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Impact of Mode of Transportation On EMS-call-to-PCI Time and Door-to-Balloon Time in STEMI Patients: A Systemic Review and Meta-Analysis of 35,057 Patients

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Abstract

Introduction: Emergency revascularization with primary percutaneous coronary intervention (PCI), has been established to improve clinical outcomes for patients with acute coronary syndromes (ACS) and healthcare facilities allot and utilize resources to minimize delays to PCI and reduce door to balloon time. To our knowledge, this is the first meta-analysis that evaluates the data from these research studies collectively. The present meta-analysis focused on evaluating modalities for emergency transport systems and their impact on the outcomes of patients with STEMI.

Methods: We performed a comprehensive literature search for published studies indexed in PubMed, Embase, and Web of Science. This meta-analysis included a total of nine studies that met our inclusion criteria and had a total of 35,057 patients. All studies were observational in nature. Our primary outcomes of interest were the door to balloon time and EMS call to PCI time. Secondary outcomes evaluated were time from arrival at non-PCI facility to PCI within 90 minutes and within 120 minutes.

Results: The major findings for STEMI patients transported by air using helicopter compared with those transported by ground ambulance were as follows: first, EMS call to PCI was shorter in air transportation compared to ground transportation (mean difference -26.28; 95% CI -28.03- -24.52; P<0.001; I2=100%). Second, air transportation had a shorter time from door to balloon (mean difference -1.52; 95% CI -2.10 - -0.93; P<0.001; I2=12%). Third, when comparing air to ground transfer from non-PCI to PCI-capable facilities within the guideline recommended time windows of 90 minutes and 120 minutes for STEMI patients, transfer via air transportation was less likely to achieve the target timeline (within 90 minutes: OR 0.21; 95% CI, 0.05-0.86; P=0.03; I2=52%; within 120 minutes: OR 0.63; 95% CI 0.59- 0.67; P<0.001; I2=64%).

Conclusion: Data included in this meta analysis show that air transport reduces EMS call to PCI time and door to balloon time for STEMI patients. However, for secondary transfer (from a non-PCI center to a PCI-capable center) air transportation was not superior for achieving guideline-recommended goal times. These results may have implications on transport protocols for STEMI patients. Mode of transportation should be individualized based on the distance from the PCI capable center, patient condition and the local environmental condition. Although thrombolytic therapy was mentioned in the introduction, it was not evaluated in this meta-analysis and remains an important consideration in remote or resource-limited settings.

Keywords: Cardiology, PCI

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1. Introduction

Cardiovascular disease, particularly acute coronary syndrome (ACS), remains a leading cause of mortality worldwide. Among ACS subtypes, ST-elevation myocardial infarction (STEMI) is associated with the highest immediate risk of death and disability. Rapid restoration of coronary blood flow through primary percutaneous coronary intervention (PCI) is the gold standard treatment for STEMI and has been shown to significantly reduce mortality, reinfarction, and stroke compared to fibrinolysis [1–4].
Timeliness is critical in the management of STEMI. Every minute of delay in reperfusion increases the extent of myocardial damage, thereby elevating the risk of adverse outcomes. It has been well-established that delays between first medical contact and PCI are associated with increased mortality [2,3,5]. In fact, studies such as Benjamin et al. have indicated that each 30-minute delay beyond the optimal window for PCI increases mortality by 1-2%. As a result, international cardiology guidelines, including those from the American Heart Association (AHA) and the European Society of Cardiology (ESC), recommend specific timeframes for treatment:

- First medical contact to balloon inflation should occur within 90 minutes for patients directly transported to a PCI-capable hospital (primary transfer).
- For patients initially evaluated at a non-PCI facility (secondary transfer), total transfer time to PCI should not exceed 120 minutes from diagnosis [2,3].

