The use of Early Warning System Scores in Pre-Hospital and Emergency Department Settings to Predict Clinical Deterioration: s Systematic Review and Meta-Analysis

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EDITORIAL NOTE:

Author's note April 4th 2022: As suggested by the Editor in Chief of *PLOS ONE*, we have also included studies that reported on patients presenting with sepsis. The meta-analyses were re-run to reflect this change. Please find the full revised article in *PLOS ONE*.

Abstract

Background:

It is unclear which Early Warning System (EWS) score best predicts in-hospital deterioration when applied in the emergency department (ED) or pre-hospital setting.

Methods:

This systematic review and meta-analysis assessed the predictive abilities of five commonly used EWS scores: National Early Warning Score (NEWS) and its updated version NEWS2, Modified Early Warning Score (MEWS), Rapid Acute Physiological Score (RAPS) and Cardiac Arrest Risk Triage (CART). Outcomes of interest included admission to ICU, up-to-≥3-day and 30-day mortality. Pooled estimates were calculated using DerSimonian and Laird random-effects models, constructed by type of EWS score, cut-off points, outcomes, and study setting. Risk of bias was assessed using the Newcastle-Ottawa Scale. Meta-regressions investigated between study heterogeneity. Funnel plots tested for publication bias.

Results:

A total of 11,565 articles was identified, of which 15 were included. Eight and seven articles conducted in the ED and pre-hospital settings, respectively. In the ED, MEWS and NEWS at cut-off points of 3, 4, or 6 had similar pooled diagnostic odds ratios (DOR) to predict 30-day mortality, ranging from 4.05 (Confidence Interval (CI) 2.35–6.99) to 6.48 (95% CI 1.83–22.89), p = 0.757. The ability of MEWS (cut-off point ≥ 3) to predict ICU admission had a similar pooled DOR of 5.54 (95% CI 2.02–15.21). In the pre-hospital setting, EWS scores failed to predict 30-day mortality. Using high cut-off points of 5, 7, or 9, their predictability improved when assessing up-to-≥3-day mortality with DOR ranging from 11.60 (95%, CI 9.75–13.88) to 20.37 (95% CI 13.16–31.52).Publication bias was not detected. Participants’ age explained 92% of between-study variance.

Conclusion:

EWS scores’ predictability of clinical deterioration improves when applied on patient populations that are already in the ED or hospital. The high thresholds used and the scores’ failure to predict 30-day mortality make them less suited for use in the pre-hospital setting.

Introduction

Initially used in the intensive care unit (ICU), Early Warning System (EWS) scores have been employed in multiple health care settings including hospital wards, the emergency department (ED), and pre-hospital community settings (1, 2). The scores primarily aim to detect clinical deterioration in patients by tracking their vital signs, with high EWS scores triggering a response to prevent any potential clinical deterioration. Patients' vital signs commonly change before clinical deterioration (3, 4), and if early and timely interventions are adequately performed, adverse outcomes of patients may be prevented. The earliest EWS score was validated in 1981 for ICU patients only (5). Variations over time were developed to suit different hospital inward settings (3) with some being more specific to certain conditions such as blunt trauma or sepsis (6–9). However, the fundamentals of the scores have not changed. They are determined by measuring variations of vital signs (e.g., systolic blood pressure, oxygen saturation, temperature, heart rate, and Glasgow Coma Scale, of which, one or all are adopted against predefined parameters to calculate an aggregated score. Other versions of the EWS scores employ advanced therapies, laboratory testing and patients’ demographic information. (10, 11). The usage of EWS scores constitutes a standardised practice across the UK in both pre-hospital and in-hospital settings (7), and in some parts of Australia, a few selected EWS scores are applied in the in-hospital setting (12).

Numerous systematic reviews and meta-analyses have identified the optimal performing EWS scores in in-hospital settings (e.g., wards or the ED) (3, 13–17), however, only a limited number of reviews have focused on pre-hospital settings (18, 19). Available systematic reviews have demonstrated that EWS scores can potentially improve patient outcomes (11–15) but, since there are several EWS scores that are used across different settings, it is unknown which score should be used in the ED or pre-hospital setting to best predict clinical outcomes (20, 21). Furthermore, it is not known which EWS scores, and which cut-off points best predict outcomes such as short-term and long-term mortality or ICU admission (7–9).

This systematic review and meta-analysis aimed to estimate the pooled odds of predicting in-hospital deterioration, including short (≥ 3-day) and long-term (30-day) mortality, and ICU admission, stratified by the EWS score cut-off points as used in the ED and pre-hospital settings. Length of stay in hospital and cardiac or respiratory arrests were also investigated.

