561-020-00287-8.
370. Snooks HA, Nicholl JP, Brazier JE, Lees-Mlanga S. The costs and benefits of helicopter emergency ambulance services in England and Wales. Journal of public health medicine 1996;18(1):67-77. (In eng).
371. Ringburg AN, Polinder S, Meulman TJ, et al. Cost-effectiveness and quality-of-life analysis of physician-staffed helicopter emergency medical services. The British journal of surgery 2009;96(11):1365-70. (In eng). DOI: 10.1002/bjs.6720.
372. Nicholl JP, Beeby NR, Brazier JE. A comparison of the costs and performance of an emergency helicopter and land ambulances in a rural area. Injury 1994;25(3):145-53. (In eng).
373. Zakariassen E, Uleberg O, Roislien J. Helicopter emergency medical services response times in norway: do they matter? Air medical journal 2015;34(2):98-103. (In eng). DOI: 10.1016/j.amj.2014.11.003.
374. Ackermann A, Pappinen J, Nurmi J, Nordquist H, Torkki P. The Estimated Cost-Effectiveness of Physician-Staffed Helicopter Emergency Medical Services Compared to Ground-Based Emergency Medical Services in Finland. Air medical journal 2024;43(3):229-235. DOI: 10.1016/j.amj.2023.12.006.
375. Brandstrom H, Winso O, Lindholm L, Haney M. Regional intensive care transports: a prospective analysis of distance, time and cost for road, helicopter and fixed-wing ambulances. Scandinavian journal of trauma, resuscitation and emergency medicine 2014;22:36. (In eng). DOI: 10.1186/1757-7241-22-36.
376. Funder KS, Rasmussen LS, Lohse N, et al. The impact of a physician-staffed helicopter on outcome in patients admitted to a stroke unit: a prospective observational study. Scandinavian journal of trauma, resuscitation and emergency medicine 2017;25(1):18. (In eng). DOI: 10.1186/s13049-017-0363-3.
377. Cummings G, O'Keefe G. Scene disposition and mode of transport following rural trauma: a prospective cohort study comparing patient costs. The Journal of emergency medicine 2000;18(3):349-54. (In eng).
378. Taylor C, Jan S, Curtis K, et al. The cost-effectiveness of physician staffed Helicopter Emergency Medical Service (HEMS) transport to a major trauma centre in NSW, Australia. Injury 2012;43(11):1843-9. (In eng). DOI: 10.1016/j.injury.2012.07.184.
379. Thomas SH, Orf J, Peterson C, Wedel SK. Frequency and costs of laboratory and radiograph repetition in trauma patients undergoing interfacility transfer. The American journal of emergency medicine 2000;18(2):156-8. DOI: 10.1016/s0735-6757(00)90008-1.
380. Diaz MA, Hendey GW, Bivins HG. When is the helicopter faster? A comparison of helicopter and ground ambulance transport times. The Journal of trauma 2005;58(1):148-53. (In eng).
381. Silbergleit R, Scott PA, Lowell MJ, Silbergleit R. Cost-effectiveness of helicopter transport of stroke patients for thrombolysis. Academic emergency medicine : official journal of the Society for Academic Emergency Medicine 2003;10(9):966-72. (In eng).
382. Selmer R, Halvorsen S, Myhre KI, Wisloff TF, Kristiansen IS. Cost-effectiveness of primary percutaneous coronary intervention versus thrombolytic therapy for acute myocardial infarction. Scandinavian cardiovascular journal : SCJ 2005;39(5):276-85. (In eng). DOI: 10.1080/14017430510035988.
383. Jagtenberg CJ, Uleberg O, Waaler Bjornelv GM, Roislien J. Utopia for Norwegian helicopter emergency medical services: Estimating the number of bases needed to radically bring down response times, and lives needed to be saved for cost effectiveness. PloS one 2023;18(3):e0281706. DOI: 10.1371/journal.pone.0281706.
384. Safford SD, Hayward TZ, Safford KM, Georgiade GS, Rice HE, Skinner MA. A cost and outcomes comparison of a novel integrated pediatric air and ground transportation system. Journal of the American College of Surgeons 2002;195(6):790-5. (In eng).
385. Mulholland SA, Cameron PA, Gabbe BJ, et al. Prehospital prediction of the severity of blunt anatomic injury. The Journal of trauma 2008;64(3):754-60. (In eng). DOI: 10.1097/01.ta.0000244384.85267.c5.
386. Cudnik MT, Werman HA, White LJ, Opalek JM. Prehospital factors associated with mortality in injured air medical patients. Prehospital emergency care : official journal of the National Association of EMS Physicians and the National Association of State EMS Directors 2012;16(1):121-7. (In eng). DOI: 10.3109/10903127.2011.615011.
