

Impact of smartphone applications on reperfusion times and clinical outcomes in acute STEMI: a systematic review and meta-analysis

William Gibson, Dawoud Al Kindi, Elie Akl, kshitij badal dandona, Jean-Philippe Pelletier, Nicolo Piazza, Ali Zgheib, Giuseppe Martucci, Marco Spaziano

Submitted to: JMIR mHealth and uHealth
on: September 18, 2024

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Impact of smartphone applications on reperfusion times and clinical outcomes in acute STEMI: a systematic review and meta-analysis

William Gibson¹ MBChB, MSc; Dawoud Al Kindi¹ MD; Elie Akl¹ MD, MSc; kshitij badal dandona¹ MD; Jean-Philippe Pelletier¹ MD; Nicolo Piazza¹ MD, PhD; Ali Zgheib¹ MD; Giuseppe Martucci¹ MD; Marco Spaziano¹ MD

¹Cardiology Department Royal Victoria Hospital McGill University Health Centre Montreal CA

Corresponding Author:

William Gibson MBChB, MSc
Cardiology Department
Royal Victoria Hospital
McGill University Health Centre
1001 Decarie Blvd
Montreal
CA

Abstract

Background: Mobile health applications are increasingly used by practitioners at the point of care in acute STEMI to improve coordination which may improve reperfusion times.

Objective: We investigated the impact of app-based care strategies in acute STEMI.

Methods: This is a systematic review of observational studies. We searched PubMed & Embase databases from 2008 to February 2024. Two reviewers independently performed the literature selection. The primary outcome was the mean difference in reperfusion times. The secondary outcomes were short term mortality and false activation rates. For the primary outcome,

Results: 15 studies with 2113 patients were included in the meta-analysis. Door to balloon times were significantly lower in the group with mobile app-based care than in the control group (mean difference -19.73 minutes 95% CI -26.32 to -13.14 $p < 0.01$; I² 0.83). For the secondary outcome of short-term mortality, 6 studies with 814 patients were included in the meta-analysis. A modest reduction in short term mortality was associated with an app-based strategy versus usual care (Risk difference -0.05 95% CI -0.09 to -0.01 $p = 0.02$.)

Conclusions: Mhealth app based care coordination in acute STEMI care pathways was associated with a significant reduction in door to balloon and a higher likelihood of meeting guideline directed time targets for reperfusion. Clinical Trial: PROSPERO registration: CRD42023481024

https://www.crd.york.ac.uk/prospero/display_record.php?ID=CRD42023481024

(JMIR Preprints 18/09/2024:66605)

DOI: <https://doi.org/10.2196/preprints.66605>

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Original Manuscript

Impact of smartphone applications on reperfusion times and clinical outcomes in acute STEMI: a systematic review and meta-analysis

Abstract

Background: Smartphone and tablet-based applications have been increasingly utilized in the management of acute STEMI, with the goal of enhancing care efficiency. These applications facilitate improved team coordination through a single platform, enabling secure sharing of clinical data, arrival times, and offering data storage and processing capabilities. The potential of these technologies to reduce reperfusion times and improve both clinical and process outcomes, compared to traditional communication methods, is promising. This systematic review and meta-analysis aimed to evaluate the effectiveness of smartphone-based interventions in reducing door-to-balloon (D2B) time, first medical contact-to-balloon (FMC2B) time, mortality, and false activation rates in STEMI care pathways.

Methods: This review followed the PRISMA guidelines and the PICO framework for eligibility criteria. Studies were included if they compared smartphone/tablet-enabled interventions with usual care for STEMI management, focusing on D2B time, FMC2B time, short-term mortality, and false activation rates. A systematic literature search was conducted across MEDLINE, EMBASE, and Google Scholar for studies published between 2008 and 2024. Studies using purpose-built software or commercially available instant messaging applications that enabled digital ECG transfer and real-time communication between providers were included. The protocol was registered with PROSPERO [31] (CRD42023481024). Data synthesis was performed using SPSS (IBM®) with random-effects meta-analysis for continuous and binary outcomes.

Results: A total of 903 articles were identified after removing duplicates, and 21 studies, involving 2954 patients, were included in the final review. The studies varied in design, with 14 being retrospective and 7 prospective, conducted across 12 countries. Thirteen studies evaluated dedicated applications, and eight used instant messaging platforms such as WhatsApp® and WeChat®. The primary outcome, D2B time,

showed a significant reduction in the intervention group compared to usual care (mean difference: -19.11 minutes; 95% CI: -26.22 to -12.00; $p < 0.01$), with substantial heterogeneity ($I^2 = 89\%$). A similar reduction in FMC2B time was observed (mean difference: -19.85 minutes; 95% CI: -29.45 to -20.25; $p = 0.01$). Subgroup analysis indicated a more pronounced reduction in D2B time in low-income countries compared to high-income countries. There were no significant differences regarding short-term mortality (risk difference: -0.03; 95% CI: -0.07 to 0.01; $p = 0.10$). False activation rates were evaluated in seven studies, with varying results, but no pooled analysis was feasible due to differences in definitions and study design. The healthcare setting (i.e., low- or high-income countries) was the most significant factor contributing to the observed heterogeneity in the meta-regression analysis

Conclusions: Smartphone-based interventions significantly reduce reperfusion times (D2B and FMC2B) in STEMI care pathways, with no significant effect on short-term mortality. These findings suggest that digital technology can improve the efficiency of STEMI management, particularly in settings with lower-resource healthcare infrastructure. Future studies should explore the impact on long-term outcomes and investigate regional differences in treatment effects.

Key Words: Digital health; Door-to-balloon time; Mobile app; ST-elevation myocardial infarction (STEMI); Telemedicine; prehospital

Abbreviations

ACS ----- Acute coronary syndrome

App ----- Application

Cath lab----- Catheterization laboratory

D2B ----- Door to Balloon

ED ----- Emergency Department

EMS ----- Emergency Medical Services

FMC2B --- First medical contact to Balloon

GPS ----- Global positioning system

OR ----- Odds ratio

PCI ----- Percutaneous coronary intervention

pPCI ----- Primary percutaneous coronary intervention

STEMI ---- ST-segment elevation myocardial infarction

Data Availability Statement

The data supporting the findings of this systematic review are available within the article and its supplementary materials. All relevant data are included in the manuscript and the supplementary files. Additionally, the datasets generated and/or analyzed during the current study are available from the corresponding author upon reasonable request.

For any queries regarding the data, please contact William Gibson at William.gibson@mail.mcgill.ca.

Introduction

ST elevation myocardial infarction (STEMI) is a time sensitive medical emergency in which prompt diagnosis and management is integral to minimising total ischemic time and reducing morbidity and mortality.[1] Ischemic time is influenced by a number of elements and delays may result from patient, emergency services or systemic factors which can further vary depending on mode of patient presentation i.e. direct presentation to the Emergency Department of a PCI capable centre, presentation to a non-PCI centre Emergency Department or via the emergency medical services (EMS). A number of time goals to achieving

reperfusion are recommended by societal best practice guidelines internationally [2] and there is evidence to suggest an association between shorter door-to-balloon times and improved survival outcomes. One pooled analysis including 300,000 patients from 32 prospective cohort studies demonstrated an association between longer door to balloon times (>90 minutes) and increased short-term mortality.[3] Furthermore, shorter door to balloon times have been associated with lower hospital readmission rates and greater economic efficiency.

Achieving reperfusion within these targets requires streamlined patient transitioning, achieved by adequate coordination between the multidisciplinary systems involved in the chain of care and promoted by effective communication. Furthermore, coordinated efforts to collect, access and interpret data efficiently is integral to improving the quality of these systems on an ongoing basis through continuous clinical audit. While patient delay is multifactorial and necessitates public health measures to enhance awareness of symptoms to reduce the time to the 'first call for help,' system delays can be amenable to improvements by organisational means.[4] Advancements in telemedicine technologies, have improved the efficiency of acute STEMI care in recent years, primarily through the transmission of prehospital electrocardiograms leading to earlier activation of the catheterisation lab and mobilisation of the STEMI team. For example, prehospital ECG transmission was associated with a 40% relative reduction in the time to treatment in one meta-analysis, including 11 non-randomised studies, [5] while this effect was mirrored in a more recent analysis which further demonstrated an association between the implementation of a telemedicine strategy in acute STEMI and a reduction in mortality compared with usual care. [6] Notably, these reviews primarily included more outdated telecommunication methods such as telephone and fax. Meanwhile, however, a recent a meta-analysis of non- randomised studies, explored the impact of exclusively digital prehospital ECG transmission methods on reperfusion times and mortality and noted a significant a reduction in door to device times (-33.3 minutes,) in addition to in all- cause mortality (HR 0.53, 95% CI: 0.40- 0.69,) highlighting the potential benefits of digital technology for use in this setting.