Methods

This systematic review reviewed the five most used EWS scores in either the ED or pre-hospital settings: the National Early Warning Score (NEWS) and its updated version the National Early Warning Score 2 (NEWS2), the Modified Early Warning Score (MEWS), the Rapid Acute Physiological Score (RAPS) and the Cardiac Arrest Risk Triage (CART) (13, 15–18, 22). These scores were selected since they rely solely on observations that are readily available to health care professionals in the pre-hospital setting and are easy to calculate and apply. This is important as expensive and time-consuming pathological and other complex testings are less commonly performed in the pre-hospital environment (23).

A PICO framework was used to inform the literature search strategy (Appendix 1).

Protocol And Registration

The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement was used to design and report this systematic review (24). The protocol was registered with the PROSPERO-International register of systematic reviews (registration number of CRD42020191254).

Inclusion Criteria And Exclusion Criteria

Experimental, quasi-experimental or observational studies using EWS scores in either the ED or pre-hospital setting were eligible for inclusion. Studies were considered eligible if they reported on medical or trauma patients aged ≥ 14 years with study outcomes including in-hospital mortality up to 3 or 30 days, ICU admission, cardiac arrest/respiratory arrest, and length of stay. Publication language was restricted to English, but no restrictions were applied to year of publication.

Studies focusing on obstetric, maternal, or palliative care patients were excluded. Similarly, articles focusing only on patients experiencing sepsis or septic shock or Severe Acute Respiratory Syndrome Coronavirus 2 infections were excluded. Such patients were not representative of the general population treated in either setting. Articles focusing on rare or specific conditions (e.g., portal hypertension, traumatic brain injuries and splenic abscess) were excluded. Articles containing duplicate data were excluded.

Search Strategy

Four databases (CINAHL, Embase, PubMed/MEDLINE, and Web of Science) were systematically searched in April 2020 and updated in February 2021. Key search terms included pre-hospital/ambulance/paramedic, ED/emergency room and the selected EWS scores. All synonyms and MeSH terms were included in the searches (Appendix 2). The references of the identified articles were hand-searched for additional articles that could have been missed in the electronic searches.

Selection Process And Data Extraction

Three reviewers (GG, GM, CL) independently screened all articles based on title and abstract. In addition, reviewer GG screened all potential articles cross-checked by CL (80%) and GM (20%). Any disagreements or conflicts were discussed to make the final decision for inclusion.

Data extracted included author name, year and country of publication, study setting (ED or pre-hospital), study outcomes, EWS score applied, cut-off points of the EWS scores, sample size, sensitivity and specificity of the EWS score to predict investigated study outcomes, mean or median age of study population, sex proportion, study design and study inclusion and exclusion criteria. The Newcastle-Ottawa Scale was used to assess the methodological quality of the included articles (23). The assessments were independently conducted by GG and SB with conflicts resolved after discussion with co-authors.

Statistical analysis

An odds ratio (OR) was computed as a summary measure of the predictive accuracy of each EWS from (TP x TN) / (FP x FN), in which TP, TN, FP and FN respectively express true positive, true negative, false positive and false negative (25). The confidence interval (CI) of the OR was estimated as:

$$CI = \exp(\log(OR) \pm Z\alpha/2 * \sqrt{1/TP + 1/TN + 1/FP + 1/FN}),$$

where $Z\alpha/2$ denotes the critical value of the normal distribution at $\alpha/2$ (e.g., for a CI 95%, α is 0.05, and the critical value reaches 1.96).

To express the diagnostic accuracy of the EWS scores, the log ORs, together with their corresponding log standard errors, were meta-analysed using DerSimonian and Laird random-effects models (26). The analyses were conducted by types of EWS scores, and the cut-off points utilised, patient outcomes (short- and long-term mortality from hospital admission, and ICU admission) and study setting (ED or pre-hospital). This systematic review defined short-term mortality as death within 3 days from admission and long-term mortality as death within 30 days from admission. Between study heterogeneity was estimated with I^2 statistic. Meta-regressions were constructed to quantify the proportion of between study variances explained by sample size, sex proportion, and age. Deeks' funnel plot asymmetry test was used to test publication bias. Pooled ORs were compared after converting them to z scores. The p values were estimated using the normal distribution table. Sensitivity analyses were conducted by risk of bias.

All analyses were conducted using Stata/SE 15.1 (Stata Corp LP., College Station, Texas, USA).

