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Systematic review

Diagnostic Accuracy of the HACOR Score and Updated HACOR Score for Predicting Noninvasive Ventilation Failure in Adults with Acute Respiratory Failure: A Systematic Review

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Abstract

Background: Noninvasive ventilation (NIV) failure in acute respiratory failure carries high mortality, and delayed intubation worsens outcomes. The HACOR score (heart rate, acidosis, consciousness, oxygenation, respiratory rate) and its updated version aim to detect failure early. Objective: To synthesise the diagnostic accuracy of both scores for predicting NIV failure in adults with acute respiratory failure. Methods: Following PRISMA 2020, we searched PubMed, Scopus and Web of Science to 31 October 2026. Two authors independently screened records, extracted data and assessed bias with QUADAS-2. Cohorts reporting the area under the curve (AUC), sensitivity, specificity or two-by-two data against NIV failure were eligible. Results were synthesised narratively. Results: Thirteen cohorts (5,916 patients) were included, with NIV failure rates of 8.9% to 59.4%. After 1-2 hours of NIV, the original score achieved AUCs of 0.65-0.91; at a threshold above 5, sensitivity ranged from 53.7% to 98.0% and specificity from 75.8% to 100%. The updated score achieved AUCs of 0.76-0.85 and outperformed the original version in all three comparative cohorts. The original score discriminated poorly when measured before NIV. Ten studies carried high risk of bias in the reference standard domain. Conclusion: Both scores showed acceptable to excellent discrimination after 1-2 hours of NIV, with better performance for the updated version. Specificity exceeded sensitivity at the conventional threshold in most cohorts. Prospective multicentre validation with prespecified thresholds is required.

Keywords: HACOR score; noninvasive ventilation; acute respiratory failure; treatment failure; intubation; diagnostic accuracy; systematic review

Introduction

Noninvasive ventilation (NIV) is a first-line support for selected adults with acute respiratory failure (ARF), and international guidelines give strong recommendations for its use in hypercapnic exacerbations of chronic obstructive pulmonary disease (COPD) and in cardiogenic pulmonary oedema. The same guidelines offered no recommendation for de novo hypoxemic respiratory failure because evidence of benefit was uncertain (1). In the LUNG SAFE study, 15.5% of patients with acute respiratory distress syndrome (ARDS) received NIV, and NIV failure increased with ARDS severity. Hospital mortality reached 45.4% after NIV failure, compared with 16.1% after NIV success (2).

In a multicentre French cohort, NIV success was associated with lower mortality, whereas NIV failure in de novo ARF was associated with higher mortality (3). The timing of intubation adds to this risk, since survivors among intubated patients with de novo ARF from community-acquired pneumonia had received NIV for a shorter period than non-survivors, at 32 versus 78 hours (4). In ARDS, patients intubated late had a 60-day mortality of 56%, against 36% in those intubated early (5). These data place a premium on bedside tools that identify NIV failure within the first hours of treatment (3-5).

Duan et al. derived the HACOR score from heart rate, acidosis, consciousness, oxygenation and respiratory rate, with a maximum of 25 points (6). In 449 hypoxemic patients, the score measured after 1 hour of NIV reached an AUC of 0.88, and a separate cohort of 358 patients served for validation. In patients with a score above 5 who failed NIV, intubation within 12 hours was associated with lower hospital mortality than later intubation, at 66% versus 79% (6). Because the original score ignored baseline conditions, the updated HACOR score added pneumonia, cardiogenic pulmonary oedema, pulmonary ARDS, immunosuppression, septic shock and the Sequential Organ Failure Assessment (SOFA) score. The updated score reached AUCs of 0.85 in a training cohort of 1,451 patients and 0.78 in an external cohort of 728 patients from China and Turkey (7). Both scores were derived by one research group in Chinese critical care units, and their transportability to emergency departments, other regions and conditions such as coronavirus disease 2019 (COVID-19) remains uncertain (6, 7). This review synthesised the diagnostic accuracy of

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the original and updated HACOR scores for predicting NIV failure in adults with ARF.