Nowadays, mobile devices are ubiquitous and an essential tool for healthcare practitioners in their day to day

practice with accompanying technological features including WiFi, global positioning system (GPS), Bluetooth pairing, cameras, microphones, sensors, and cloud storage,[7, 8] which enhance the potential utility of mobile health applications to enhance care coordination in acute STEMI care. A number of applications have emerged in this domain – using tailor built platforms as well as commercially available, non-dedicated instant messaging applications (e.g. WhatsApp®).[9] In comparison to instant messaging platforms, dedicated applications provide a number of added functions beyond a communication channel alone. Firstly, they allow for notification of each individual STEMI team members' acknowledgement of the incoming case which can foster more rapid and effective mobilisation of the team. They may further enable GPS and live time tracking of the patient relative to reperfusion targets, with integrated push alerts in situations where time to reperfusion may not favour primary percutaneous coronary intervention and thrombolytics may be warranted. Moreover, they may provide a single interface for the entry of automated time stamped data which can be accessed easily, promoting improved efficiency of clinical auditing. Of further relevance, these technologies can be tailored to comply with data regulations ensuring confidentiality of storage and transmission of protected health information between healthcare providers. [10-12] At the time of writing, and to the best of our knowledge, there have been no reviews published exploring the effects of these technologies on outcomes in acute STEMI. This systematic review and meta-analysis aims to (i) evaluate the impact of smartphone-based STEMI coordination applications on reperfusion time targets and mortality in acute care settings, (ii) identify the key features of available applications that may contribute to improved clinical efficiency and patient outcomes, and (iii) compare the effects of dedicated versus non-dedicated platforms, assessing their potential advantages and limitations in streamlining STEMI care. By synthesizing the current evidence, this review seeks to provide insights into the role of mobile health technologies in optimizing acute STEMI pathways and informing future advancements in digital healthcare solutions.

Methods

Selection and eligibility criteria

The review was conducted in accordance with the PRISMA (preferred reporting items for systematic reviews and meta-analyses) guidelines; the prespecified eligibility criteria and search strategy were structured using the PICO (P—Populations/People/Patient/Problem, I—Intervention(s), C—Comparison, O—Outcome) template as displayed in Table 1. The study protocol was registered with PROSPERO (the International prospective register of systematic reviews; CRD42023481024.) Studies were included if they had a comparative study design and compared a strategy of smartphone/ tablet enabled technology as outlined in the eligibility criteria combined with usual care versus traditional methods of communication (e.g. via telephone; review of STEMI ECG in person by STEMI team) for the diagnosis and management of patients with STEMI. The co-primary outcome was the difference in reperfusion times including door to balloon time and first medical contact to balloon time; door to balloon time was defined as the time from arrival at the

primary percutaneous coronary intervention (PPCI) centre to the deployment of a balloon within the infarct related coronary artery, while in prehospital and/ or hospital setting eligible to receive primary intervention (percutaneous coronary intervention or lysis where applicable) contact with a healthcare professional in the chain of care to the initial balloon inflation. Prespecified secondary outcomes of interest between groups, in addition to door to balloon time ≤90 minutes or first medical contact to balloon time ≤90 minutes	<u>Population</u>	Patients >18 years of age treated for suspected acute ST elevation myocardial infarction (STEMI) in prehospital and/ or hospital setting eligible to receive primary intervention (percutaneous coronary intervention or lysis where applicable)
	<u>Intervention</u>	Inclusion criteria: (i) Smartphone and/or tablet enabled mobile applications (ii) Used by healthcare provider (iii) Cloud based ECG transmission (iv) Real-time communication between relevant health providers/ stakeholders involved in the chain of care in acute STEMI. Exclusion criteria: (i) Patient centred app usage (ii) Chronic care or post myocardial infarction management (iii) Non mobile/ cellular enabled telemedicine (iv) Post hoc communication i.e. not enabled in real time (v) Focus on qualitative or technical process related outcomes
	<u>Comparator</u>	Patients treated for suspected acute STEMI where traditional methods of communication between relevant stakeholders undertaken i.e. not mobile/ tablet app based communication
	<u>Outcomes</u>	(i) Reperfusion times (Door to balloon, First medical contact to balloon,) in addition to the proportion of patients meeting targets (eg. Proportion of patients with door to balloon <90 minutes, FMC2B <120 mins) (ii) False activation rate (iii) Clinical events (mortality, heart failure.)

Table 1. PICO framework for study eligibility

The types of digital technology studied in this review include purpose-built software applications in addition to commercially available instant messaging applications into STEMI care pathways granted the latter fulfilled the prespecified eligibility checklist, namely, digital ECG transfer and real time communication between providers at the point of care. In cases wherein duplicate studies were identified, those with the largest sample size and follow up duration were solely included.

Two investigators independently screened potential titles and abstracts and those with potential eligibility by either reviewer were selected for full-text review. Disagreements were subsequently resolved by a third reviewer. Efforts were made to contact corresponding authors as required where relevant data was not included in the published report. The article was subsequently excluded if a satisfactory response or the relevant data was not obtained. Attempts were made to contact all authors in relation to missing data and study design clarification via email to which four replies were received.

Data Sources and Search strategy

A systematic literature search was conducted across multiple databases, including MEDLINE, EMBASE & Google Scholar, to identify relevant studies published between January 1st, 2008, and February 1st, 2025. Table 2 details the structured search strategy employed. The search was restricted to English-language studies, with exclusion of the term 'rehab' to focus on studies evaluating acute care. To ensure comprehensive coverage, simultaneous searches of identified app names (e.g., STENOA, SCUNA) were performed using title-word searches."

Table 2. Database search strategy.

Search Strategy	
Search Statement 1	"mhealth".tw OR "mobile health".tw OR "app".tw OR "smartphone".tw OR "smart phone".tw OR "mobile phone".tw OR "tablet".tw OR "mobile application".tw OR "m-health".tw OR "mobile device".tw OR "mobile app".tw OR "mobile apps".tw OR "cloud*".tw
	AND
Search Statement 2	"STEMI".tw OR "ST elevation myocardial infarction".tw OR "door to balloon".tw OR "door-to-balloon".tw OR "myocardial infarction".tw OR "acute coronary syndrome".tw OR "ACS".tw
	NOT "rehab*".tw

Data extraction and quality assessment

Two investigators (WG; DA) extracted data from each study according to a standardised protocol. Any disagreements were resolved by the third reviewer (MS.) The methodological quality of each study included was assessed using the Newcastle Ottawa Scale. One author (WG) assessed the quality of each study while a second author (DA) reviewed these assessments in conjunction with the studies to support article inclusion. A third reviewer (MS) resolved any discordance.

Quantitative data synthesis

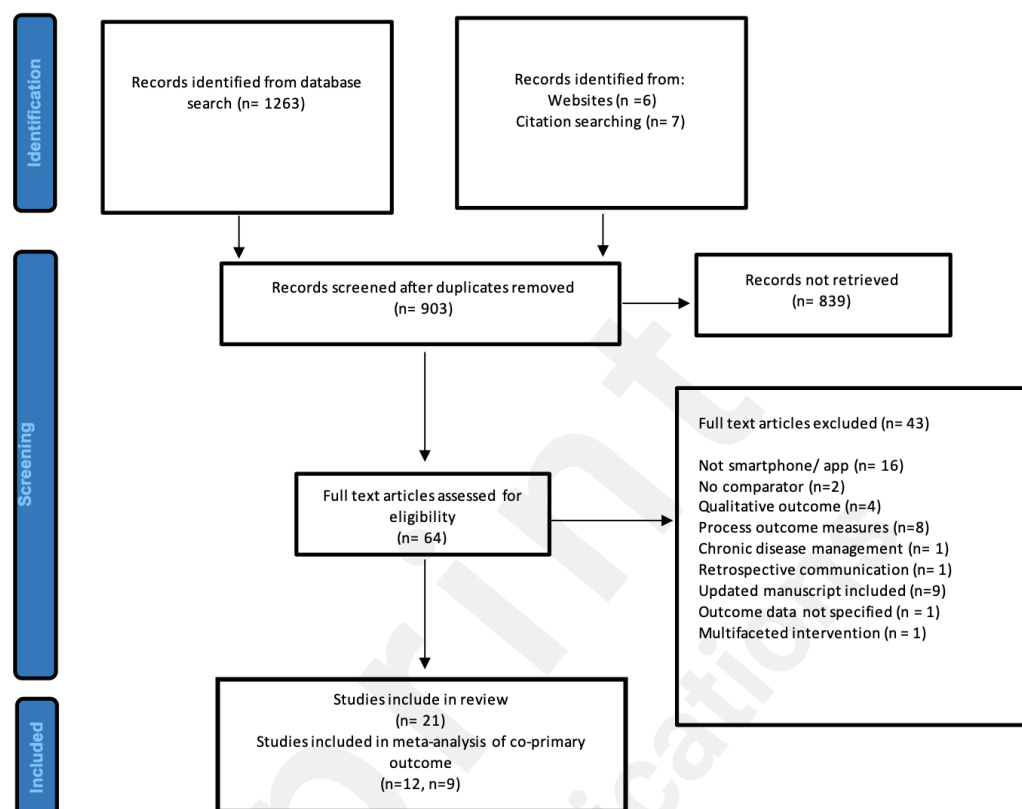
All analyses were performed using the meta-analysis function within SPSS (IBM®) comparing app based care with usual care with respect to D2B times, FMC2B and the proportion of patients meeting reperfusion targets (<90 mins; <120 mins) with continuous outcome measurements (unstandardised mean difference in minutes) and odds ratio & 95% CI, accordingly.) The risk difference was used for the secondary outcome of mortality. When data concerning the mean and variance were not available, efforts to obtain these were made by contacting the authors. Failing this, the mean and variance were estimated by using the median, interquartile range (IQR), sample size and/or reported CIs.[13] In cases where the standard deviations for the mean in both control and intervention groups were not given, these were derived from the mean difference and corresponding 95% CI and/ or the p value, where available. [14] In situations where more than one control group was encountered, the group which bore more similarity to the intervention group was selected. For example, if the intervention group concerned patients transferred from a non-PCI capable hospital, compared to those transferred by EMS or direct ED presentations with whom no app was used, the EMS transfers were chosen as the control group for analysis. Owing to expected clinical heterogeneity, a random effects model was used for pooling the results of included studies. Mean differences were calculated for continuous outcomes; pooled relative risks (RRs) and pooled risk difference for binary outcomes, and calculated 95% CIs and two-sided P values for each outcome. Cochran Q test, X^2 statistic and I^2 statistic were performed to investigate statistical heterogeneity of the treatment effect among the included studies and values greater than 50% were considered to indicate high heterogeneity. A p value of <0.05 (two sided) was