To meet these standards, healthcare systems around the world have invested significant resources in optimizing emergency transportation logistics, including the use of ground ambulance services (GEMS) and helicopter emergency medical services (HEMS).
Studies have attempted to assess the efficiency of these transport modalities; however, their conclusions have varied due to differing geographic settings, patient populations, operational capacity, and operational protocols (27-28). To our knowledge, no prior meta-analysis has comprehensively synthesized these data to evaluate the time-effectiveness and clinical implications of air versus ground transport for STEMI patients.
In this study, we aim to fill this gap by examining the relative performance of air and ground transport in achieving the guideline-recommended timeframes for PCI treatment. This study's hypothesis is that air transport leads to a quicker time to PCI and improved clinical outcomes compared to ground transport, although we anticipate no significant difference in mortality or complications. Furthermore, this paper does not assess thrombolytic intervention at non-PCI facilities, an option commonly provided when rapid PCI is not feasible due to geographical limitations, minimal EMS resources, or more distant PCI centers. Data on thrombolysis in non-PCI centers could further inform the management of this challenging patient population.
Our analysis shows that air transport outperforms ground transport in meeting the 90-minute threshold for primary transfer (Figure 2), but ground transport is more effective at meeting the 120-minute target for secondary transfer, as illustrated in Figure 3. Figure 4 further highlights that air transport, while faster overall, does not guarantee adherence to the 120-minute guideline for secondary transfer, suggesting that logistics and protocol variations play a substantial role in determining transport efficacy.
By evaluating these findings, this study contributes new insights into how transport modality impacts the timeliness of PCI treatment, providing evidence that could guide future changes in emergency medical services (EMS) protocols worldwide.

2. Methods

We performed this systematic review and meta-analysis based on the guidelines of the Preferred Reporting Items for Systematic Reviews and Meta-analysis (PRISMA) (5). Initially, as seen in Figure 1, 273 studies were identified from multiple databases, including PubMed, Cochrane Library, and Scopus. After screening and quality assessment, 9 studies were selected based on relevance, quality, and inclusion criteria. These studies were primarily focused on the impact of air versus ground transport in STEMI patients, analyzing time to PCI, clinical outcomes, and mortality rates.

Data Sources and Search Strategy

We performed a comprehensive literature search for published studies indexed in PubMed, Embase, and Web of Science from inception to October 30, 2022. We also performed a manual search for additional relevant studies using references from the included articles. Supplementary Table S1

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Study or Subgroup	Air Mean	Air SD	Air Total	Ground Mean	Ground SD	Ground Total	Weight	Mean Difference IV, Random, 95% CI	Year
Knudsen 2012	40.5	28.8	22	44	40	376	0.2%	-3.50 [-16.20, 9.20]	2012
Benjamin 2013	28.4	13.3	6274	30.1	14.8	10778	80.9%	-1.70 [-2.13, -1.27]	2013
Funder 2018	32	11.1	384	32.7	10.4	1220	18.9%	-0.70 [-1.95, 0.55]	2018
Total (95% CI)			**6680**			**12374**	**100.0%**	**-1.52 [-2.10, -0.93]**	

Heterogeneity: Tau² = 0.06; Chi² = 2.27, df = 2 (P = 0.32); I² = 12%
Test for overall effect: Z = 5.09 (P < 0.00001)

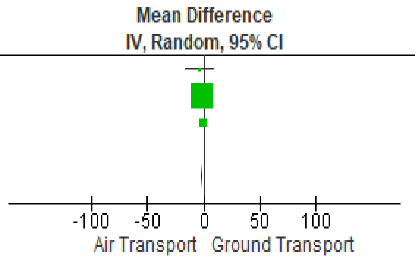

Figure 1: *Mean Time from Door to Balloon- significantly lower in air transportation compared to ground transportation*