Results

The electronic databases searches identified 11,565 potential references. After removing duplicates and excluding irrelevant articles based on the title and abstract, 260 articles were included in the full-text review. Of these, 15 articles with a total sample of 79,214 patients were meta-analysed (Fig. 1).

Characteristics of articles included

The characteristics of the studies are presented in Tables 1a and 1b. Of the 15 included studies, 8 were conducted in the ED (27–34), and 7 in the pre-hospital setting (11, 35–40). Nine studies were prospective cohort (28, 30–34, 36–38), five were retrospective cohort (11, 27, 29, 35, 39), and one study followed a pragmatic clinical trial design (40). In the ED setting, all studies except one examined the use of MEWS (34), with two reporting on NEWS (29, 34). In the pre-hospital setting, five articles assessed NEWS2 (36–40) and three used NEWS (11, 35, 40). Overall, the meta-analysis included 7,556 and 71,658 patients from the ED and pre-hospital settings, respectively.

Table 1
a: Description of Included Studies: ED Setting

Study	Inclusion	Exclusion	Mean/ Median age (yrs)	% Male	Sample size	Outcome	EWS	Cut-off points	SEN%	SPE%	AUC/OR(95% CI)	ROB
Jiang et al. 2019 (27)	Multiple trauma	Age < 16yrs and missing data, DOA, medical patients	48.0	73.7	1127	28 days in-hospital mortality	MEWS	≥ 3	93.0	75.0	0.78	Poor
Demircan, Ergin et al. 2020 (28)	Age ≥ 65yrs, Yellow or red triage code	TRI, CPR prior arrival, loss of contacts	77.2	52.0	1106	28 days in-hospital mortality	MEWS	≥ 3	58.4	65.3	0.65	Good
Mitsunaga, Hasegawa et al. 2019 (29)	Age ≥ 65yrs	N/S	78.0	53.9	2204	28 days in-hospital mortality	NEWS	≥ 5	78.7	64.0	0.79	Good
						28 days in-hospital mortality	MEWS	≥ 3	69.3	67.6	0.72	
Koksal, Torun et al. 2016 (30)	Age ≥ 18yrs, triage category 1 or 2	Age < 18yrs and TRI	62.0	49.4	502	28 days in-hospital mortality	MEWS	≥ 3	78.0	79.9	0.85	Poor
Maftoohian, Assarroudi et al. 2020 (31)	Age ≥ 18yrs	Advance airway, CPR, intubation applied, not admitted, DOA	62.1	50.9	381	30 days in-hospital mortality	MEWS	≥ 3	78.3	68.4	0.73	Good
						30 days in-hospital mortality	MEWS	≥ 4	30.4	83.2	N/S	
						ICU admission	MEWS	≥ 3	85.7	67.6	0.77	
Yuan, Tao et al. 2018 (32)	Stay longer than 24 hours	Age < 14yrs, LOS less than 24 hours, incomplete information, lost follow up, non-cooperative family members	64.0	60.0	612	28 days in-hospital mortality	MEWS	≥ 4	56.9	79.4	0.72	Good
						ICU admission	MEWS	≥ 3	64.5	68.7	0.73	
Dundar, Ergin et al. 2016 (33)	Age ≥ 65yrs	Age < 65yrs and TRI patients, CPR	75.0	55.9	671	28 days in-hospital mortality	MEWS	≥ 4	74.0	89.0	0.89	Good
Graham, Leung et al. 2020 (34)	Age ≥ 18yrs with triage as Emergency or Urgent	Age < 18yrs, pregnant, presenting out of research hours	72.0	50.9	1253	30 days in-hospital mortality	NEWS	≥ 5	35.8	86.8	0.61	Good

