J Korean Med Sci. 2026 Oct 26;41(41):e272
https://doi.org/10.3346/jkms.2026.41.e272
eISSN 1598-6357·pISSN 1011-8934

JKMS

Original Article
Emergency Medicine

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System Delay and Mortality in ST-Elevation Myocardial Infarction: A Multicentre, Retrospective, Observational Study in Seoul

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OPEN ACCESS

Received: Sep 13, 2025
Accepted: Mar 11, 2026
Published online: Jul 7, 2026

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ABSTRACT

Background: Prompt recognition and early management of ST-segment elevation myocardial infarction (STEMI) are crucial for improving outcomes. This study investigates the association between system delay and in-hospital mortality in patients with STEMI.
Methods: Using data from the Seoul GOLDEN-time emergency medical system registry, a multicentre retrospective registry in Seoul, this study analysed patients with STEMI who were transported to an emergency department via emergency medical service for cardiac complaints between July 2020 and December 2022. System delay included the response time (first medical contact to an ambulance on the scene), scene time (ambulance on the scene to departure), scene-to-door time (departure to hospital arrival), and door-to-balloon time.
Results: Among 654 patients with STEMI who received percutaneous coronary intervention, survivors had shorter overall system delay, prehospital time, scene time, scene-to-door time, and door-to-balloon time than non-survivors. A system delay > 127.5 minutes was associated with high mortality (adjusted odds ratio [aOR], 2.07; 95% confidence interval [CI], 1.05–4.13). Prolonged prehospital time (aOR, 2.35; 95% CI, 1.16–4.95), scene time (aOR, 2.61; 95% CI, 1.24–5.75), and door-to-balloon time (aOR, 2.20; 95% CI, 1.09–4.39) were each independently associated with mortality.
Conclusion: Prolonged system delays were associated with increased in-hospital mortality. These findings highlight the need for a comprehensive, system-level approach to reducing system delay across the entire STEMI care pathway.

Keywords: Emergency Medical Services; ST Elevation Myocardial Infarction; Mortality; Percutaneous Coronary Intervention

INTRODUCTION

Prompt recognition and early management of acute ST-segment elevation myocardial infarction (STEMI) are critical for reducing the associated morbidity and mortality and improving clinical outcomes. Early restoration of normal epicardial flow through primary percutaneous coronary intervention (PCI) is a key component of effective treatment.

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Funding

This work was supported by an Institute of Information & Communications Technology Planning & Evaluation (IITP) grant funded by the Korean government (MSIT) (No. RS-2020-II201373, Artificial Intelligence Graduate School Program [Hanyang University]).
This study was supported by a National Research Foundation of Korea grant (NRF-2022R1A2C1012627).

Disclosure

The authors have no potential conflicts of interest to disclose.

Author Contributions

Conceptualization: Lee SH, Yoo KH. Formal analysis: Lee SH, Oh J. Methodology: Lee SH, Yoo KH. Resources: Oh J, Lee J, Yoon YH, Park JH. Supervision: Kang H, Oh J, Lee J, Yoon YH, Park JH. Visualization: Oh J. Writing - original draft: Lee SH. Writing - review & editing: Kang H, Oh J, Ko BS, Lee J, Kim J.

Research indicates that each 30-minutes delay in treatment after symptom onset increases the risk of STEMI-associated death by 7.5%.[1,2]

System delay, defined as the time from first medical contact (FMC) to reperfusion, is a significant predictor of mortality in STEMI patients.[1,3,4] System delay is divided into prehospital and in-hospital delays. The prehospital delay is further categorised into the response time (from FMC to emergency medical service [EMS] arrival at the scene), scene time (from EMS arrival at the scene to departure from the scene), and scene-to-door time (from EMS departure from the scene to hospital arrival).[5] **Fig. 1** presents a schematic overview of time delays in the STEMI care pathway. Improvements have predominantly been observed in the in-hospital stage, specifically in door-to-balloon time, and reductions in prehospital delays are still needed.[6,7] In the United States and Europe, prehospital delay times have remained largely unchanged during the past few decades. In the United States, no statistically significant changes in prehospital delay for acute myocardial infarction were observed between 1987 and 2000,[7] and from 2001 to 2011, prehospital delay times remained unchanged among patients aged 65 years and older.[6]

South Korea, with a population of approximately 50 million and an area of about 100,000 km^2, has Seoul as its capital city.[8] Seoul accounts for approximately 20% of the national population, with 9 million residents living in an area of 605 km^2.[9] Thus it has a population density that surpasses that of other major cities such as Tokyo, Paris, Beijing, London, and Singapore.[9] Ischemic heart disease is the second leading cause of death in South Korea, consistent with global trends,[10] and the number of myocardial infarction patients is increasing in both South Korea and Seoul.[8-12] Achieving early reperfusion in STEMI patients requires a reduction in system delays and identification of the stages in which delay occurs. This study analyses delays at each step of care and their associations with STEMI-associated mortality in the metropolitan city of Seoul.