Study or Subgroup	Air Transport Events	Air Transport Total	Ground Transport Events	Ground Transport Total	Weight	Odds Ratio M-H, Random, 95% CI
Benjamin 2013	790	6274	2640	10778	59.3%	0.44 [0.41, 0.48]
Mixon 2014	1	19	10	24	24.6%	0.08 [0.01, 0.68]
Phillips 2013	0	66	3	31	16.1%	0.06 [0.00, 1.22]
Total (95% CI)		**6359**		**10833**	**100.0%**	**0.21 [0.05, 0.86]**
Total events	791		2653			

Heterogeneity: Tau² = 0.86; Chi² = 4.15, df = 2 (P = 0.13); I² = 52%
Test for overall effect: Z = 2.17 (P = 0.03)

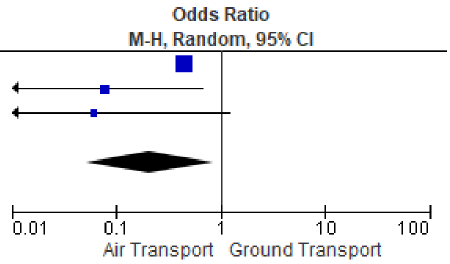

Figure 2: *Time from arrival at non-PCI facility to PCI in less than 90 minutes were is higher odds in air transportation compared to ground transportation*

Study or Subgroup	Air Events	Air Total	Ground Events	Ground Total	Weight	Odds Ratio M-H, Fixed, 95% CI
Benjamin 2013	2860	6274	6143	10778	99.1%	0.63 [0.59, 0.67]
Mixon 2014	9	19	22	24	0.4%	0.08 [0.01, 0.45]
Phillips 2013	16	66	11	31	0.5%	0.58 [0.23, 1.47]
Total (95% CI)		**6359**		**10833**	**100.0%**	**0.63 [0.59, 0.67]**
Total events	2885		6176			

Heterogeneity: Chi² = 5.55, df = 2 (P = 0.06); I² = 64%
Test for overall effect: Z = 14.53 (P < 0.00001)

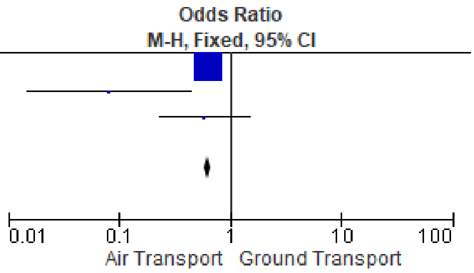

Figure 3: *Time from Arrival at Non-PCI Facility to PCI- less than 120 minutes favors air transportation compared to ground transportation*

Study or Subgroup	Air Events	Air Total	Ground Events	Ground Total	Weight	Odds Ratio M-H, Fixed, 95% CI
Benjamin 2013	2860	6274	6143	10778	99.1%	0.63 [0.59, 0.67]
Mixon 2014	9	19	22	24	0.4%	0.08 [0.01, 0.45]
Phillips 2013	16	66	11	31	0.5%	0.58 [0.23, 1.47]
Total (95% CI)		**6359**		**10833**	**100.0%**	**0.63 [0.59, 0.67]**
Total events	2885		6176			

Heterogeneity: Chi² = 5.55, df = 2 (P = 0.06); I² = 64%
Test for overall effect: Z = 14.53 (P < 0.00001)

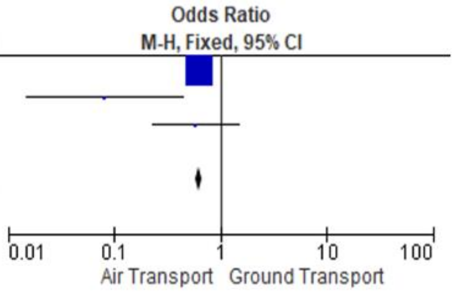

Figure 4: *Time from arrival at non-PCI facility to PCI in less than 120 minutes favors air transportation compared to ground transportation.*

describes the full search terms used in each database searched.