deemed statistically significant. We specified the following possible explanations for heterogeneity: study quality and specificities of the telemedicine intervention (dedicated or non-dedicated app) and healthcare setting (i.e. low or middle versus developed countries,) owing to expected differences in health system organisation that might influence overall reperfusion times. Sensitivity analyses were predefined to evaluate the robustness of the primary outcome results. In sensitivity analyses, the effect size was examined by omitting studies individually and also excluding simultaneously studies with extreme results (highest and lowest impact.) Subgroup analyses were performed to assess whether the treatment effect differed with regards to the type of technology used (dedicated vs non-dedicated platform) in addition to study quality (low vs. medium to high risk of bias.) Publication bias was investigated by constructing a funnel plot and plot symmetry was determined both visually and formally using Egger's test.

Results

The search yielded 1263 results and 360 duplicates were removed. Of the remaining 903 studies, 890 were derived from databases (MEDLINE; EMBASE,) while citations of evaluated studies and web searching (Google Scholar) identified applications provided a further 13 records for screening. Figure 1. displays the PRISMA flow chart depicting the final article inclusion. Following title/ abstract screening, 839 records were removed, and the remaining 64 studies underwent full text assessment for inclusion based on the eligibility criteria. Exclusion of 43 studies was carried out with the reasons outlined in the supplementary data (Table S1.) Thus, the final number of studies included in the review was 21, involving 2954 patients.

Figure 1: Prisma Flow Chart of articles identified at during search process.



Characteristics of Included studies

The main characteristics of each included study are shown in Table 3. Selected studies were published from 2013 until 2024. Eighteen studies were published in peer reviewed journals, three were published conference abstracts [15- 17]. All studies were non-randomised in design: fourteen were retrospective involving a historical comparator group made up of patients treated before the implementation of a telemedicine intervention while the remaining seven studies were prospective, quasi-experimental studies which included a concurrent parallel control group in which the technology was not utilised. [9, 18-23] The total number of participants in each study ranged from 46 to 428. Studies were conducted in twelve countries: Japan (n=4) USA (n=3) Taiwan (n=3) Canada (n=2); Australia (n=2) Argentina (n=1) Slovakia (n=1) Turkey (n=1) Egypt (n=1) China (n=1.) Thirteen studies evaluated purpose-built applications and included

eight distinct platforms, while instant messaging applications (WhatsApp® (n=3), LINE® (n=2), Band® (n=1) and WeChat® (n=2)) were implemented in eight.[9, 21-24] [23, 25] [26, 27] The platforms described were commercially available from mainstream app stores and in all cases, the software was used to transmit the ECG to a dedicated chat group involving STEMI care providers and the referring practitioner and in certain cases, the emergency physicians. The app was used in patients transferred by the emergency medical services from the field in fourteen studies, interhospital transfer from non-PCI capable centers in eight, while five studies dealt with patients presenting directly to the emergency department; in nine instances, a combination of the type of presentation to the primary PCI center was dealt with. All but one [26] of the studies involving non-dedicated platforms evaluated interhospital transfers of patients from non-PCI capable centers to a pPCI center.

Table 3. Characteristics and primary outcome of included studies.

Study	Participants				Presentation			App Users			Outcome
	Year	Country	(I/C)	App	EMS	IHT	ED	EMS	ED	pPCI	D2B (min)
Aboal et al. [19]	2024	Spain	98/129	ODISEA	✓	✓	✗	✓	✓	✓	-
Abraham et al. [28]	2023	USA	132/296	e-Bridge	✓	✗	✓	✓	✓	✓	61.2 ±24.3 vs ±24.6 ^a
Aldajani et al. [29]	2024	Canada	31/84	STENOA	✓	✗	✓	✗	✓	✓	-
Anai et al. [17]	2024	Japan	113/130	SCUNA	✓	✗	✗	✓	✗	✓	60± 25.1 vs 20 ^a
Arinaga et al. [30]	2022	Japan	23/25	SCUNA	✓	✗	✗	✓	✗	✓	49 (41–85.5) vs (38–67) ^b
Astarcioğlu et al. [9]	2015	Turkey	53/55	WhatsApp®	✗	✓	✗	✗	✓	✓	-
Bendary et al. [21]	2019	Egypt	100/100	WhatsApp®	✓	✓	✗	✗	✓	✓	120 ±35 vs 1 ±30 ^a
Bladin et al. [18]	2022	Australia	171/76	Pulsara®	✓	✗	✓	✓	✓	✓	59.37±41.33 vs 77.3 ±61.6
Brouillette et al. [15]	2023	Canada	31/84	STENOA	✓	✗	✓	✗	✓	✓	-
Chao et al. [26]	2017	Taiwan	44/40	LINE®	✗	✗	✓	✗	✓	✓	90.4 ±9.8 vs 1 ±16.3 ^b
Cordero et al. [16]	2013	Spain	177	MBEAT	✓	✗	✗	✓	✗	✓	-
Dickson et al.	2023	USA	69/36	Pulsara®	✓	✗	✓	✓	✓	✓	71 ±49 vs 91 ±

[33]											
Ibanez et al. [22]	2019	Argentina	43/62	WhatsApp®	✓	✓	X	✓	✓	✓	-
Kang et al.[24]	2023	China	100/98	WeChat®	X	✓	X	X	✓	✓	65.9± 13.86 98.21± 21.0
Kini et al.[34]	2024	USA	17/43	STEMICathAid	X	✓	X	✓	✓	✓	-
Kohashi et al. [35]	2023	Japan	77/160	SCUNA	✓	X	X	✓	X	✓	67.7 ±23.6 vs ±29.3 ^a
Liu et al.[25]	2020	Taiwan	70/70	WeChat®	X	✓	X	✓	✓	✓	60 vs 95.5
Park et al.[23]	2016	Korea	50/64	BAND	X	✓	X	X	✓	✓	47.5 (40–56 56.5 (47–69)
Studencan et al.[36]	2018	Slovakia	178/67	STEMI Global	✓	X	X	✓	X	✓	-
Yu et al.[27]	2019	Taiwan	51/89	LINE®	X	✓	X	X	✓	✓	52.6 ±42.2 vs ±50.6 ^a
Yufu et al [20].	2019	Japan	17/29	SCUNA	✓	X	X	✓	X	✓	70 ±26 vs 96.3

^a = p < 0.05 (significant); ^b = p ≥ 0.05 (not significant); Values in () = median & interquartile range (IQR); Values with ± = mean & (SD)

I/C: Intervention/Control; App: application; D2B: door to balloon; FMC2B: first medical contact to balloon; ED: emergency department; EMS: emergency medical services; IHT: interhospital transfer; min: minute; pPCI: primary percutaneous coronary intervention team;

Table 4. Key functions enabled by different mobile app types.

Features	Non-dedicated	Dedicated
Cloud based ECG transmission	✓	✓
Real time communication	✓	✓
Automatic Notification of provider readiness	X	✓
Real time treatment target tracking ^a	X	✓
Automated data recording & reporting	X	✓
GPS location enabled	X	✓
Security & compliance	X	✓

^a automatic notification when estimated FMC2B time exceeds target, recommendation to alter treatment course i.e.. fibrinolytic therapy, subsequent deactivation of Cath lab

Assessment of Study Quality

Table 3. outlines the quality assessment as graded by Newcastle Ottawa Scale. Eleven studies were deemed to be at low risk of bias, while ten were considered medium to high risk of same with a median score of 6.5 [IQR 5-7] being observed.