METHODS

Study design

Using data from the Seoul GOLDEN-time emergency medical system data registry, this multicentre, retrospective, observational study analysed patients with STEMI who were transported by the national EMS to any of the 26 hospitals in the registry that could provide 24-hour emergency PCI between July 2020 and December 2022.

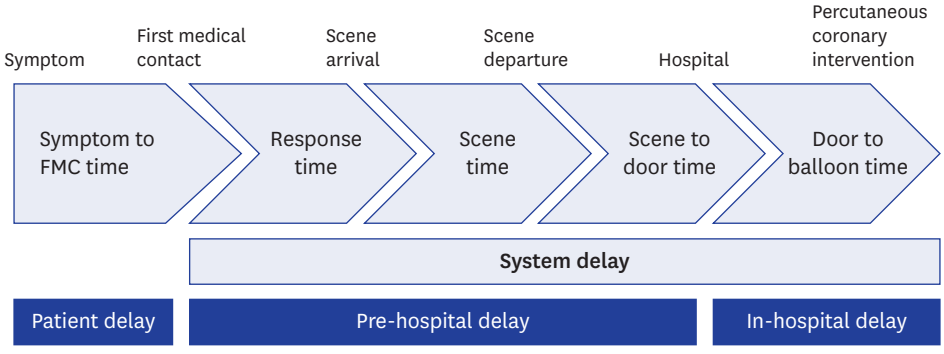

Fig. 1. Schematic overview of time delays during ST-segment elevation myocardial infarction care.
FMC = first medical contact.

https://doi.org/10.3346/jkms.2026.41.e272

Participants met the diagnostic criteria for myocardial infarction, defined as symptom onset within seven days and an International Classification of Diseases 10th revision (ICD-10) code of I21 (acute myocardial infarction) recorded in the emergency department. Eligibility further required ST-segment elevation on the initial electrocardiogram (ECG) in the emergency department. The exclusion criteria were inter-hospital transfer, missing data, cardiac arrest during prehospital transport, unavailable symptom onset time, cases in which PCI was not performed, inconsistencies in temporal sequencing, and a door-to-balloon time exceeding 360 minutes.[13]

Setting

Seoul has 14 tertiary and 43 general hospitals; 14 tertiary and 14 general hospitals provide 24-hour emergency PCI. Among them, 14 tertiary and 12 general hospitals participated in the Seoul GOLDEN-time system during the study period. The registry collects patients' medical histories and detailed time intervals from symptom onset to PCI ballooning, categorized by stage of care. Detailed situation reports were completed for patients that the paramedics judged to be in cardiac arrest or suspected of cardiovascular disease, cerebrovascular disease, or severe trauma. Patients suspected of cardiovascular disease were classified as non-trauma patients aged ≥ 18 years with symptoms such as chest pain, dyspnoea, fainting, or other conditions that led the EMS paramedics to suspect cardiovascular disease. For those patients, additional information was collected on the chief complaint, underlying comorbidities, 3-lead or 12-lead ECG findings, and ST-segment changes. In-hospital data reported ECG findings, ICD-10 codes, whether coronary angiography or PCI was performed, time of arrival, and mortality before discharge. Registry data are collected using a standardised registry form and uploaded to a web-based electronic database. A quality management committee oversees the registry to ensure reliability and data integrity.

Data extraction and definition

We analysed age, sex, and comorbidities (hypertension, diabetes mellitus, heart disease, dyslipidaemia, stroke) as baseline characteristics and mental status (alert, verbal response, pain response, or unresponsive), prehospital 12-lead ECG acquisition, intensive care unit (ICU) admission, and prehospital notification to the receiving hospital as clinical data. Prehospital systolic blood pressure (SBP), diastolic blood pressure (DBP), and heart rate (HR) were collected, along with the same measurements recorded in the hospital. The first prehospital pulse oximetry saturation (SpO_2) was included; however, in-hospital SpO_2 was excluded because information on oxygen administration during transport was unavailable. Additionally, survival status at discharge was included to distinguish between survivors and non-survivors.

For the analyses, age was categorised into three groups: < 65 years, 65–80 years, and ≥ 80 years. SBP was categorised as < 90 mmHg and ≥ 90 mmHg. DBP was categorised as < 60 mmHg and ≥ 60 mmHg. SpO_2 levels were categorised as < 90%, 90–94%, and ≥ 94%. HR was categorised as < 60 bpm, and ≥ 60 bpm. Mental status was categorized as alert and non-alert. Severity was defined as ICU admission or death in the emergency department versus general ward admission.