Eligibility Criteria

Cohort studies comparing air versus ground transportation in STEMI patients were evaluated for inclusion in the meta-analysis. We excluded studies that involved patients who had been transported for conditions other than STEMI, such as unstable angina or non-ST-segment elevation myocardial infarction (NSTEMI). We also excluded conference abstracts, preliminary reports, case reports, and editorial letters. Two investigators (A.A. and A.F.) independently screened the literature, shortlisted the studies, and extracted the data. The bibliographic software EndNote was used for screening. Any discrepancies were resolved by consensus.

Data extraction

The following data were extracted from the studies: first author name, publication year, country of origin, study design, patient demographics, inclusion and exclusion criteria, total number of patients, gender and age of patients, mode of transportation (air or ground), nature of transportation (primary or secondary), end point definitions, effect estimates, and follow-up duration. Two investigators (A.A. and A.F.) independently extracted the data from the included studies. Microsoft Excel 2019 (Microsoft Corporation, Redmond, WA, USA) was used for data extraction. Any discrepancies were resolved by consensus.

Outcomes of interest

Our primary outcomes of interest were the EMS call to PCI time and door to balloon time. Secondary outcomes evaluated were time from arrival at non-PCI facility to PCI within 90 minutes and within 120 minutes. Two methods of transfer were evaluated in this meta-analysis: primary transfer (from home to the nearest PCI-capable center) and secondary transfer (from a non-PCI center to a PCI-capable center).

Statistical analysis

The comparison between pre-hospital delays of STEMI patients transported by Helicopter Emergency Medical Services (HEMS) and Ground Emergency Medical Services (GEMS) was assessed as continuous variables' average mean. The random-effects model was used in the estimation of pooled means with the corresponding 95% confidence intervals (CI). Heterogeneity was assessed using the Higgins I2 index, where I2 values >50% implied the presence of substantial heterogeneity (6). Statistical analysis was performed using Review Manager 5.3 (Cochrane Collaboration, Copenhagen, Denmark, The Nordic Cochrane Centre). We used the Hong Kong Baptist University Department of Mathematics online calculator to convert data provided as median with respective interquartile ranges to means with confidence intervals (7).

3. Results

Study Selection

A total of 273 studies were retrieved by our search strategy. Among these, 49 were eligible for the systematic review. A total 9 studies met our inclusion criteria and were included in the meta-analysis (8–16). Chart 1 shows the PRISMA flow chart that illustrates how the final studies were selected.

Study Characteristics

The characteristics of the studies included in this meta-analysis are presented in Table 1. All studies were observational in nature, some being retrospective (8,9,13,17) and some being prospective (10,12,14,15). Studies were conducted across the world with two in the United States (8,17), two in Denmark (9,15), and one each from Japan (13), Belgium (10), and France (14). Duration of these studies ranged from 12 months (18) to 80 months (9) and dates spanned from 2002 (13) to 2019 (14). The total number of participants was 35,057 with 26963 transported by ground EMS and 8618 transported by helicopter EMS. Among the studies that reported gender, 73.2% of patients were male, with ages ranging from their late fifties to early seventies.

Clinical Outcomes:

1. EMS Call to PCI:

Five studies (9,10,12–14) reported that the mean time from EMS call to PCI, and it was shorter in air transportation compared to ground transportation (mean difference -26.28; 95% CI -28.03- -24.52; P<0.001; I2=100%). While all included studies defined system delay as EMS call to PCI, high heterogeneity could be explained by differences in HEMS dispatch criteria reported in the included studies. For example, in one single-center study (10) HEMS was always dispatched due to rural location. In another study (18) HEMS was dispatched only when time from the scene to PCI