Table 1

b: Description of Included Studies: Pre-Hospital Setting

Study	Inclusion	Exclusion	Mean/ Median age (yrs)	% Male	Sample size	Outcome	EWS	Cut-off points	SEN%	SPE%	AUC/OR(95% CI)	ROB
Pirneskoski, Kuisma et al. 2019 (35)	Age ≥ 18yrs	Missing data, data errors, without Finnish ID	65.8	47.5	35800	1 day in-hospital mortality	NEWS	≥ 7	77.0	77.1	0.84	Good
						30 days in-hospital mortality	NEWS	≥ 7	75.9	63.4	0.76	
Martin-Rodriguez, Castro-Villamor et al. 2019 (36)	Age ≥ 18yrs, attended by ALSU and transported to ED	Age < 18yrs, CPR, DOA pregnancy, psychiatric, palliative, or discharge in situ	66.0	58.5	349	48 hours in-hospital mortality	NEWS2	≥ 9	88.0	80.0	N/S	Good
Martin-Rodriguez, Lopez-Izquierdo et al. 2020 (37)	Age ≥ 18yrs, attended by ALSU and transported to ED	Age < 18yrs, CPR, DOA pregnancy, psychiatric, palliative, or discharge in situ, loss of follow-ups	69.0	58.9	2335	48 hours in-hospital mortality	NEWS2	≥ 9	74.8	85.2	0.86	Good
Martin-Rodriguez, Del Pozo Vegas, et al. 2019 (38)	Age ≥ 18yrs, attended by ALSU and transported to ED	Age < 18yrs, CPR, DOA pregnancy, psychiatric, palliative, or discharge in situ	68.0	59.5	1288	48 hours in-hospital mortality	NEWS2	≥ 9	79.7	84.5	0.87	Good
					1026	48 hours in-hospital mortality medical only	NEWS2	≥ 7	87.5	71.8	N/S	
Vihonen, Laaperi et al. 2020 (11)	Age ≥ 18yrs	Age < 18yrs	69.0	48.0	27141	24 hours in-hospital mortality	NEWS	≥ 7	71.0	83.0	0.84	Good
						30 days in-hospital mortality	NEWS	≥ 7	51.0	54.0	0.75	
Magnusson, Herlitz et al. 2020 (39)	Age ≥ 16yrs, attended by ALSU and transported to ED	Missing data, DOA	69.0	48.0	473	48 hours in-hospital mortality	NEWS2	≥ 5	72.7	81.9	0.77	Good
Martín-Rodríguez, Sanz-García, et al. (40)	Age ≥ 18yrs, attended by ALSU and transported to ED	Cardiac arrest, terminally ill, pregnant, or not transported by ALSU	69.0	58.9	3273	2 days in-hospital mortality	NEWS2	≥ 7	78.1	75.9	11.2 (7.5–16.7)	Good
						3 days in-hospital mortality	NEWS2	≥ 5	91.2	60.0	15.5 (8.9–26.9)	
						1 day in-hospital mortality	NEWS	≥ 7	78.9	76.6	12.3 (7.7–19.4)	

Abbreviations:

ALSU: advanced life support units; BLS: basic life support; CPR: cardio-pulmonology resuscitation commenced; CFS: clinical frailty scale; DOA: dead on arrival; HRV: heart rate variability; ENT: ears, nose, throat related patients; IHCA: in-hospital cardiac arrest; LOC: loss of consciousness; LOS: length of stay;

OHCA: out of hospital cardiac arrest; PACS: Patient Acuity Category Scale; TRI: trauma-related injuries; NFR: not for resuscitation.

AUC: Area under the ROC Curve, OR: Odds ratios; Sen%: sensitivity, Spe%: specificity, ROB: risk of bias

N/S: Not stated.

NEWS: National Early Warning Score; NEWS2: National Early Warning Score 2; MEWS: Modified Early Warning Score

Risk of bias and quality assessment

Quality and risk of bias assessments of each included study are found in Appendix 3. Of all studies, two were rated poor (13.3%), and the remaining 12 (86.7%) were rated good. A sensitivity analysis was conducted with and without studies with high ROB in the ED setting, as shown in Figures 2a and 2b.

Meta-analysis: ED setting

The pooled diagnostic ORs (DOR) of MEWS (cut-off points of ≥3 and ≥4) and NEWS (cut-off point ≥6) to predict 30-day mortality and of MEWS (cut-off point ≥3) to predict ICU admission were estimated (Figure 2). The lowest and highest DORs to predict 30-day mortality were 4.05 (95% confidence interval (CI) 2.35 - 6.99, I^2=73.0%) for the use of MEWS with a cut-off point of ≥3 and 6.48 (95% CI 1.83 - 22.89, I^2=90%) for the use of MEWS with a cut-off point of ≥4. A similar DOR for NEWS at a cut-off point ≥ 6 was found [4.92 (95% CI 2.71-8.96, I^2=65.5%)]. MEWS at a cut-off point of 3 or higher also predicted admission to ICU with a pooled DOR of 5.54 (95% CI 2.02-15.21, I^2=50.9%). The confidence intervals of the highest and lowest pooled ORs overlapped, and no statistical differences were detected between them, p=0.757.