Author	Selection				Comparability	Outcomes				Points
	Year	1	2	3	4	1	1	2	3	
al. [19]	2024	*	-	*	*	*	*	*	-	6
al. [28]	2024	*	*	*	*	-	*	*	-	6
al. [29]	2024	*	*	*	*	*	*	*	-	7
al. [17]	2024	*	-	*	*	-	*	-	-	4
al. [30]	2023	*	-	*	*	**	-	*	-	7
t al. [9]	2015	*	*	*	*	*	-	-	-	5
al.[21]	2019	*	-	*	*	**	*	*	-	7
al.[18]	2023	*	-	-	*	*	*	*	-	5
al.[15]	2022	*	*	*	*	*	*	*	-	7
al. [26]	2017	*	*	*	*	*	*	*	-	7
al. [16]	2014	-	*	*	*	-	-	-	-	3
al. [33]	2014	*	*	*	*	-	**	*	-	7
al.[22]	2019	*	*	*	*	**	-	*	-	7
al.[24]	2024	-	*	*	*	*	-	*	-	5
al.[34]	2024	*	-	*	*	-	*	*	-	5
al. [35]	2023	*	*	*	*	**	*	*	*	9
al. [25]	2020	*	*	*	*	*	*	*	-	7
al. [23]	2016	*	-	*	*	-	-	-	-	3
al. [36]	2018	*	-	*	*	*	*	*	-	6
al. [27]	2019	*	-	*	-	*	-	-	*	4
al. [20].	2019	*	*	*	*	**	-	*	*	8

Table 3. Newcastle Ottawa Assessment Scale of study quality

Outcomes

Primary outcome

With respect to the primary outcome, all but one of the included studies evaluated the association of a digital telemedicine strategy with reperfusion times, including door to balloon, first medical contact to

balloon or total ischemic time. The remaining study investigated 'false activations,'[15] exclusively, within a similar patient cohort from another included study.[29] Time target definitions varied across studies and were standardised according to our prespecified definitions as follows: door to device time was used in one study in reference to "the interval from the initial presentation at the referring hospital until the first balloon inflation or use of another device to achieve reperfusion"[34] and thus, we labelled this as the first medical contact to balloon time. Similarly, "first medical contact to wire"[24] or "device" [23, 29] was considered the first medical contact to balloon, as was "ECG diagnosis to wire crossing." Regarding meta-analysis, complete data including both the mean and standard deviation for the treatment and control groups was documented in thirteen studies. The individual standard deviations were not reported in two studies [17, 33] and these were therefore estimated from the mean difference and provided p value using validated methods. [14] Furthermore, the median values alone were reported in five studies; one author provided the necessary data upon request [35] and mean and standard deviation values were estimated, accordingly for the remaining four.[18, 22, 23, 30] A further study was excluded from quantitative data synthesis [16] as it did not report the number of participants in both the treatment and control groups.

Differences in door to balloon times versus usual care was reported in thirteen studies with sufficient data available from 12 to conduct meta-analysis, involving 1977 patients. There was a significant difference in door to balloon times observed, favoring a smartphone app based intervention versus usual care (unstandardized mean difference, -19.11 min (95% CI: -26.22 to -12.00), $p < 0.01$,) (Figure 2.) while substantial statistical heterogeneity was evident ($I^2 = 89\%$.) First medical contact to balloon times were reported in eleven studies overall, with nine included in the meta-analysis ($n=1888$). A similar treatment effect was evident, favoring the intervention group (unstandardized mean difference, -19.85 mins (95% CI: -29.45 -20.25; $p = 0.01$) (Figure 3,) with similar degrees of statistical heterogeneity found ($I^2 = 88\%$.)

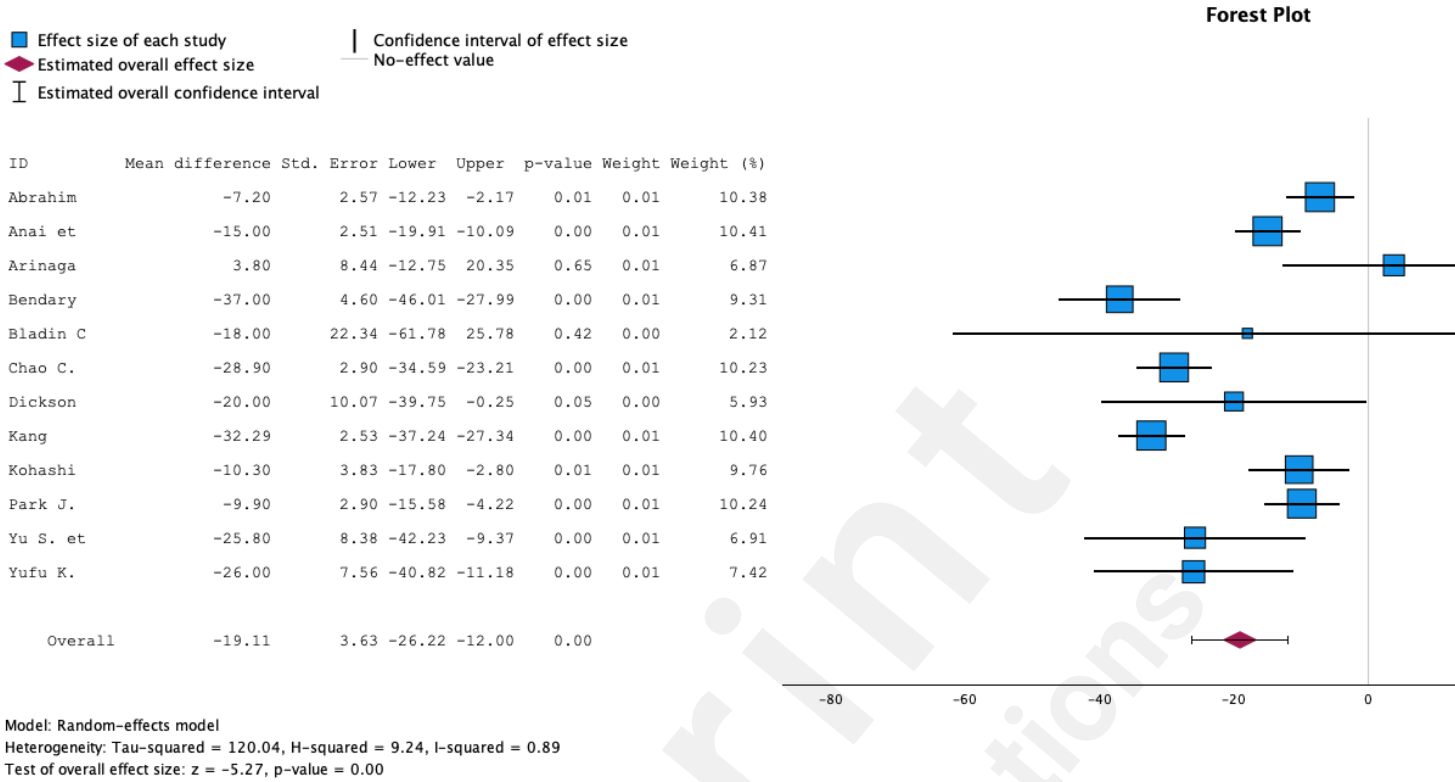


Figure 2. Forest plot showing the unstandardised mean difference of D2B times (minutes) between patients submitted to telemedicine strategies associated to usual care versus usual care. (D2B: door to balloon)

Interval: 0.00 to 0.00

Figure 3. Forest plot showing the unstandardised mean difference in FMC2B times (minutes) between patients submitted to telemedicine strategies associated to usual care versus usual care (FMC2B: first medical contact to balloon)

■ Effect size of each study
 ◆ Estimated overall effect size
 ▮ Estimated overall confidence interval

| Confidence interval of effect size
 — No-effect value

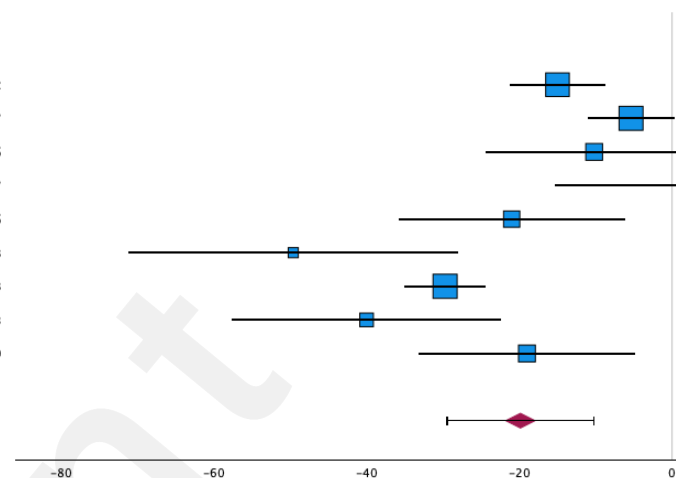
Forest Plot

ID	Mean difference	Std. Error	Lower	Upper	p-value	Weight	Weight (%)
Aboal et al.	-15.00	3.20	-21.28	-8.72	0.00	0.01	13.32
Abraham C. et al	-5.37	2.89	-11.03	0.29	0.06	0.01	13.47
Aldajani et al.	-10.20	7.28	-24.47	4.07	0.16	0.00	10.76
Arinaga et. al 2022	1.70	8.71	-15.37	18.77	0.85	0.00	9.77
Astarcioğlu M. et al.	-21.00	7.58	-35.85	-6.15	0.01	0.00	10.56
Ibanez E. et al	-49.60	11.03	-71.22	-27.98	0.00	0.00	8.23
Kang et al.	-29.72	2.74	-35.08	-24.36	0.00	0.01	13.53
Kini et al.	-40.00	8.98	-57.60	-22.40	0.00	0.00	9.58
Park J. et al	-19.00	7.24	-33.20	-4.80	0.01	0.00	10.79
Overall	-19.85	4.90	-29.45	-10.25	0.00		

Model: Random-effects model

Heterogeneity: Tau-squared = 169.82, H-squared = 8.26, I-squared = 0.88

Test of overall effect size: $z = -4.05$, $p\text{-value} = 0.00$



Secondary outcomes

Mortality was evaluated in eight studies, including 1711 patients: half of these reported in-hospital mortality [19-21, 24], 30-day mortality in three [26, 30, 35] and one year mortality in the remaining study [17]. For meta-analysis, the study involving one year mortality was excluded, resulting in a total of seven publications included in the pooled analysis. There was no significant effect observed with respect to short-term mortality associated with a smartphone based strategy versus usual care (Risk difference, -0.03 (95% CI: -0.07 to 0.01), $p = 0.10$; Figure 4.)