Time data were categorised as follows: symptom onset to FMC, prehospital time (the sum of response time, scene time, and scene-to-door time), response time, scene time, scene-to-door time, door-to-balloon time, and system delay (sum of prehospital time and door-to-balloon time).

https://doi.org/10.3346/jkms.2026.41.e272

Outcome variables

The primary outcome was the difference in system delay between survivors and non-survivors, with survival defined as living until hospital discharge. The optimal cutoff was determined as the point with the minimum distance to the upper-left corner (0,1) of the receiver operating characteristic curve, and survivor proportions were analysed accordingly.[14,15] To examine the relationship between system delay and mortality, delays were divided into 30-minute intervals, with patient counts and mortality displayed in a graph. The secondary outcome assessed mortality by grouping patients by ≤ 90 or > 90 minutes of system delay, consistent with international STEMI guidelines recommending a 90-minute system delay threshold.[1,5,16]

Statistical analysis

We examined the association between the survival and non-survival groups for all variables and models. Continuous baseline variables are presented as means and medians with interquartile ranges (IQRs), and their normality was assessed using the Shapiro-Wilk test. For continuous variables with normality, Student's *t*-test was performed, and the Mann-Whitney *U* test was applied to non-normally distributed continuous variables. Categorical variables are expressed as absolute counts and percentages, and they were analysed using Pearson's χ^2 test or Fisher's exact test, depending on whether the proportion of cells with an expected frequency < 5 exceeded 20% in a univariate analysis.[17-19] Trends in mortality across increasing time categories were evaluated using the Cochran-Armitage test for trends.

Both univariable and multivariable logistic regression analyses were performed for each system delay category. All logistic regression models were examined with the Hosmer-Lemeshow goodness-of-fit test. Firth's penalized likelihood logistic regression with increased iteration limits was used to handle complete separation.[20-22] As a rule, all tests were performed as two-sided tests with a significance level of 5%. All statistical analyses were performed using R (version 4.3.2; The R Foundation for Statistical Computing, Vienna, Austria).

Ethics statement

The Institutional Review Boards of Hanyang University Hospital approved the protocol for this study (approval No. HYUH 2022-15-055-015). Given the study's observational design, informed consent was waived, and all patient data in the registry were anonymised.

RESULTS

We analysed 654 EMS-transported STEMI patients who underwent PCI in Seoul, South Korea (**Fig. 2**). The mean age was higher among non-survivors than among survivors, and patients aged < 65 years represented the largest proportion of survivors. Hypertension and diabetes mellitus were more prevalent in non-survivors than survivors, but the other comorbidities showed no differences between groups. Significant differences were also noted in prehospital SBP, SpO_2, and mental status (**Table 1**).

Comparison of system delay between survivors and non-survivors

Significant differences between survivors and non-survivors were observed for system delay, prehospital time, scene time, scene-to-door time, and door-to-balloon time, both in terms of their mean values and when categorized according to their respective cutoff values (**Table 2**). **Fig. 3** presents the numbers of patients and deaths and the mortality rate

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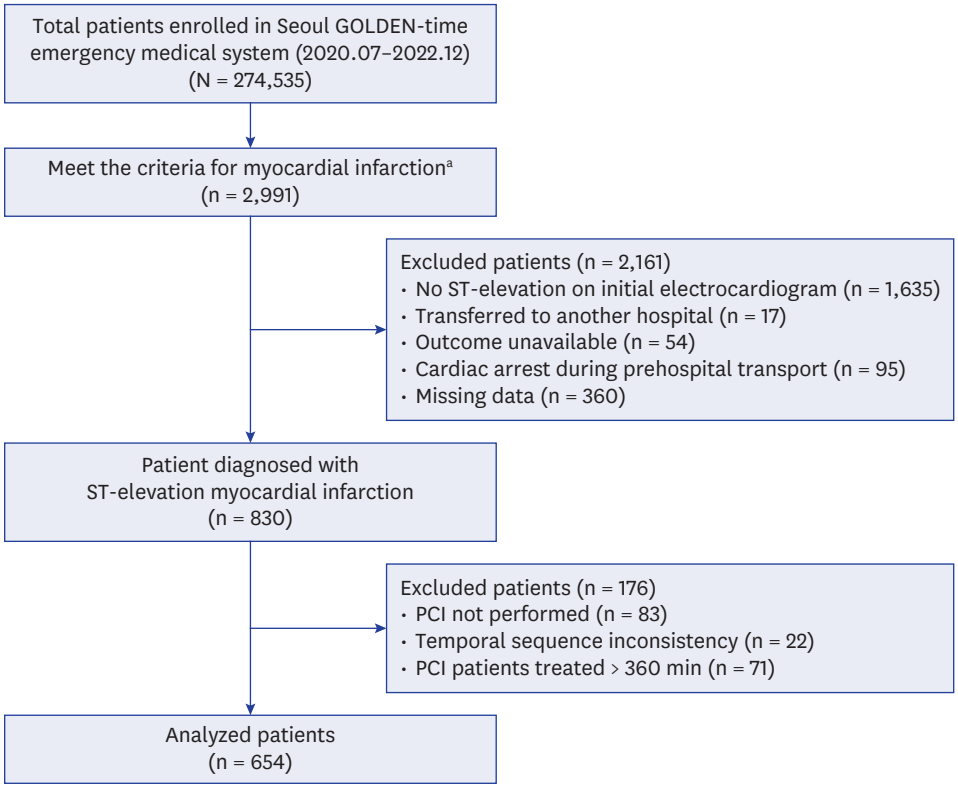