Meta-analysis: Pre-hospital setting

As illustrated in Figure 3, NEWS2 was evaluated for short-term mortality with cut-off points at 5, 7 and 9. The DORs were 14.06 (95% CI 9.09 - 21.75, I^2=0%,), 12.26 (95%, CI 8.58 – 17.64, I^2=4.4%,) and 20.37 (95% CI 13.16 - 31.52, I^2 = 0%), respectively. Predicting short-term mortality using NEWS at a cut-off point of 7 or higher had a DOR of 11.63 (95%, CI 9.75 - 13.88, I^2=0%,), being not statistically different from NEWS2 using the same cut-off point. Using a relatively high cut-off point such as 9 significantly improved the predictability of the tool to predict short-term mortality. However, in the pre-hospital setting, NEWS could not accurately predict 30-day mortality [DOR of 2.58 (95% CI 0.59–11.21)].

Between-study variances

Studies reporting on 30-day mortality had moderate to high heterogeneity (I^2 >70%) in both the ED and pre-hospital settings. Meta-regressions, including studies from the ED setting, were constructed to detect which known study variables contributed to the between-studies differences. Of the study variables, only patients' age contributed to heterogeneity, explaining 92% of the between-study variance. In the pre-hospital setting, meta-regression could not be performed due to a limited number of studies investigating 30-day mortality.

Publication bias

Since studies often reported multiple results for different EWS scores, to detect any publication bias, the highest and lowest reported ORs in each study were included in two separate Deeks' funnel asymmetry tests, as shown in Figures 4a and 4b. No evidence for publication bias was detected, with p values using the highest or lowest ORs p=0.82 and p=0.44, respectively.

Discussion

The use of EWS scores in the ED is well documented, while only limited studies have been published in the pre-hospital setting. This systematic review and meta-analysis explored the predictability of different EWS scores, as utilised in the ED or pre-hospital setting, to predict up-to-3- and 30-day mortality and admission to an ICU. The systematic review found that different cut-off points of different EWS scores applied in the ED had similar ability to predict clinical deterioration. However, in the pre-hospital setting, where relatively high cut-off points were utilised, the EWS only predicted short-term clinical deterioration with it failing to predict 30-day mortality.

Similar to other studies, our systematic review demonstrated the ability of EWS scores to predict 30-day mortality when applied in the ED setting (41, 42). However, unlike other studies that suggested optimal cut-off points of different EWS scores to predict clinical deterioration (43-47), this systematic review did not detect any significant variation in the predictability of different scores by different cut-off points when applied in the ED. The choice of cut-off points mostly depends on the severity of illness and the acuteness of the investigated condition. Patient presentation varies across different settings; in the pre-hospital setting, the general population attended by paramedics are less severely ill (with a considerable majority having non-urgent low acuity presentations) than patients who were sick enough to have been brought to the ED(48). In critically ill patients, lower cut-off points are able to predict clinical deterioration, which may indicate that the predictability of the score is outcome and patient population specific, as evidenced by this systematic review with both settings requiring different optimal thresholds. The cut points applied in ED are typically lower than those used in the pre-hospital setting. The high cut-off points in the pre-hospital setting may imply that EWS scores are adequate to predict short-term clinical deterioration among the critically ill, as the higher EWS scores target more severely ill patients who are at high risk of clinical deterioration in the short term (19, 49, 50). Thus, the high thresholds used in the pre-hospital setting may be targeting the critically ill patients who will constitute a relatively small proportion of the overall pre-hospital patient population that paramedics treat. The review conducted by Williams et al on the use of EWS scores in pre-hospital setting also suggests that critically ill patients are the best candidates for the use of pre-hospital EWS scores; the authors also argue that achieving an optimal EWS score is difficult due to the short duration of the interaction between paramedics and patients (19). The reporting of high cut-off points in the pre-hospital setting is also due to a trade-off in sensitivity and specificity. Lower cut-off points often result in poor sensitivity and specificity in the pre-hospital setting. Conversely, the cut-off points in the ED are often similar to the cut-off points used in in-hospital settings suggesting that EWS scores can be compared between the ED and in-hospital wards, whereas this comparison becomes less valid when it is conducted against the pre-hospital setting (51). In our review, NEWS2 with a cut-off point of 5, 7 or 9 and NEWS with a cut-off point of 7 had similar predictability. This is supported by a study that compared NEWS and NEWS 2 at the same threshold of 7 without detecting significant difference between the two scores when predicting short-term mortality (3). The Royal College of Physicians in London argue that NEWS2 is superior to NEWS in predicting clinical deterioration (52, 53); however, this was not supported by our findings. Similarly, Hodgson and colleagues demonstrated that NEWS2 did not outperform NEWS in predicting clinical deterioration in patients admitted to hospital with acute exacerbation of Chronic Obstructive Pulmonary Disease, (53), which was one of the main reasons why oxygen saturation was added as an additional parameter in NEWS2. Based on the available studies and our systematic review, NEWS and NEWS2 had similar predictabilities.