Furthermore, seven studies evaluated the impact of an app based coordination pathway on false or inappropriate activations of the cardiac cath lab. Due to substantial variability among studies in defining false activations and comparator groups, however, meta-analysis was not feasible. Astarcioğlu et al. reported false positive STEMI activations in 5 out of 55 cases in the intervention group with WhatsApp® versus none in the control group [9]. Brouillette et al. defined false activations as cancellations of cath lab activations prior to

any procedure and demonstrated a reduction in false activations with use of the STENOA platform, decreasing from 9.4% to 6.4%, a 31% relative reduction ($p < 0.05$).[15] Furthermore, the use of STEMICATHAID facilitated pre-activation screening, rejecting 45 out of 111 activations prior to cath lab mobilization, however, no false activation data was available for comparison in the control period.[34] Dickson et al. observed improved resource utilization with a reduction in PCI procedures following implementation of the Pulsara® app (from 75% to 64%), representing an 11% absolute reduction.[33] Meanwhile, there were fewer misdiagnoses of acute coronary syndrome in the group using the ODISEA app compared to controls (9.5% vs. 17.1%, $p=0.004$).[19] Additionally, another included study noted fewer inappropriate activations in the arm assigned to the SCUNA mobile ECG transmission system (13/36 vs. 20/45).[30]

Lastly, the proportion of patients meeting D2B or FMC2B times of <90 & <120 mins were reported in six [9, 18, 20, 26, 33, 36] and four studies [19, 23, 34, 36] respectively. A pooled analysis of these outcomes combined was demonstrated a higher likelihood of patients treated in the intervention arm of meeting guideline directed reperfusion times compared to those assigned to usual care. (OR 3.18; 95%CI 1.59 – 6.35; $p < 0.001$; I^2 0.77.) (Supplementary data figures S.1)

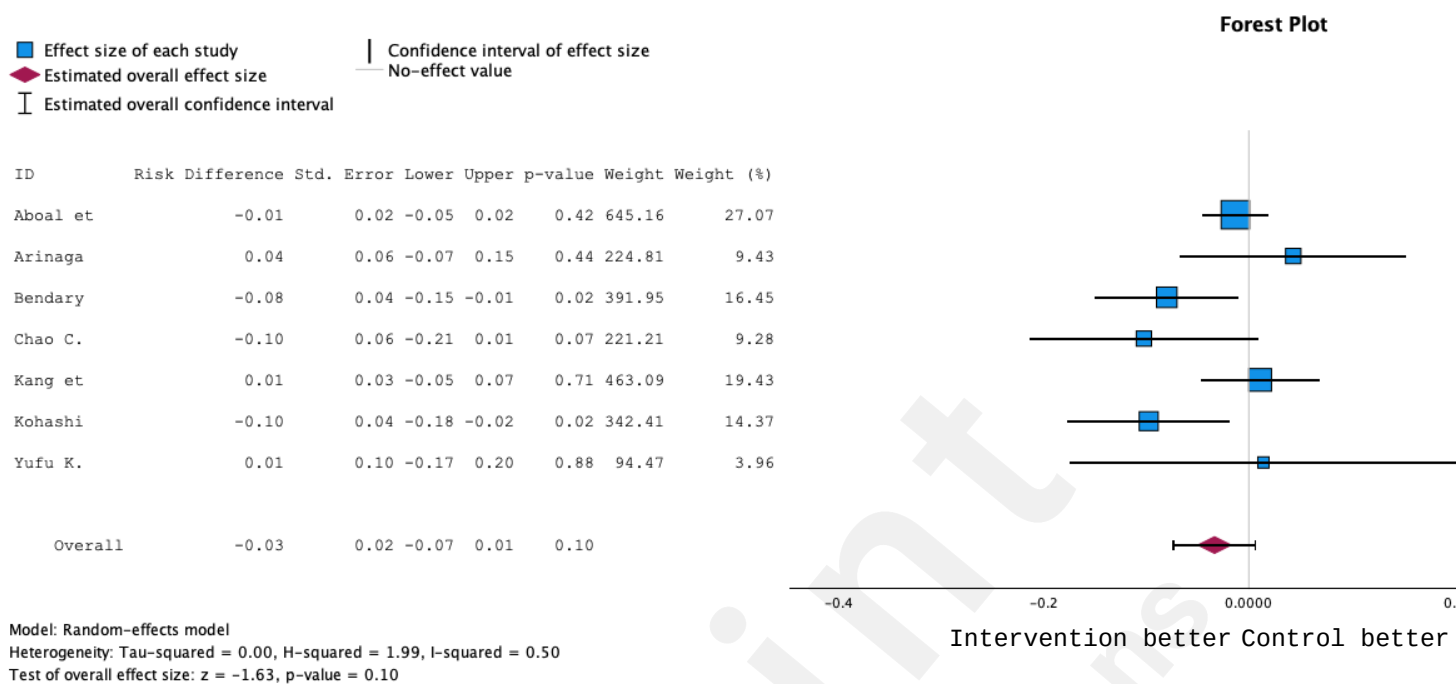


Figure 4. Forest plot showing the relative risk reduction of in-hospital or 30 day mortality in patients submitted to telemedicine strategies associated to usual care versus usual care.

Publication Bias

Publication bias was assessed using funnel plots for the primary outcomes of door-to-balloon (D2B) time and first medical contact-to-balloon (FMC2B) time. Visual inspection of the funnel plots revealed asymmetry for D2B time, suggesting potential publication bias, whereas minimal asymmetry was observed for FMC2B time. This was further supported by Egger's test, which indicated significant publication bias for D2B time ($p = 0.01$) but not for FMC2B time ($p = 0.5$). The results of these analyses are shown in Figures S.3 and S.4.

Sensitivity & Subgroup analysis

Sensitivity analysis using the leave-one-out method, where individual studies were sequentially excluded, demonstrated no significant impact on the overall treatment effect for door-to-balloon (D2B) time or first medical contact-to-balloon (FMC2B) time, confirming the robustness of the findings. Subgroup analysis based on geographical setting (low- and middle-income countries vs. high-income countries) revealed a greater

reduction in D2B time in studies conducted in low-income settings (mean difference: -31.48 minutes, 95% CI -24.86 to -28.11) compared to those in high-income settings (mean difference: -11.26 minutes, 95% CI -15.18 to -7.34). However, this trend was not as pronounced for FMC2B time (low-income: -31.02 minutes, 95% CI -42.94 to -19.11 vs. high-income: -13.86 minutes, 95% CI -23.64 to -4.07). Further subgroup analyses stratified according to the use of dedicated vs. non-dedicated mobile applications, risk of bias (high vs. low), and study sample size (above vs. below the median) did not reveal statistically significant differences between subgroups.

To explore potential sources of heterogeneity, meta-regression analysis was performed. For D2B time, geographical setting accounted for nearly all the observed heterogeneity ($R^2 = 100\%$), suggesting a strong influence of regional healthcare disparities. (Figure S2.) In contrast, for FMC2B time, geographical setting explained only a moderate proportion of heterogeneity ($R^2 = 31.4\%$). Other factors, including sample size, use of dedicated vs. non-dedicated apps, and study quality, had minimal influence on heterogeneity for both D2B and FMC2B times.