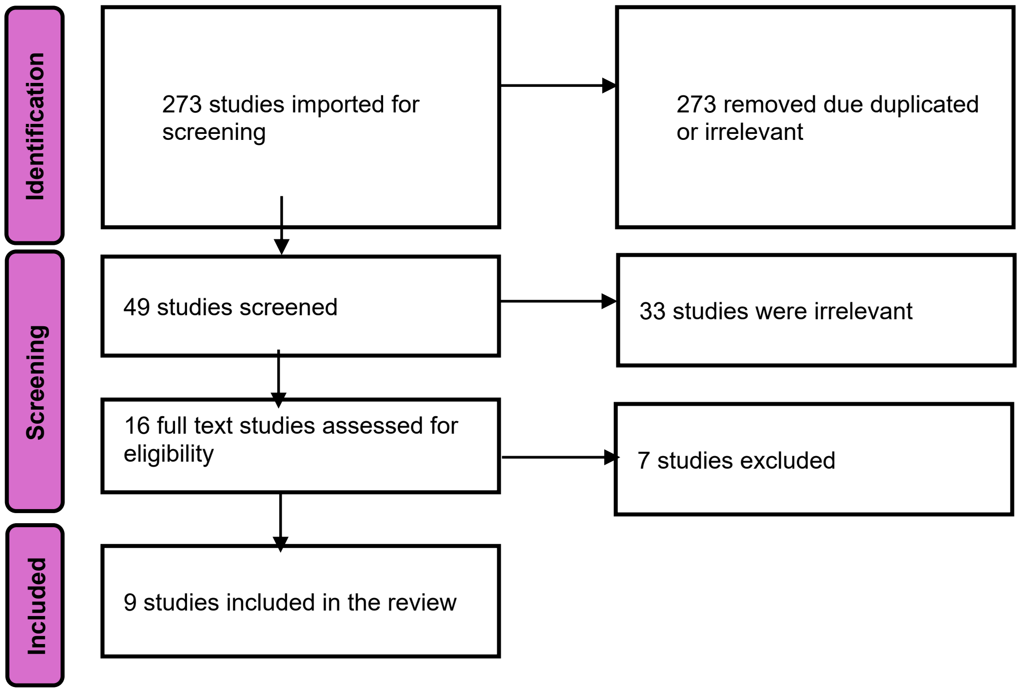

Chart 1: *PRISMA Diagram of Studies Included in the Review*

Table 1: ***Study and Participants' Characteristics of the Included Studies***

Study	Origin	Study design	Total number	Duration
Mørk, 2022	Denmark	Observational, retrospective	13,534	6 years
Hakim, 2019	France	Prospective	1911	4 years
Funder, 2018	Eastern Denmark	Prospective observational study	1604	3 years
Moens, 2015	BELGIUM	Prospective study	342	5 years
Benjamin , 2014	USA	retrospective	17,052	4 years
Mixon, 2014	Texas, USA	Retrospective	43	5 years
Phillips, 2013	Oklahoma, USA	Retrospective	97	2 years
Knudsen, 2012	Denmark	Prospective study	398	1 year
Hata, 2005	Japan	Prospective study	76	2 years

center was estimated to be ≥30 mins, in another (9) ≥75km, and in another single-center study (13) patients needing transport >50km were not included. Additionally, one study was nationwide (9) and one covered a large area with 5 HEMS platforms (14). The other included studies were single-center (10,13) or covered a rural area (10,18).

2. Door to Balloon Time:
Three studies (11,15,16) reported the mean time from door to balloon which was significantly shorter in air transportation compared to ground transportation (mean difference -1.52; 95% CI -2.10 - -0.93; P<0.001; I2=12%). One study (19) was excluded from this analysis due higher heterogeneity which could be explained by their study limitation which was a retrospective, single-center, observational study and the reasons why ambulance crews requested (or did not request) HEMS were not surveyed. In addition, data on transport time and distance were not available.

3. Time from Arrival at Non-PCI facility to PCI ≤90 minutes:
Three studies (11,15,16) reported that arrival at a non-PCI facility to PCI in ≤90 minutes is less likely with air transportation compared to ground transportation (OR 0.21; 95% CI, 0.05- 0.86; P=0.03; I2=52%). One study (20) was excluded from this analysis due higher heterogeneity which could be explained by their study being a single-center study which covered only a small geographical area of the country and used a small patient sample size (n=97).