Limitations

The number of articles included in this systematic review was limited due to the use of multiple EWS scores with different thresholds in different settings. The results of the systematic review apply only to the most commonly used EWS scores assessed in this study. The analysis lacked power to assess medical versus trauma conditions separately. Patients' main complaints and diagnoses were not known and could not be accounted for in the systematic review. The number of studies reporting on cardiac and/or respiratory arrest, and length of stay were limited and could not be meta-analysed.

Conclusions

The accuracy and predictability of the EWS scores depend on numerous factors such as the outcome measure, population and setting being investigated. In the ED setting, the patient population is by default more morbid than those managed by caregivers in the community. This, in turn, explains why in the ED, low cut-off points of such scoring systems predict clinical deterioration of patients. We report that different EWS cut-off points in the ED have similar predictability.

Studies using EWS scores in the pre-hospital setting utilised relatively high cut-off points. This may indicate that early warning scoring systems may be less applicable for the general population treated by paramedics in the pre-hospital setting. This scoring system may only be suited for critically ill patients treated in the pre-hospital setting. Our findings suggest that EWS scores applied to the pre-hospital setting cannot accurately predict long-term events such as 30-day mortality. EWS scores used in the pre-hospital setting can predict immediate outcomes when applied on a relatively sicker patient population compared to the general population seen by paramedics.

Declarations

If any of the sections are not relevant to your manuscript, please include the heading and write 'Not applicable' for that section.

Ethics approval and consent to participate

Not applicable

Consent for publication

Not applicable

Availability of data and materials

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

GG has completed all reference screening, data extraction, risk of bias assessment, a significant contribution to manuscript preparation and final editing.CL has completed reference screening, manuscript preparation and final editing.SB has contributed to the risk of bias assessment, final manuscript editing.AC has contributed to manuscript editing.GM has completed reference screening, risk of bias assessment, manuscript preparation and a significant amount of final editing. All authors read and approved the final manuscript.