Discussion

In this comprehensive systematic review and meta-analysis, we synthesized evidence from 21 studies and 4604 patients, which evaluated smartphone applications implemented within acute STEMI care pathways. The included studies assessed the impact of these digital platforms on key reperfusion metrics and clinical outcomes. Our findings suggest that an average reduction in reperfusion times of up to twenty minutes might be achieved with the integration of smart phone apps in STEMI care pathways, with the potential for a larger proportion of patients achieving guideline directed target times (door to balloon <90mins and first medical contact to balloon <120 minutes) versus usual care. Mobile health (mHealth) technologies have emerged as transformative tools in acute care settings, with up to 40% of emergency-focused mHealth solutions prioritising rapid communication and coordination functions [8]. Immediate and accurate sharing of

patient clinical and treatment information with the receiving hospital is essential in acute STEMI and a single communication channel via smart phone technology used both within the hospital and by prehospital personnel strengthens the integration of treatment advances that cover the community and medical care settings alike.[18]

To our knowledge, this is the first meta-analysis specifically examining the effectiveness of dedicated smartphone-based applications within STEMI care networks. Previous systematic reviews and meta-analyses have demonstrated improvements in reperfusion times and mortality with telemedicine based strategies as well as digital transmission of the prehospital electrocardiogram in acute STEMI care. [6, 37] However, none have exclusively addressed interventions incorporating the broader functionalities provided by smartphone applications, such as coordinated alerts, real-time geolocation, automated data collection, and integrated communication systems among multidisciplinary STEMI teams, as we have described. Since telemedicine interventions are rarely effective in isolation and instead function best as part of a multifaceted strategy integrating prehospital and in-hospital services, it stands to reason that smartphone applications offering these multiple functionalities could further streamline workflows and enhance the efficiency of STEMI care processes.

Our review further identified multiple studies reporting a significant reduction in inappropriate cath lab activations following the implementation of an app based strategy. Inappropriate activation of the cath lab represents a substantial burden to health systems with disruption of clinical workflows, prompting unnecessary mobilization of on-call teams while potentially causing unnecessary harm to patients.[38] The capacity to integrate real-time ECG assessment with structured case adjudication, supported by comprehensive clinical data, may enhance diagnostic accuracy and communication among care teams, thereby reducing rates of false-positive activations.

Notably, we found no significant difference in short-term mortality between the intervention and control arms which is in contrast with the findings of a recent meta-analysis of studies evaluating the impact of

digital prehospital ECG transmission in acute STEMI. Therein, the authors observed a significant reduction in all-cause mortality (HR 0.53 (0.40 – 0.69,)) which accompanied a greater reduction in mean door and first medical contact to balloon times than we found (mean difference -33.31 mins [95% CI: -50.47 to -16.16]). However, the substantial weighting of included studies (>50%) which reported long term mortality [39] in addition to the inclusion of larger studies with higher event rates, somewhat limits comparability to our findings. Furthermore, differences in baseline and procedural characteristics or study design may have contributed to the differences observed. They further noted substantial statistical heterogeneity (>99%) with respect to reperfusion times while demonstrating a significantly higher impact on subgroup analysis between interventions that integrated both prehospital digital ECG transmission and early cath lab activation versus ECG alone. This may be reflective of the earlier study period of their included studies, during which time STEMI care networks were comparatively rudimentary to those evaluated in our analysis, with a greater potential to yield marginal benefits from organisational improvements. Likewise, our meta-regression analysis revealed that geographical location (i.e., developing vs. developed countries) was the strongest factor contributing to the observed heterogeneity in terms of door to balloon times. Similarly, healthcare systems across developing countries may have fewer care coordination processes in place and may therefore expect to achieve a greater benefit from quality improvement interventions. Since all studies from low- and middle-income countries used non-dedicated applications, it remains unclear whether the additional functionalities of dedicated software could lead to further improvements and future research is needed to evaluate their utility in these settings.

On the other hand, the influence of geographical location was less pronounced in terms of FMC2B times. A possible explanation for this disparity is that system-level factors—such as prehospital care infrastructure and emergency medical services efficiency—may have a greater impact on FMC2B time, whereas in-hospital workflow efficiency primarily affects door-to-balloon (D2B) time. In low-income settings, delays in prehospital activation and interfacility transport [40] may have contributed to the persistence of FMC2B disparities despite significant reductions in D2B time. However, most included studies did not report data on average

transport times or distances to primary percutaneous coronary intervention centres, preventing meta-regression analysis from assessing whether these factors contributed to the observed heterogeneity

Nearly half of the included studies were assessed as having moderate to high risk of bias, primarily attributed to insufficient reporting or adjustment for baseline characteristic disparities. However, subgroup analyses comparing studies with a high- and low-risk of bias revealed no statistically significant differences in treatment effects across outcomes, suggesting that potential biases exerted minimal influence on the pooled results.

We also identified a number of important distinctions between dedicated and non-dedicated applications in the context of acute STEMI care (Table 4.) Concerning the point of care, the functions of instant messaging applications are largely confined to the facilitation of rapid ECG transmission and clinical particulars via short messaging. On the other hand, dedicated apps allow for the seamless input of various data points to designated fields while enabling custom notifications and alert systems which can confirm the acknowledgement of each team member's participation and readiness, automatically signal the presence of high risk clinical features and with GPS integration, can prompt consideration of alternative treatment strategies if expected patient arrival times exceed guideline directed targets. Moreover, the majority of dedicated applications identified boast functions beyond the point of care with automated storage of quality assurance data which can streamline clinical auditing and ultimately lessen the significant administrative burden associated with such processes. Furthermore, dedicated platforms can be structured appropriately to ensure that the handling of protected health information data is strictly compliant with local data security regulations. This is especially important for patients, as research indicates they place high value on robust data privacy and security measures in mobile health applications. Therefore, dedicated platforms that adhere to regulatory frameworks are essential to ensure compliance, build trust, and overcome adoption barriers. [41] In contrast, the use of non-dedicated apps in this context raises concerns about their appropriateness.

Limitations

All of the included studies were observational in design and mostly comprised of relatively small sample sizes. Consequently, many studies were underpowered to establish definitive conclusions regarding the impact of smartphone-based interventions on critical clinical outcomes, such as mortality. Nevertheless, the clinical implications of our findings remain important, given existing evidence linking longer door-to-balloon times to increased short-term mortality. A pooled analysis involving over 70,000 patients for example, demonstrated significantly higher short-term mortality among patients with door-to-balloon times exceeding 90 minutes (OR 1.39; 95% CI 1.19–1.62).[32] Similarly, an individual patient data analysis comprising more than 4,000 patients found consistent results, even after adjusting for multiple potential confounders.[3] A further limitation of this study is the reliance on statistical imputation for a number of outcome variables, as only the median and interquartile range values were provided in the original reports. This approach may have introduced bias and limited the precision of our analysis, owing to uncertainties regarding the underlying distribution of the data. [31] Additionally, the lack of distributional data in most studies in terms of different patient presentation modes (i.e. direct ED, EMS, or interhospital transfer) poses a limitation. The impact of the app on outcomes across these modes is not yet clear, and further investigation is needed to determine whether the use of smartphone apps has a differential effect based on the mode of presentation.

Conclusion

Smartphone applications are playing an increasingly transformative role in emergency care, offering the potential to enhance processes and, ultimately, improve clinical outcomes. By consolidating critical functionalities into a single platform, these applications address the systemic fragmentation between prehospital and in-hospital care, facilitating more coordinated workflows. Our analysis highlights a reduction in reperfusion times with the integration of these systems; however, larger prospective studies are needed to further explore and validate these findings.

Supplementary material

Figures S1 – S4: Forest plots depicting likelihood of meeting reperfusion targets (<90 mins or <120 mins) with the intervention versus usual care, subgroup analysis of primary endpoint and funnel plots for the assessment of publication bias for the primary endpoint.

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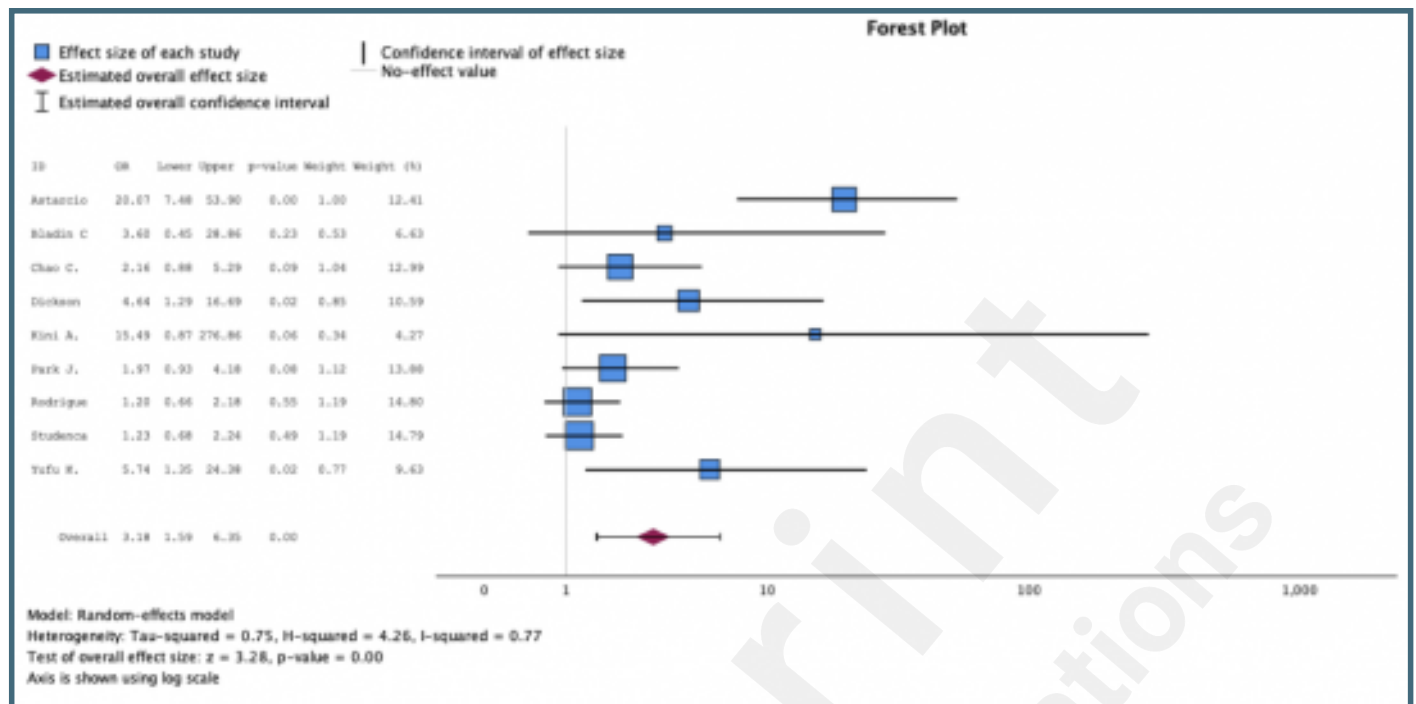
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Supplementary Files