4. Time from Arrival at Non-PCI Facility to PCI ≤120 minutes:
Three studies (11,15,16) reported arrival at a non-PCI facility to PCI in ≤120 minutes is less likely with air transportation compared to ground transportation (OR 0.63; 95% CI 0.59- 0.67; P<0.001; I2=64%). The study (20) excluded from the PCI in ≤90 minutes was also excluded here due to higher heterogeneity which could be explained by their study being a single-center study which covered only a small geographical area of the country and using a small patient sample size (n=97).

Quality and Bias Assessment:
The Newcastle Ottawa Quality Assessment Scale (NOS) was used to assess the methodology of the observational studies based on the selection of the study groups, comparability of study groups, and ascertainment of exposure/outcome (21). All studies included in this analysis had a NOS score of 7 or more and studies with total scores of ≥6 were considered to have a low risk of bias. We were not able to conduct an assessment of publication bias due to the small number of studies (<10 studies) (22).

4. Discussion

The current meta-analysis aimed to assess the outcomes for transportation modalities, air versus ground, for STEMI patients who underwent reperfusion therapy. To our knowledge, this meta-analysis is the first to collectively evaluate studies that have assessed time efficiency and outcomes of such transportation modalities. The results showed that air transportation had shorter times from door to balloon and from the Emergency Medical Services (EMS) call to PCI (Percutaneous Coronary Intervention) compared to ground transportation. However, air transportation was less likely to achieve the target timeline when comparing air to ground transfer from non-PCI to PCI-capable facilities within 90 minutes and 120 minutes, specifically.

Among the studies included in this meta-analysis, Benjamin et al. emerged as influential, contributing to the pooled outcomes presented in Figures 2 through 4. This study offered key insights into how transportation delays—especially those associated with air travel—can negatively impact patient outcomes. By highlighting critical logistical and operational differences between air and ground modalities, Benjamin et al. reinforced the broader finding of this review: that air transport, while faster in some contexts, often falls short of consistently meeting the guideline-recommended timelines for STEMI care as evidenced by Figures 3 and 4 which further reinforce that air transport was less likely to achieve the recommended timeline in comparison to ground transfer from non-PCI to PCI-capable facilities.

When evaluating first EMS contact to PCI, air transport demonstrates advantageous time savings over ground transport as seen in Figure 2. This is supported by our analysis which shows over 26 minutes faster transport with air compared to ground emergency transport. It has been determined that air transport via helicopter must achieve at least 15 minutes of total time savings to be clinically significant (20). This translates into “lives saved per 100 transported” in the literature

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which describes deaths from STEMI that could be prevented when times savings achieved during transportation are exclusively taken into account (14, 20).

Door to balloon time is an essential element in the optimization of care for STEMI patients. An observational study conducted by Nicholson et al, using the ACTION registry in the USA including data from 17,052 STEMI patients transferred from non-PCI to PCI-capable hospitals, found that patients often failed to achieve the guideline-recommended goal of STEMI diagnosis to PCI time of ≤120 minutes regardless of transfer distance or modality. Additionally, EMS transport time to the non-PCI capable hospital was not available for most patients, likely underestimating the first medical contact to balloon time regardless of the mode of transfer later used to the PCI-capable facility (23).
The same study conducted by Nicholson et al, demonstrated that even in transfer distances >40 miles, helicopter transfer did not achieve shorter first medical contact to balloon times than ground transfer. Another study conducted by Hakim et al, in France using a PCI registry for 1,911 STEMI patients demonstrated that air transport of STEMI patients was five times less likely to achieve PCI in ≤ 90 minutes than ground transport patients, especially for transport distances < 50 km (17). Additionally, a small study by Schoos et al, comparing patients with STEMI transported by helicopter from a remote island to a PCI-capable facility to patients with STEMI transported by ground on the mainland reported that transportation by helicopter was associated with longer treatment delays despite similar mortality outcomes (22). These data are consistent with others that found air transport frequently exceeded guideline recommendations (18, 21). On the other hand, a study by Knudsen et al, out of Denmark indicated that air transport should be considered for STEMI patients requiring long transport of ≥60 km to PCI-capable facilities in order shorten the reperfusion delay compared to ground transport (15).