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Figures

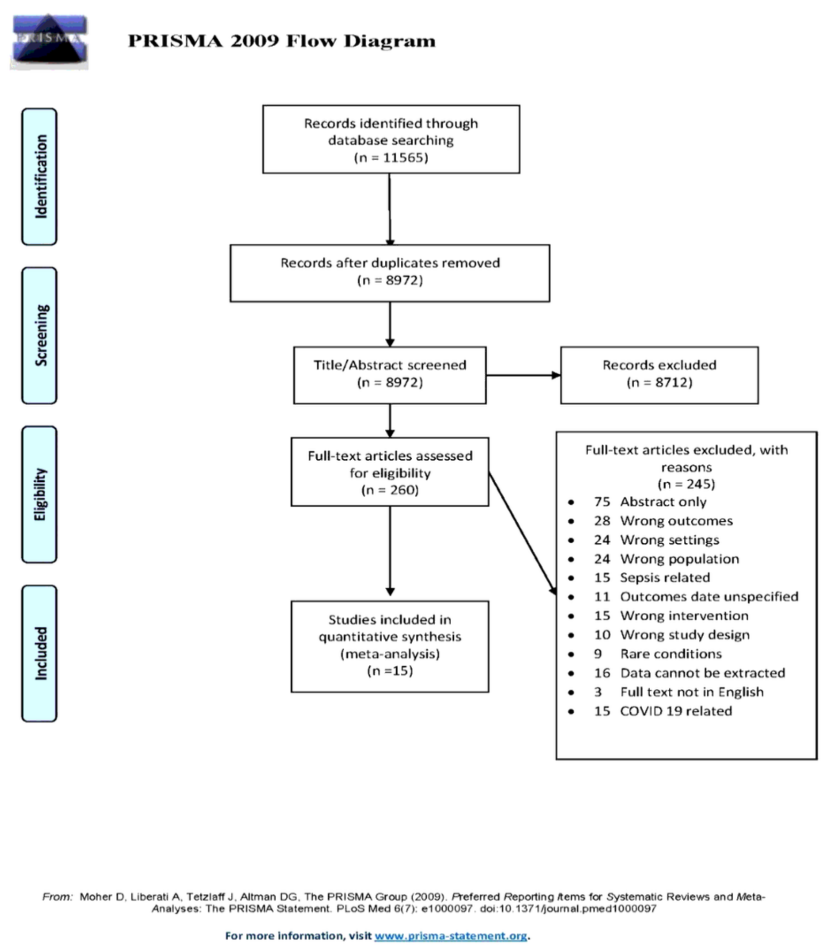

Figure 1

PRISMA chart

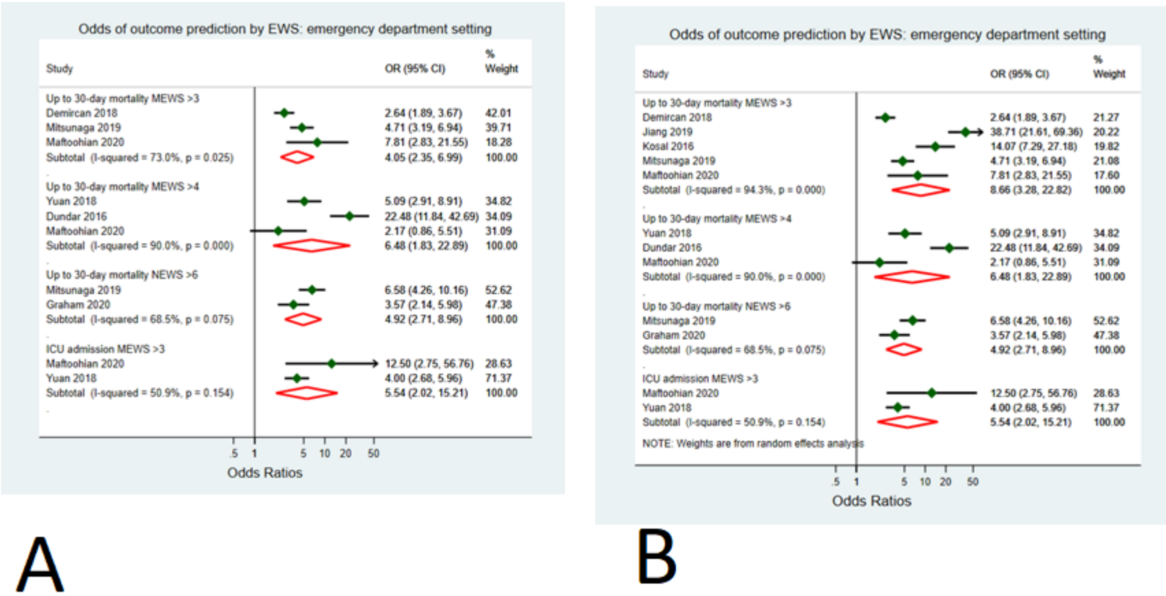

Figure 2

a Meta-analysis result for ED setting (Excluding studies with high ROB) b Meta-analysis result for ED setting (Including studies with high ROB)