Fig. 2. Flow chart of this study.
PCI = percutaneous coronary intervention.
[a]A patient transported through the national emergency medical service developed symptoms within 7 days and had a diagnosis of acute myocardial infarction (International Classification of Disease-10 code: I21) in an emergency department.

across system delay intervals. No patients had a system delay of 0–30 minutes. A significant increasing trend in mortality was observed across increasing time intervals (Cochran-Armitage test for trend, $P = 0.002$).

Comparison between system delays ≤ 90 and > 90 minutes

Table 3 compares the median values of each time interval between patients with a system delay ≤ 90 minutes and those with a system delay > 90 minutes. Of the 654 patients analysed, 176 (26.9%) achieved ≤ 90 minutes, with 7 deaths (4.0%), and 478 (73.1%) exceeded 90 minutes, with 45 deaths (9.4%). Significant differences were observed in all components of system delay, except for symptom onset to FMC time.

Association between system delays and mortality in patients with STEMI

Table 4 presents the adjusted odds ratios (aORs) for mortality according to the system delay (> 90 vs. ≤ 90 minutes). In the overall cohort, system delay (aOR, 2.07; 95% confidence interval [CI], 1.05–4.13), prehospital time (aOR, 2.35; 95% CI, 1.16–4.95), scene time (aOR, 2.61; 95% CI, 1.24–5.75), and door to balloon time (aOR, 2.20; 95% CI, 1.09–4.39) were significantly associated with mortality. Among patients with a system delay of less than 90 minutes, no significant associations were observed except for scene time. In contrast, among patients with a system delay greater than 90 minutes, prehospital time showed a significant association (aOR, 2.33; 95% CI, 1.05–5.50). We also performed a separate analysis of the odds ratios for mortality according to time delays among patients with high-severity STEMI,

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Table 1. Baseline characteristics

Variables	Total patients (N = 654)	Survivors (n = 602)	Non-survivors (n = 52)	*P* value
Age, yr	63.3 ± 12.9	62.5 ± 12.6	72.1 ± 12.8	< 0.001
< 65	351 (53.7)	336 (55.8)	15 (28.8)	
65–80	233 (35.6)	210 (34.9)	23 (44.2)	
≥ 80	70 (10.7)	56 (9.3)	14 (26.9)	
Sex				0.777
Male	568 (86.9)	524 (87.0)	44 (84.6)	
Female	86 (13.1)	78 (13.0)	8 (15.4)	
Comorbidities				
Hypertension	268 (41.0)	239 (39.7)	29 (55.8)	0.035
Diabetes mellitus	134 (20.5)	117 (19.4)	17 (32.7)	0.036
Heart disease	111 (17.0)	97 (16.1)	14 (26.9)	0.072
Dyslipidaemia	64 (9.8)	60 (10.0)	4 (7.7)	0.775
Stroke	18 (2.8)	16 (2.7)	2 (3.8)	0.952
Prior notification to the hospital				0.923
Yes	595 (91.0)	547 (90.9)	48 (92.3)	
No	59 (9.0)	55 (9.1)	4 (7.7)	
Prehospital 12-lead electrocardiogram				0.957
Yes	96 (14.7)	89 (14.8)	7 (13.5)	
No	558 (85.3)	513 (85.2)	45 (86.5)	
Severity				0.290
Intensive care unit admission or death in ED	566 (86.5)	518 (86.0)	48 (92.3)	
General ward admission	88 (13.5)	84 (14.0)	4 (7.7)	
Prehospital clinical data				
Systolic blood pressure, mmHg				0.027
< 90	54 (8.3)	45 (7.5)	9 (17.3)	
≥ 90	600 (91.7)	557 (92.5)	43 (82.7)	
Diastolic blood pressure, mmHg				0.200
< 60	72 (11.0)	63 (10.5)	9 (17.3)	
≥ 60	582 (89.0)	539 (89.5)	43 (82.7)	
Heart rate, per minute				0.068
< 60	133 (20.3)	128 (21.3)	5 (9.6)	
≥ 60	521 (79.7)	474 (78.7)	47 (90.4)	
Pulse oximetry saturation				< 0.001
< 90	52 (8.0)	36 (6.0)	16 (30.8)	
90–94	20 (3.1)	15 (2.5)	5 (9.6)	
≥ 94	582 (89.0)	551 (91.5)	31 (59.6)	
Mental status				< 0.001
Alert	635 (97.1)	590 (98.0)	45 (86.5)	
Other	19 (2.9)	12 (2.0)	7 (13.5)	
In-hospital clinical data				
Systolic blood pressure, mmHg				< 0.001
< 90	61 (9.3)	47 (7.8)	14 (26.9)	
≥ 90	593 (90.7)	555 (92.2)	38 (73.1)	
Diastolic blood pressure, mmHg				< 0.001
< 60	92 (14.1)	75 (12.5)	17 (32.7)	
≥ 60	562 (85.9)	527 (87.5)	35 (67.3)	
Heart rate, per minute				0.225
< 60	123 (18.8)	117 (19.4)	6 (11.5)	
≥ 60	531 (81.2)	485 (80.6)	46 (88.5)	
Mental status				< 0.001
Alert	635 (97.1)	590 (98.0)	45 (86.5)	
Others	19 (2.9)	12 (2.0)	7 (13.5)	