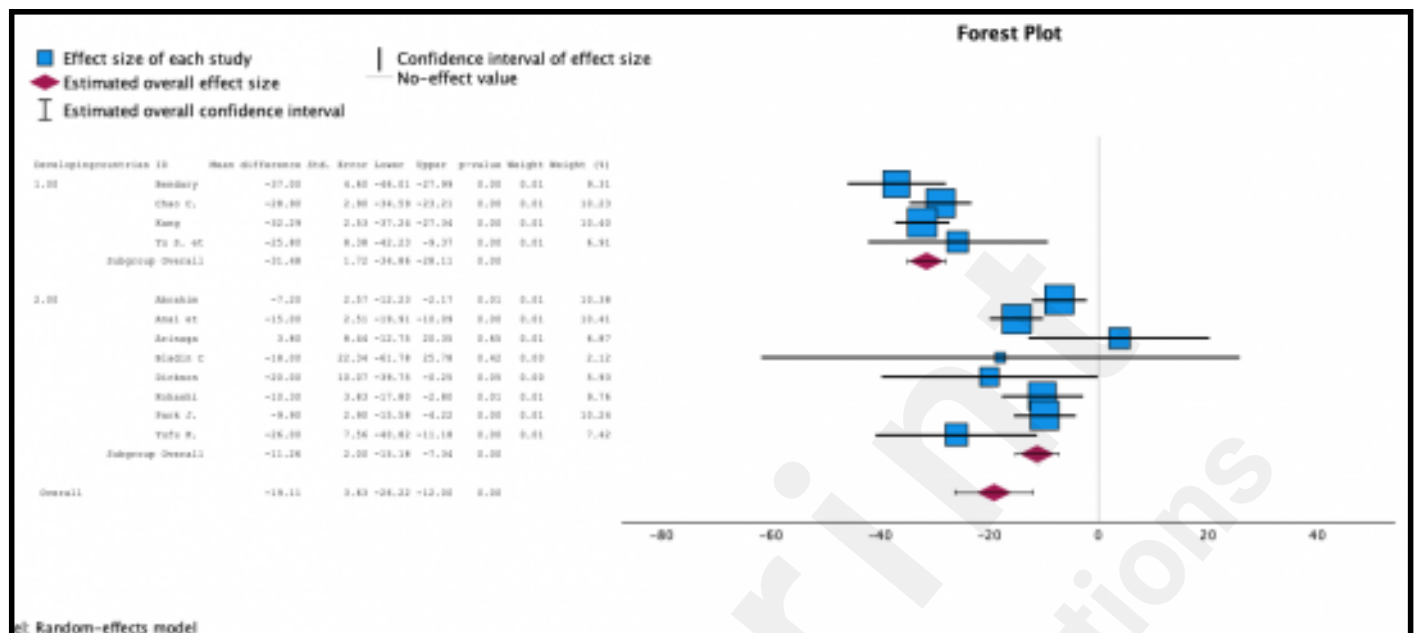
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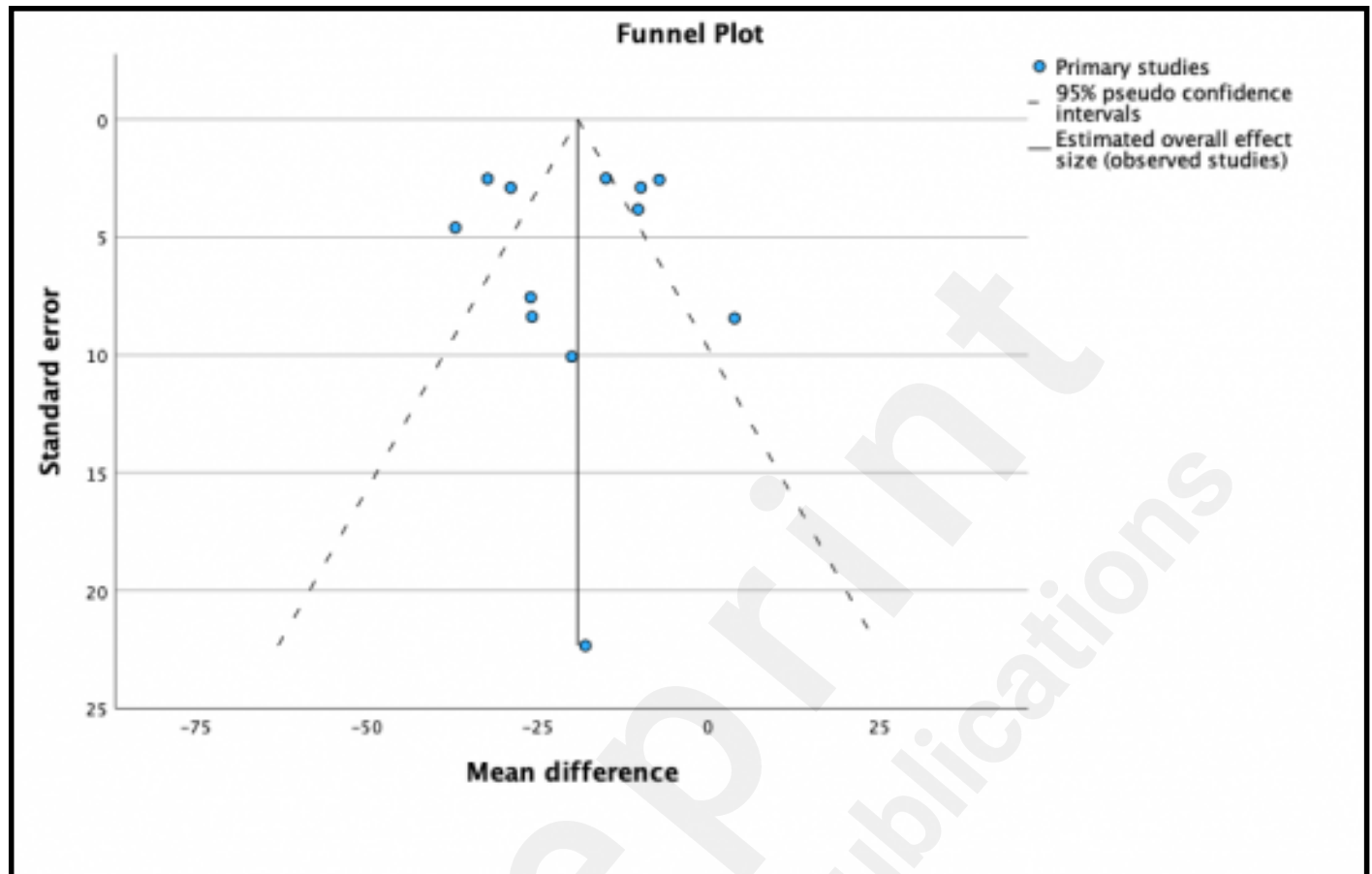
Figures