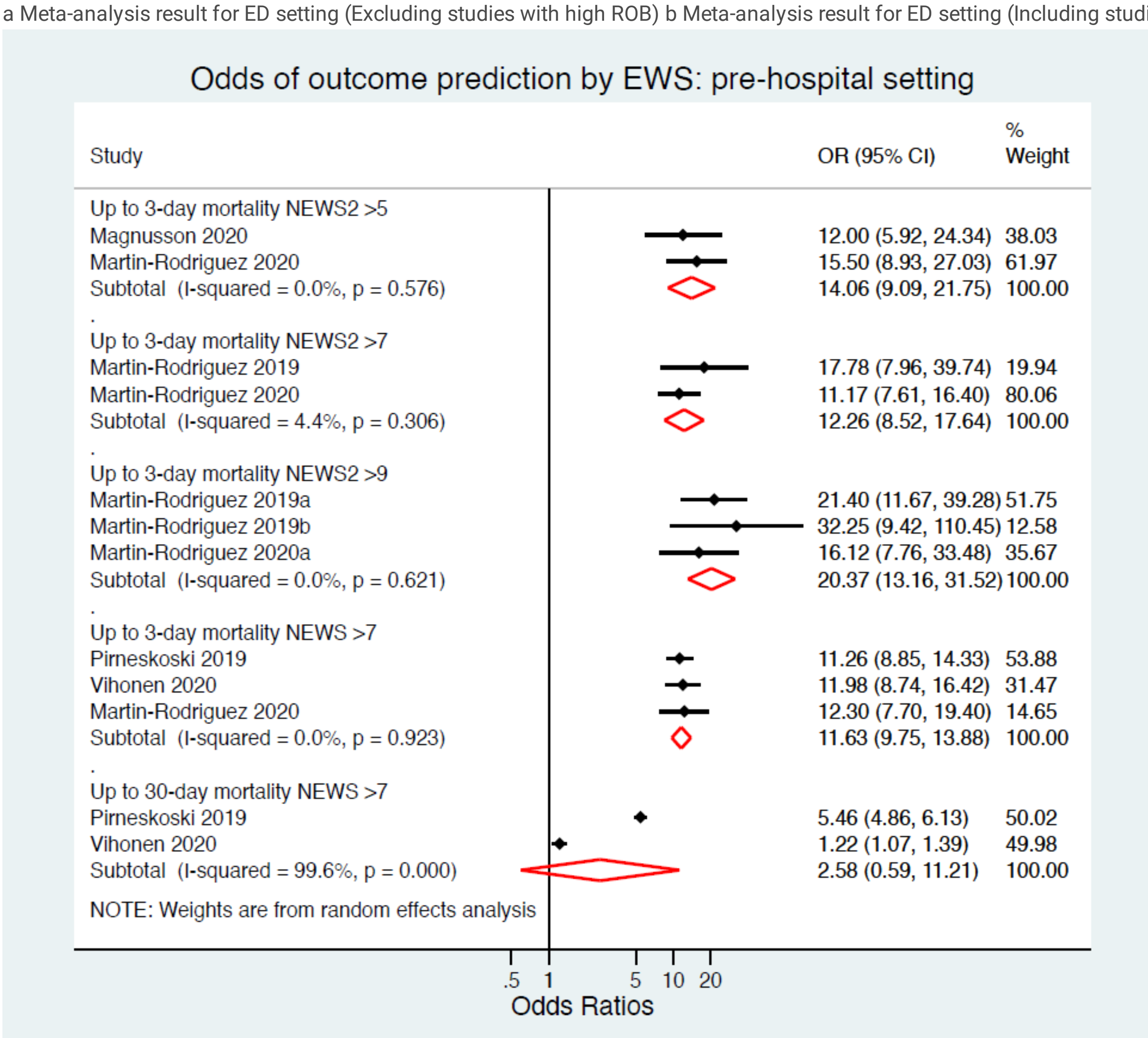

Figure 3

Meta-analysis result for pre-hospital setting

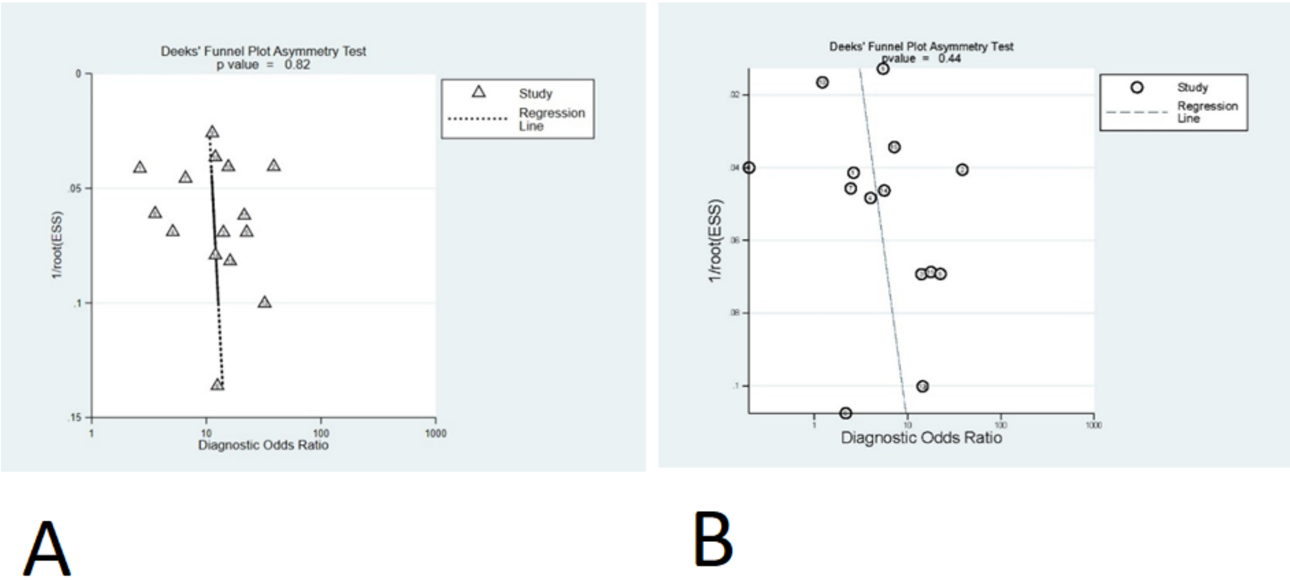

Figure 4

a Deeks' funnel plot testing for publication bias using the highest OR b Deeks' funnel plot testing for publication bias using the lowest OR