Values are presented as number (%) or mean ± standard deviation.
ED = emergency department.

defined as those who were admitted to the ICU or died in the emergency department, and observed results similar to those of the main analysis (**Supplementary Table 1**).

https://doi.org/10.3346/jkms.2026.41.e272

Table 2. Difference in time delay between survivors and non-survivors

Variables	Total patients (N = 654)	Survivors (n = 602)	Non-survivors (n = 52)	*P* value
Symptom onset to FMC time, min	225.6 ± 1,038.5	212.7 ± 1,050.9	374.7 ± 878.0	0.281
≤ 138.0	503 (76.9)	469 (77.9)	34 (65.4)	0.060
> 138.0	151 (23.1)	133 (22.1)	18 (34.6)	
System delay, min	123.2 ± 52.1	121.0 ± 50.4	149.0 ± 63.5	0.003
≤ 127.5	420 (64.2)	399 (66.3)	21 (40.4)	< 0.001
> 127.5	234 (35.8)	203 (33.7)	31 (59.6)	
Prehospital time, min	28.2 ± 12.5	27.6 ± 12.4	34.6 ± 12.2	< 0.001
≤ 27.5	391 (59.8)	376 (62.5)	15 (28.8)	< 0.001
> 27.5	263 (40.2)	226 (37.5)	37 (71.2)	
Response time, min	8.5 ± 3.6	8.5 ± 3.6	8.8 ± 3.4	0.600
≤ 8.5	397 (60.7)	369 (61.3)	28 (53.8)	0.364
> 8.5	257 (39.3)	233 (38.7)	24 (46.2)	
Scene time, min	8.8 ± 7.5	8.5 ± 7.5	11.7 ± 6.3	0.004
≤ 7.5	360 (55.0)	347 (57.6)	13 (25.0)	< 0.001
> 7.5	294 (45.0)	255 (42.4)	39 (75.0)	
Scene to door time, min	10.9 ± 8.0	10.6 ± 7.8	14.1 ± 8.8	0.002
≤ 9.5	359 (54.9)	339 (56.3)	20 (38.5)	0.019
> 9.5	295 (45.1)	263 (43.7)	32 (61.5)	
Door to balloon time, min	95.0 ± 50.3	93.4 ± 48.7	114.4 ± 63.6	0.023
≤ 106.5	466 (71.3)	439 (72.9)	27 (51.9)	0.002
> 106.5	188 (28.7)	163 (27.1)	25 (48.1)	

Values are presented as number (%) or mean ± standard deviation.
FMC = first medical contact.

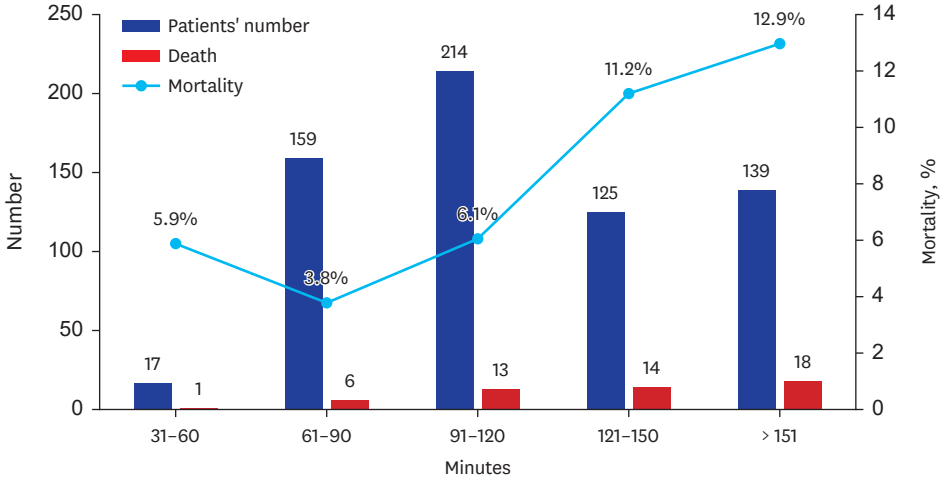

Fig. 3. Mortality according to system delay. No patients had a system delay of 0–30 minutes.
The *P* value for the trend in mortality across time intervals is 0.002.