387. Madiraju SK, Catino J, Kokaram C, Genuit T, Bukur M. In by helicopter out by cab: the financial cost of aeromedical overtriage of trauma patients. The Journal of surgical research 2017;218:261-270. (In eng). DOI: 10.1016/j.jss.2017.05.102.
388. Gibbons JP, Breathnach O, Quinlan JF. Emergency aeromedical services in Ireland: a retrospective study for "MEDEVAC112". Irish journal of medical science 2017;186(1):33-39. (In eng). DOI: 10.1007/s11845-016-1403-

0.
389. Gearhart PA, Wuerz R, Localio AR. Cost-effectiveness analysis of helicopter EMS for trauma patients. Annals of emergency medicine 1997;30(4):500-6. (In eng).
390. Newgard CD, Hsia RY, Mann NC, et al. The trade-offs in field trauma triage: a multiregion assessment of accuracy metrics and volume shifts associated with different triage strategies. The journal of trauma and acute care surgery 2013;74(5):1298-306; discussion 1306. DOI: 10.1097/TA.0b013e31828b7848.
391. Wuerz R, Taylor J, Smith JS. Accuracy of trauma triage in patients transported by helicopter. Air medical journal 1996;15(4):168-70. (In eng).
392. Henry MC. Trauma triage: New York experience. Prehospital emergency care : official journal of the National Association of EMS Physicians and the National Association of State EMS Directors 2006;10(3):295-302. DOI: 10.1080/10903120600721669.
393. Sebastian C, Collopy K, Clancy TV, Acquista E. Analysis of Helicopter-Transported Trauma Patients at a Regional Trauma Center. The American surgeon 2018;84(6):952-958. (https://www.ncbi.nlm.nih.gov/pubmed/29981630).
394. Weidman AC, Malakouti S, Salcido DD, et al. A Machine Learning Trauma Triage Model for Critical Care Transport. JAMA Netw Open 2025;8(6):e259639. DOI: 10.1001/jamanetworkopen.2025.9639.
395. Brown JB, Gestring ML, Guyette FX, et al. External validation of the Air Medical Prehospital Triage score for identifying trauma patients likely to benefit from scene helicopter transport. The journal of trauma and acute care surgery 2017;82(2):270-279. (In eng). DOI: 10.1097/ta.0000000000001326.
396. Brown JB, Gestring ML, Guyette FX, et al. Development and Validation of the Air Medical Prehospital Triage Score for Helicopter Transport of Trauma Patients. Annals of surgery 2016;264(2):378-85. (In eng). DOI: 10.1097/sla.0000000000001496.
397. D'Andrea PA, van Hoving DJ, Wood D, Smith WP. A 5-year analysis of the helicopter air mercy service in Richards Bay, South Africa. South African medical journal = Suid-Afrikaanse tydskrif vir geneeskunde 2014;104(2):124-6. (In eng).
398. Gavrilovski M, Griggs JE, Ter Avest E, Lyon RM, Air Ambulance Kent Surrey S. The contribution of helicopter emergency medical services in the pre-hospital care of penetrating torso injuries in a semi-rural setting. Scandinavian journal of trauma, resuscitation and emergency medicine 2021;29(1):112. DOI: 10.1186/s13049-021-00929-8.
399. O'Connor RE. Trauma triage: concepts in prehospital trauma care. Prehospital emergency care : official journal of the National Association of EMS Physicians and the National Association of State EMS Directors 2006;10(3):307-10. DOI: 10.1080/10903120600723947.
400. Lemson J, van Grunsven PM, Schipper IB, et al. [Helicopter-Mobile Medical Teams in The Netherlands: significant differences in deployment frequencies between different emergency room regions]. Nederlands tijdschrift voor geneeskunde 2008;152(19):1106-12. (In dut).
401. Wormer BA, Fleming GP, Christmas AB, Sing RF, Thomason MH, Huynh T. Improving overtriage of aeromedical transport in trauma: a regional process improvement initiative. The journal of trauma and acute care surgery 2013;75(1):92-6; discussion 96. DOI: 10.1097/TA.0b013e3182984ab0.
402. Bible JE, Kadakia RJ, Kay HF, Zhang CE, Casimir GE, Devin CJ. How often are interfacility transfers of spine injury patients truly necessary? The spine journal : official journal of the North American Spine Society 2014;14(12):2877-84. (In eng). DOI: 10.1016/j.spinee.2014.01.065.
403. Adcock AK, Minardi J, Findley S, Daniels D, Large M, Power M. Value Utilization of Emergency Medical Services Air Transport in Acute Ischemic Stroke. The Journal of emergency medicine 2020;59(5):687-692. DOI: 10.1016/j.jemermed.2020.08.005.
404. Kaufmann M, Moser B, Lederer W. Changes in injury patterns and severity in a helicopter air-rescue system over a 6-year period. Wilderness & environmental medicine 2006;17(1):8-14. (In eng).