While the use of Helicopter Emergency Medical Service (HEMS) in STEMI has numerous benefits, there are also a few limitations and challenges associated with its use (25). One of the most significant challenges is the cost of HEMS, which can be substantial, particularly in areas where HEMS services are not widely available. This can make it difficult for patients in these areas to access the life-saving care they need. Furthermore, the availability of HEMS services can be limited, especially in rural or remote areas, where access to helicopters and medical teams may be limited. Additionally, HEMS operations can be high-risk due to factors such as inclement weather conditions or the need for medical teams to make quick and effective decisions under pressure. Despite these challenges, the potential benefits of HEMS in STEMI make it an important tool in providing timely and effective care for patients experiencing this type of heart attack.

Clinical Implications:
Our findings underscore the importance of tailored emergency transport protocols based on geographic and infrastructural factors. In urban and suburban regions with shorter distances to PCI-capable centers, GEMS may be preferable due to faster loading, fewer logistical complexities, and better adherence to treatment timelines. Conversely, in rural or remote regions where ground travel time would significantly exceed guideline recommendations, HEMS may offer a clinically significant benefit—provided system efficiencies can be optimized to reduce takeoff delays, flight coordination times, and inter-hospital transfer inefficiencies.
These insights could inform regional EMS protocols by encouraging the integration of pre-hospital triage tools that account for transport mode, travel distance, hospital PCI capability, and weather or resource availability. Additionally, health systems might benefit from expanding regional STEMI networks that optimize not only the proximity but the accessibility and speed of available transport modalities. Further investment in decision support tools and dispatch algorithms that dynamically assess time-to-treatment could ensure patients are routed via the most effective mode of transport in real time.
Despite these challenges, the potential benefits of HEMS in STEMI make it an important tool in providing timely and effective care for patients experiencing this type of heart attack. Future studies should aim to compare multimodal systems of care that include thrombolytics, where applicable, as well as hybrid EMS strategies to address gaps in timely reperfusion.

Limitations:
Our study has several limitations that should be acknowledged. First, all the studies included were observational, with their own selection and confounding biases. More large-scale prospective

cohort studies are needed to validate our findings. Second, even though we only included studies using multivariate analysis, we cannot rule out residual confounding due to factors affecting mode of transportation, such as traffic, urban density, and weather. Third, although we employed the random-effects model in our analysis, there was significant variability among the studies. We could not identify the source of significant heterogeneity between the studies but differences in participants' comorbidities, concomitant medications, patients and hospital location may be partially responsible. Fourth, while it is difficult to make specific generalizations based on distance between non-PCI capable facility to PCI-capable facility, terrestrial characteristics, weather circumstances, and many other factors that affect the time efficiency of transport modalities, this meta-analysis does not make specific conclusions for each of these factors because it is difficult to adjust for these factors individually. This meta analysis does, however, allow for generalized conclusions about the time efficiency of different transport modalities. Finally, because this is a meta-analysis of observational data, there is no way to conclude a causal association between mode of transportation and the reported outcomes.

5. Conclusion

Data included in this meta analysis show that air transport saves time for STEMI patients requiring PCI. However, for secondary transfer (from a non-PCI center to a PCI-capable center) air transportation was not superior for achieving guideline-recommended goal times. Mode of transportation should be individualized based on the distance from the PCI-capable center, patient condition and local environmental conditions. Further studies should compare how air and ground emergency transports are received and how information is coordinated between EMS, hospital staff and cardiac catheterization laboratories to efficiently expedite PCI procedures.

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