DISCUSSION

This study examined system delays and mortality in EMS-transported STEMI patients in Seoul. Survivors had shorter system delays across all components except response time. Among those with > 90 minutes delays, prolonged prehospital times were significantly associated with increased mortality.

Our study has the advantage of being, to our knowledge, the first to evaluate mortality according to time delays along the STEMI treatment pathway in a large metropolitan setting such as Seoul. In addition, compared with previous studies on time delays in STEMI care, our study offers several methodological strengths. Unlike previous studies, which either

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Table 3. Comparison of time delays between system delays of ≤ 90 and > 90 minutes

Variables	System delay ≤ 90 min (n = 176)			System delay > 90 min (n = 478)			*P* value
	Median, min	Interquartile range, min	Median (95% CI)	Median, min	Interquartile range, min	Median (95% CI)	
Symptom onset to FMC time, min	30.0	5.8–112.0	23.0–46.5	32.5	5.00–128.3	25.5–41.0	0.807
System delay, min	77.0	68.0–84.0	74.5–79.0	126.0	106.0–161.8	121.0–131.0	< 0.001
Total prehospital time, min	23.0	18.0–27.0	21.0–24.0	26.0	21.0–35.0	25.0–28.0	< 0.001
Response time, min	7.0	6.0–9.3	7.0–8.0	8.0	6.0–10.0	8.0–8.0	0.004
Scene time, min	6.0	3.0–8.0	5.0–7.0	8.0	5.0–12.0	7.0–8.0	< 0.001
Scene-to-door time, min	8.0	6.0–11.0	7.0–9.0	9.0	6.0–14.0	9.0–10.0	< 0.001
Door-to-balloon time, min	53.0	44.8–61.0	52.0–55.0	95.5	79.0–126.8	91.5–101.0	< 0.001

FMC = first medical contact, CI = confidence interval.

Table 4. Association between time delays and in-hospital mortality of ST segment elevation myocardial infarction patients

Variables	Total patients (N = 654)			System delay ≤ 90 min (n = 176)			System delay > 90 min (n = 478)		
	No. (%)	Unadjusted OR (95% CI)	Adjusted OR (95% CI)	No. (%)	Unadjusted OR (95% CI)	Adjusted OR (95% CI)	No. (%)	Unadjusted OR (95% CI)	Adjusted OR (95% CI)
Symptom onset to FMC time, min									
≤ 138.0	503 (76.9)	Reference	Reference	139 (79.0)	Reference	Reference	364 (76.2)	Reference	Reference
> 138.0	151 (23.1)	1.87 (1.00–3.37)	1.50 (0.71–3.05)	37 (21.0)	0.62 (0.03–3.76)	1.12 (0.09–11.6)	114 (23.8)	2.10 (1.09–3.97)	1.61 (0.71–3.56)
System delay, min									
≤ 127.5	420 (64.2)	Reference	Reference	176 (100.0)	-	-	244 (51.0)	Reference	Reference
> 127.5	234 (35.8)	2.90 (1.64–5.24)	2.07 (1.05–4.13)	0 (0.0)	-	-	234 (49.0)	2.51 (1.32–4.99)	2.00 (0.91–4.56)
Prehospital time, min									
≤ 27.5	391 (59.8)	Reference	Reference	134 (76.1)	Reference	Reference	257 (53.8)	Reference	Reference
> 27.5	263 (40.2)	4.10 (2.25–7.87)	2.35 (1.16–4.95)	42 (23.9)	2.50 (0.48–11.81)	1.87 (0.13–22.61)	221 (46.2)	4.07 (2.07–8.61)	2.33 (1.05–5.50)
Response time, min									
≤ 8.5	397 (60.7)	Reference	Reference	116 (65.9)	Reference	Reference	281 (58.8)	Reference	Reference
> 8.5	257 (39.3)	1.36 (0.76–2.40)	1.20 (0.62–2.31)	60 (34.1)	1.47 (0.28–6.90)	0.12 (0.00–1.60)	197 (41.2)	1.28 (0.69–2.37)	1.28 (0.63–2.63)
Scene time, min									
≤ 7.5	360 (55.0)	Reference	Reference	123 (69.9)	Reference	Reference	237 (49.6)	Reference	Reference
> 7.5	294 (45.0)	4.08 (2.19–8.10)	2.61 (1.24–5.75)	53 (30.1)	15.57 (2.57–298.33)	14.21 (1.56–4219.28)	241 (50.4)	2.97 (1.54–6.14)	1.91 (0.85–4.49)
Scene-to-door time, min									
≤ 9.5	359 (54.9)	Reference	Reference	114 (64.8)	Reference	Reference	245 (51.3)	Reference	Reference
> 9.5	295 (45.1)	2.06 (1.16–3.74)	1.54 (0.78–3.10)	62 (35.2)	0.72 (0.10–3.48)	0.33 (0.07–1.53)	233 (48.7)	2.27 (1.20–4.44)	1.62 (0.75–3.62)
Door-to-balloon time, min									
≤ 106.5	466 (71.3)	Reference	Reference	176 (100.0)	-	-	290 (60.7)	Reference	Reference
> 106.5	188 (28.7)	2.49 (1.40–4.43)	2.20 (1.09–4.39)	0 (0.0)	-	-	188 (39.3)	2.07 (1.12–3.88)	2.06 (0.97–4.54)