405. Reid BO, Rehn M, Uleberg O, Kruger AJ. Physician-provided prehospital critical care, effect on patient physiology dynamics and on-scene time. European journal of emergency medicine : official journal of the European Society for Emergency Medicine 2016 (In eng). DOI: 10.1097/mej.0000000000000432.
406. Zhao Z, Liu Y, Yang B, et al. The safety and efficacy of high-speed train transport for critical children: a retrospective propensity score matching cohort study. Sci Rep 2021;11(1):19293. DOI: 10.1038/s41598-021-98944-3.

407. Lerner EB, Billittier AJt, Sikora J, Moscati RM. Use of a geographic information system to determine appropriate means of trauma patient transport. Academic emergency medicine : official journal of the Society for Academic Emergency Medicine 1999;6(11):1127-33. (In eng).
408. Park KD, Seo SJ, Oh CH, Kim SH, Cho JM. The Effectiveness Evaluation of Helicopter Ambulance Transport among Neurotrauma Patients in Korea. Journal of Korean Neurosurgical Society 2014;56(1):42-7. (In eng). DOI: 10.3340/jkns.2014.56.1.42.
409. Shepherd MV, Trethewy CE, Kennedy J, Davis L. Helicopter use in rural trauma. Emergency medicine Australasia : EMA 2008;20(6):494-9. (In eng). DOI: 10.1111/j.1742-6723.2008.01135.x.
410. Roislien J, van den Berg PL, Lindner T, Zakariassen E, Aardal K, van Essen JT. Exploring optimal air ambulance base locations in Norway using advanced mathematical modelling. Injury prevention : journal of the International Society for Child and Adolescent Injury Prevention 2017;23(1):10-15. (In eng). DOI: 10.1136/injuryprev-2016-041973.
411. Garner AA, van den Berg PL. Locating helicopter emergency medical service bases to optimise population coverage versus average response time. BMC emergency medicine 2017;17(1):31. (In eng). DOI: 10.1186/s12873-017-0142-5.
412. Brown JB, Rosengart MR, Billiar TR, Peitzman AB, Sperry JL. Distance matters: Effect of geographic trauma system resource organization on fatal motor vehicle collisions. The journal of trauma and acute care surgery 2017;83(1):111-118. (In eng). DOI: 10.1097/ta.0000000000001508.
413. Dodds N, Emerson P, Phillips S, Green DR, Jansen JO. Analysis of aeromedical retrieval coverage using elliptical isochrones: An evaluation of helicopter fleet size configurations in Scotland. The journal of trauma and acute care surgery 2017;82(3):550-556. (In eng). DOI: 10.1097/ta.0000000000001335.
414. Floccare DJ, Stuhlmiller DF, Braithwaite SA, et al. Appropriate and safe utilization of helicopter emergency medical services: a joint position statement with resource document. Prehospital emergency care : official journal of the National Association of EMS Physicians and the National Association of State EMS Directors 2013;17(4):521-5. (In eng). DOI: 10.3109/10903127.2013.804139.
415. Caldow SJ, Parke TR, Graham CA, Munro PT. Aeromedical retrieval to a university hospital emergency department in Scotland. Emergency medicine journal : EMJ 2005;22(1):53-5. (In eng). DOI: 10.1136/emj.2004.016618.
416. Black JJ, Ward ME, Lockey DJ. Appropriate use of helicopters to transport trauma patients from incident scene to hospital in the United Kingdom: an algorithm. Emergency medicine journal : EMJ 2004;21(3):355-61. DOI: 10.1136/emj.2002.004473.
417. Freshwater ES, Dickinson P, Crouch R, Deakin CD, Eynon CA. Extending access to specialist services: the impact of an onsite helipad and analysis of the first 100 flights. Emergency medicine journal : EMJ 2014;31(2):121-5. (In eng). DOI: 10.1136/emermed-2012-201948.
418. Burany B, Rudas L. [Interhospital transport of acute coronary syndrome patients from Bacs-Kiskun county]. Orvosi hetilap 2005;146(35):1819-25. (https://www.ncbi.nlm.nih.gov/pubmed/16187541).
419. Thomas SH. On-site hospital helipads: resource document for the NAEMSP position paper on on-site hospital helipads. Prehospital emergency care : official journal of the National Association of EMS Physicians and the National Association of State EMS Directors 2009;13(3):398-401. (In eng). DOI: 10.1080/10903120902731077.
420. Thomson DP, Thomas SH. Air Medical Services Committee of the National Association of EMS Physicians: Guidelines for air medical dispatch. Prehospital emergency care : official journal of the National Association of EMS Physicians and the National Association of State EMS Directors 2003;7(2):265-71. DOI: 10.1080/10903120390936923.