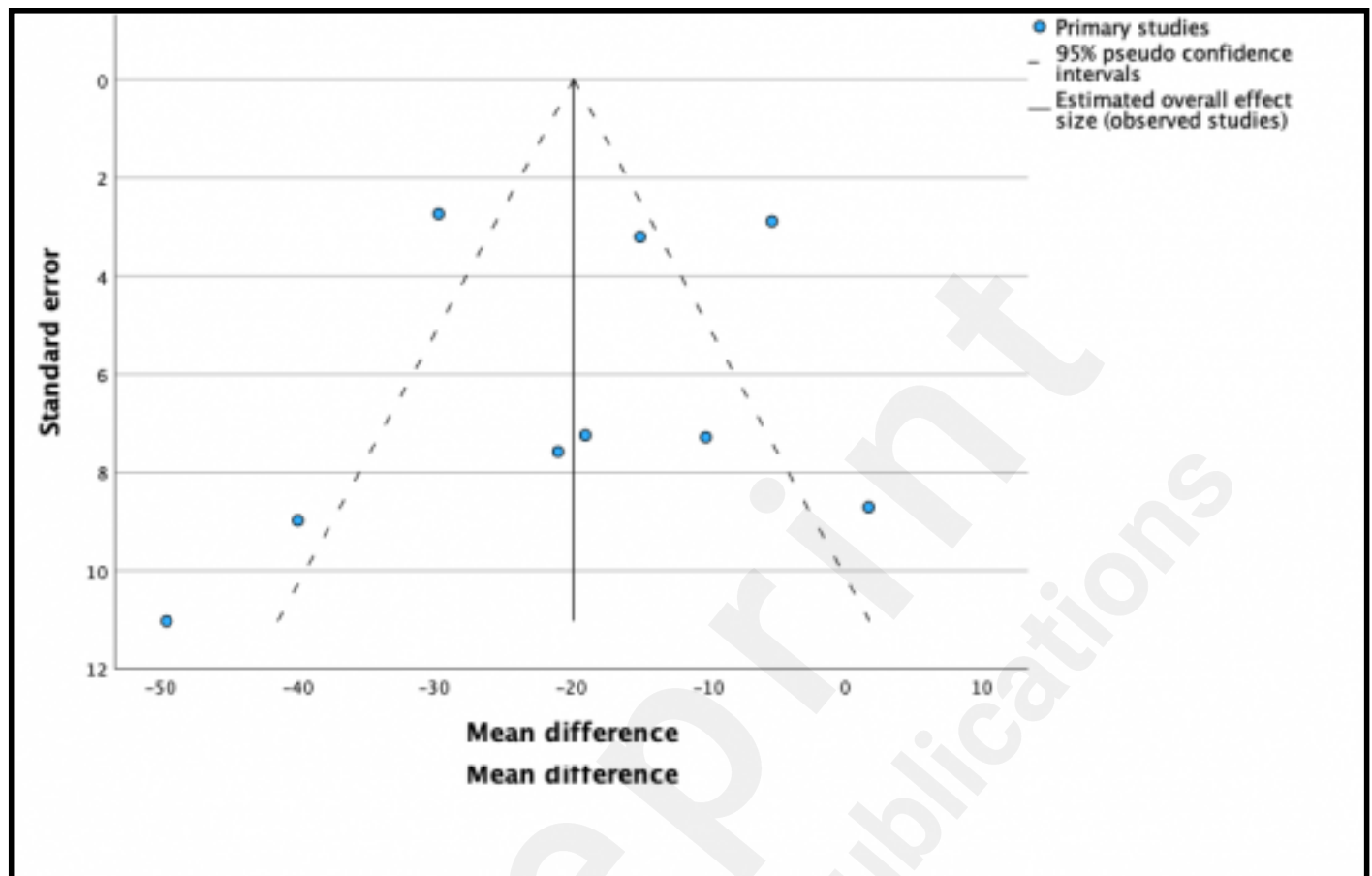
Subgroup analysis of primary endpoint D2B times stratified according to healthcare setting (1: low or middle income versus vs 2: developed countries).



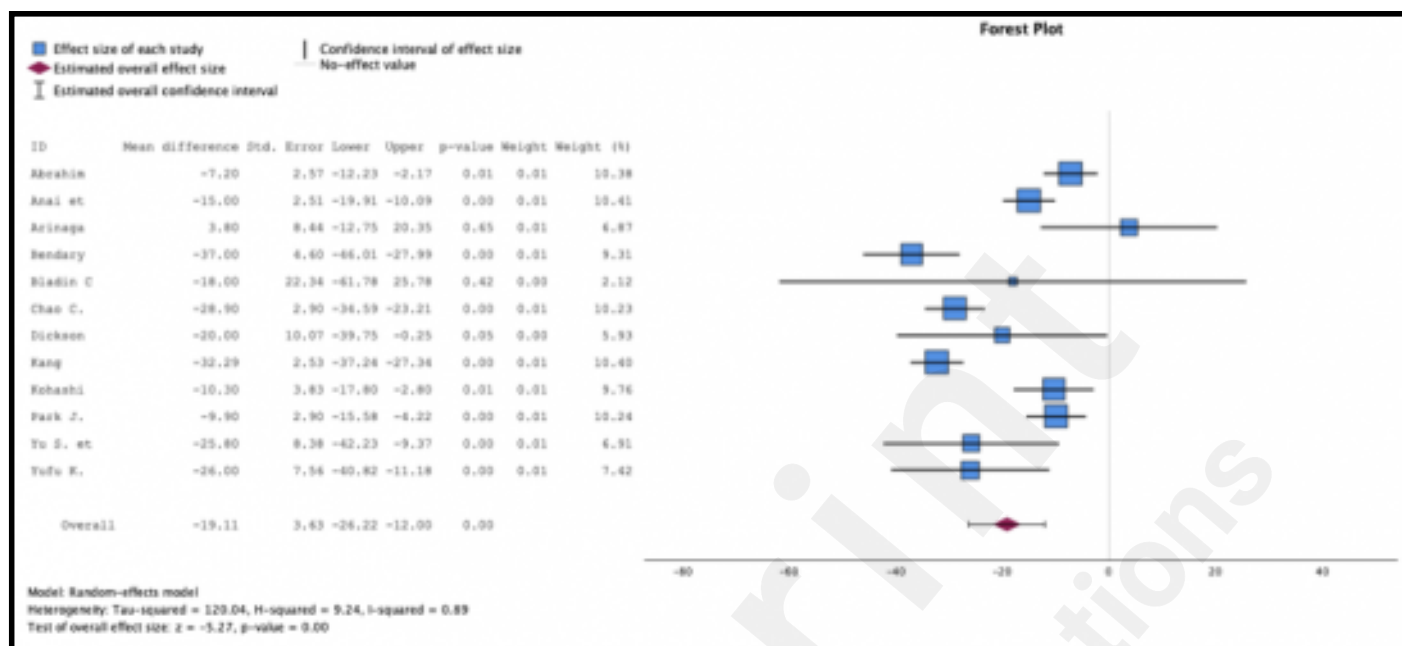
Funnel plot assessing publication bias for the primary endpoint of D2B times.



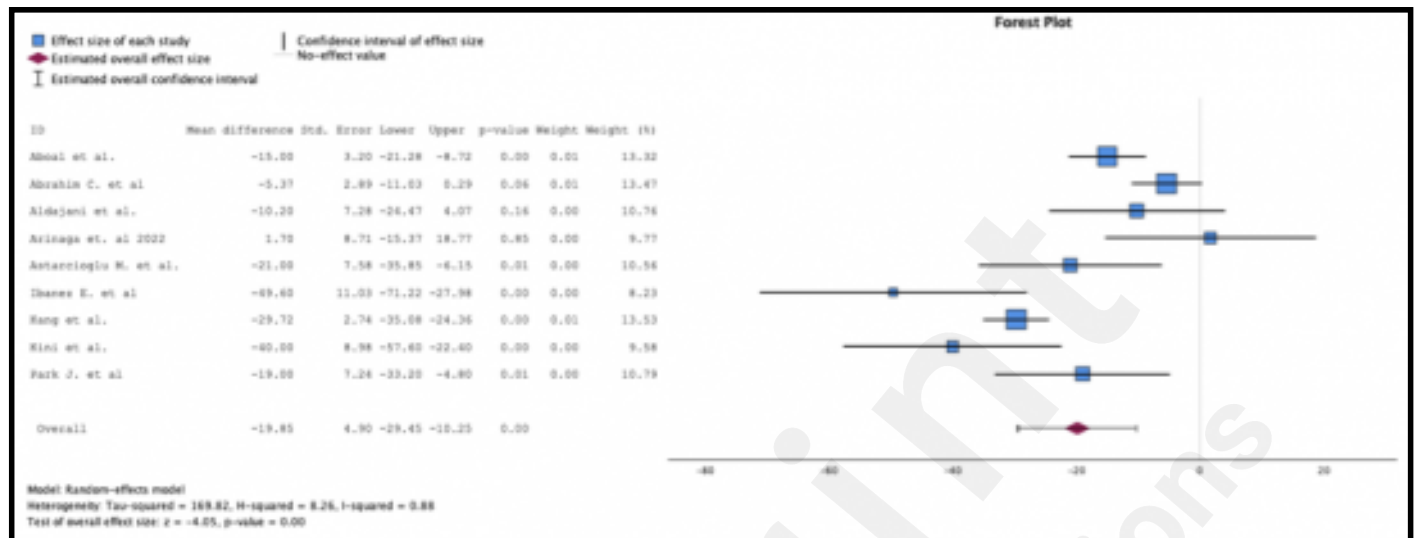
Funnel plot assessing publication bias for publication bias with respect to the outcome of FMC2B times.



Forest plot showing the unstandardised mean difference of D2B times (minutes) between patients submitted to telemedicine strategies associated to usual care versus usual care. (D2B: door to balloon).



Forest plot showing the unstandardised mean difference in FMC2B times (minutes) between patients submitted to telemedicine strategies associated to usual care versus usual care (FMC2B: first medical contact to balloon).



Forest plot showing the relative risk reduction of in-hospital or 30 day mortality in patients submitted to telemedicine strategies associated to usual care versus usual care.