The multivariable logistic regression model was adjusted for all variables listed in **Table 1**: age; sex; comorbidities; prior hospital notification; prehospital 12-lead electrocardiogram; disease severity; prehospital and in-hospital systolic and diastolic blood pressure, heart rate, and mental status; and prehospital pulse oximetry saturation. ORs for in-hospital mortality comparing patients with system delays of > 90 minutes versus ≤ 90 minutes (crude OR, 2.51; 95% CI, 1.18–6.19; adjusted OR, 2.13; 95% CI, 0.91–5.67).
OR = odds ratio, CI = confidence interval, FMC = first medical contact.

examined overall system delay without analysing its stages (Kitamura et al.,[23] Żurowska-Wolak et al.[24]), identified stages without linking them to outcomes (Ho et al.[25]), or focused on small rural cohorts (Stopyra et al.[26]), our study assessed each stage of system delay and its association with mortality in a large metropolitan setting. Consistent with previous findings, system delays were associated with mortality.

https://doi.org/10.3346/jkms.2026.41.e272

Although prolonged symptom onset to FMC time was expected to be associated with higher mortality, no significant association was observed (**Table 4**). This finding might, at least in part, reflect the survivor bias inherent in registry-based analyses because patients who died before hospital arrival after prolonged ischemia are not captured in the registry. The large odds ratio for scene time in patients with a system delay ≤ 90 minutes is likely influenced by sparse events and quasi-separation because only seven deaths occurred among 176 patients (4%), with one death among 123 patients with a scene time ≤ 7.5 minutes and six deaths among 53 patients with a scene time > 7.5 minutes. Nevertheless, this finding suggests that delays at the scene could be critically associated with outcomes, and prolonged on-scene time could reflect greater clinical instability, the need for airway or hemodynamic support, or delays in decision-making and transport initiation, all of which can postpone definitive reperfusion.

As shown in **Fig. 3**, mortality increased with longer system delay, and prehospital time emerged as an independent predictor of death only when the system delay was more than 90 minutes (**Table 4**). These findings provide support for the current guideline recommendation of keeping the system delay below 90 minutes.[27]

Response time, defined as the time between the FMC and the arrival of emergency personnel at the scene, showed no statistically significant link with mortality, likely because it is generally unaffected by patient condition. U.S. studies reported longer prehospital times than in our data: 55 minutes (IQR, 44–68) in rural and 35 minutes (IQR, 28–45) in urban settings.[28] In metropolitan Seoul, the response time showed no significant effect. However, within the prehospital time, scene times were associated with mortality. Prior studies also identified scene time as a key factor in trauma, cardiac arrest, and stroke, with multiple factors influencing the prehospital time.[29-32] Several factors can influence both scene time and scene-to-door time. First, the number of phone calls made by EMS personnel to hospitals can prolong the scene time.[23] Kitamura et al.[23] reported that for patients with acute myocardial infarction, the prehospital time increased from 23.2 minutes for a single call to 39.7 minutes for five or more calls, which was a statistically significant difference (P for trend < 0.001). In South Korea, EMS must confirm hospital acceptance before transport, and refusals can extend scene or transport times. The uncertainty of hospital acceptance leads to prolonged time spent at the scene or on the road. Second, the European Society of Cardiology recommends that an ECG be performed within 10 minutes of FMC to enable rapid diagnosis.[16] However, in South Korea, EMS personnel are not legally permitted to perform prehospital 12-lead ECGs, which delays STEMI recognition. A pilot program since 2019 has allowed selected EMS staff to conduct ECGs in chest pain cases, but their use remains limited, as shown in **Table 1**. Third, obstacles at the scene can affect outcomes. In South Korea, where a significant urban population resides in high-rise apartment buildings, the floor level can be associated with the survival rates of patients with out-of-hospital cardiac arrest.[32] Therefore, high-rise apartment settings in South Korea could potentially influence the scene time.

The door-to-balloon time in our study (mean, 95 minutes) was comparable to that reported by Ho et al.[25] (median, 92 minutes; IQR, 62–177) but substantially longer than that reported in the United States (median, 43 minutes; IQR, 33–57; Stopyra et al.[26]). In a study by Terkelsen et al.[3] in Denmark, the median time from hospital arrival to PCI was 39 minutes (IQR, 24–70 minutes). In a study by Żurowska-Wolak et al.[24] in Cracow, Poland, the median in-hospital delay was approximately 35 minutes. The difference in in-hospital delays between studies with shorter and longer delays is more than double and might be influenced by the

https://doi.org/10.3346/jkms.2026.41.e272

effect of prehospital ECG transmission to the hospital. For example, a study conducted in the Victoria region of Australia found that when prehospital ECGs of STEMI patients were transmitted to the hospital, enabling pre-activation of the cardiac catheterization laboratory, the mean door-to-balloon time was 53 minutes.[33] Whereas this study and the study by Ho et al.[25] did not incorporate ECG transmission to the hospital, Stopyra et al.'s study[26] did include ECG transmission. Transmission of ECGs during the prehospital phase reduces door-to-balloon time.[34-36] To shorten the door-to-balloon time in South Korea, consideration should be given to performing prehospital 12-lead ECGs and transmitting the results from the EMS to the hospital. However, that would require time for ECG acquisition, interpretation, and transmission. In fact, the scene time in this study, in which prehospital ECG acquisition was limited and routine ECG transmission was not implemented, was 7.0 minutes (IQR, 5.0–12), the scene to door time was 9.0 minutes (IQR, 6.0–13), and the total prehospital time was 26 minutes (IQR, 21–34). In contrast, Stopyra et al.,[26] who reported on EMS that performed and transmitted prehospital ECGs, had a longer scene time of 14 minutes (IQR, 12–18) and a scene-to-door time of 27 minutes (IQR, 22–33).[26] Żurowska-Wolak et al.[24] reported a scene time of 24 minutes (IQR, 19–30) and a scene-to-door time of 22 minutes (IQR, 17–28). In other words, adding prehospital ECGs could increase the prehospital delay in order to reduce the in-hospital delays.[24] Additionally, education to improve the ECG interpretation skills of prehospital medical personnel might be necessary.

Although the door-to-balloon time differed by more than 20 minutes between survivors and non-survivors (**Table 2**), it was not independently associated with mortality in our multivariable analysis of patients with a system delay > 90 minutes (**Table 4**). In contrast, the prehospital time showed a significant association with mortality, despite a smaller absolute difference between groups. However, when all participants were analysed together, both the prehospital and in-hospital times were significantly associated with mortality. These findings suggest that multiple components of the STEMI care pathway contribute to patient outcomes. Accordingly, efforts to reduce delays—using the strategies discussed above—should encompass both the prehospital and in-hospital phases.

This study has several limitations. First, adjustment for disease severity was limited by the availability of variables in the registry. As an alternative, we used ICU admission or emergency department death as an indicator of severity and performed a separate analysis (**Supplementary Table 1**), which showed results consistent with the main findings. Even within this high-severity subgroup, in which baseline disease severity was partially held constant, prolonged time delays remained directionally associated with higher mortality. Second, the study period coincided with the COVID-19 pandemic, which might have introduced biases into system delays and healthcare delivery.[37] Therefore, further research is needed to examine long-term, post-pandemic effects. Third, the 90-minute threshold for system delay was adopted from international guidelines in the absence of a nationally defined cutoff. Although prolonged system delay showed a higher point estimate for mortality, the adjusted association did not reach statistical significance, possibly due to limited power and residual confounding.

System delay differed between survivors and non-survivors. Prolonged system delay and prehospital time were independently associated with in-hospital mortality. Among patients with a system delay > 90 minutes, prolonged prehospital time was also significantly associated with mortality. These findings highlight the association between system delay and in-hospital mortality among patients with STEMI undergoing PCI.

https://doi.org/10.3346/jkms.2026.41.e272

ACKNOWLEDGMENTS

We would like to acknowledge and thank the investigators from all participating hospitals of the Seoul GOLDEN-time Emergency Medical System: Jae Hun Oh (The Catholic University of Korea, Eunpyeong St. Mary's Hospital), Gyu Chong Cho (Hallym University Kangdong Sacred Heart Hospital), Ji Woong Na (Kangbuk Samsung Hospital), Jong Seok Lee (Kyung Hee University Medical Center), Young Hoon Yoon (Korea University Guro Hospital), Jung In Ko (National Medical Center), Duk Ho Kim (Nowon Eulji Medical Center), Kyung Jun Song (Seoul National University Boramae Medical Center), Won Chul Cha (Samsung Medical Center), Seok Yong Ryu (Inje University Sanggye Paik Hospital), Ki Jeong Hong (Seoul National University Hospital), Sung Yeol Ye (Seoul Medical Center), Young Shin Cho (Soonchunhyang University Hospital), Yoo Seok Park (Yonsei University Severance Hospital), Sun Hwa Lee (Ewha Womans University Mokdong Hospital), Chul Han (Ewha Womans University Seoul Hospital), Jae Hoon Oh (Hanyang University Seoul Hospital), June Seob Byun (Hanil General Hospital), and Sung Hyuk Park (Kyung Hee University Hospital at Gangdong).

SUPPLEMENTARY MATERIAL

Supplementary Table 1

Association between time delays and mortality among patients with ST-segment elevation myocardial infarction who were admitted to the intensive care unit or died in the emergency department

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