Methods

Protocol and reporting

This review was conducted and reported according to PRISMA 2020 and its extension for diagnostic test accuracy studies (PRISMA-DTA).

Eligibility criteria

Eligible studies were prospective or retrospective cohorts of adults with ARF of any cause treated with NIV, including bilevel ventilation and continuous positive airway pressure (CPAP) by mask or helmet. The index test was the original or updated HACOR score measured at any time point. The reference standard was NIV failure, defined by the study authors as intubation, or intubation or death during NIV. Studies had to report the AUC, sensitivity, specificity, predictive values or data allowing reconstruction of a two-by-two table. We excluded studies limited to high-flow nasal cannula, post-extubation NIV, weaning or children, as well as reviews, letters, case reports, conference abstracts, reports giving only odds or hazard ratios, non-English reports and duplicate cohorts.

Information sources and search strategy

PubMed/MEDLINE, Scopus and Web of Science Core Collection were searched from inception to 31 October 2026. The core search string was ("HACOR" OR "heart rate, acidosis, consciousness, oxygenation") AND ("noninvasive ventilation" OR "non-invasive ventilation" OR "NIV" OR "continuous positive airway pressure" OR "CPAP" OR "bilevel" OR "noninvasive respiratory support"), adapted to the syntax of each database. Reference lists of included studies were screened by hand.

Study selection

Records were exported to reference management software for deduplication. Two authors independently screened titles and abstracts, then full texts, against the eligibility criteria. Disagreements were resolved by discussion, and a third author adjudicated when consensus was not reached.

Data extraction

Two authors independently extracted data using a piloted form: first author, year, country, design, setting, population, NIV mode, sample size, definition and rate of NIV failure, timing of score measurement, threshold, AUC with 95% confidence interval (CI), sensitivity, specificity, positive predictive value (PPV) and negative predictive value (NPV). When only counts were reported, sensitivity and specificity were calculated from reconstructed two-by-two tables.

Risk of bias assessment

Two authors independently applied the QUADAS-2 tool across four domains (patient selection, index test, reference standard, and flow and timing) and judged applicability concerns for the first three domains (Table 1). The index test domain was rated high risk when the threshold was derived from the same dataset. The reference standard domain was rated high risk when intubation was left to clinicians aware of the score components without predefined criteria.

Data synthesis

Because thresholds, assessment times, populations and outcome definitions varied, a narrative synthesis replaced bivariate meta-analysis. AUC values of 0.70-0.79, 0.80-0.89 and 0.90 or above were interpreted as acceptable, excellent and outstanding discrimination, respectively.

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Results

Study selection

The database search identified 365 records (Figure 1): PubMed (n = 96), Scopus (n = 148) and Web of Science (n = 121). After removal of 152 duplicates, 213 records underwent title and abstract screening, and 171 were excluded. Of 42 reports sought, two were unavailable, and 40 full texts were assessed for eligibility. Twenty-seven reports were excluded: high-flow nasal cannula or other non-NIV support (n = 6), weaning or post-extubation use (n = 3), no extractable accuracy data for NIV failure (n = 7), conference abstract only (n = 5), duplicate or overlapping cohort (n = 3), HACOR entered only within a composite model (n = 2) and non-English full text (n = 1). Thirteen studies met all criteria and entered the qualitative synthesis (6-18).

Study characteristics

The 13 cohorts, published between 2017 and 2026, enrolled 5,916 patients (Table 2) (6-18). Eight cohorts came from China or India (6-9, 12, 14, 16, 18), and the remainder from Italy, Malaysia, the United Kingdom, Brazil and a three-country collaboration (10, 11, 13, 15, 17). Nine cohorts used prospectively collected data (6, 7, 9-13, 17, 18), three were retrospective (14-16), and one combined both (8). Populations comprised hypoxemic ARF (6, 7, 17, 18), hypercapnic or obstructive disease (8, 9, 16), COVID-19 pneumonia (10, 11, 14), mixed emergency department ARF (12), cardiogenic pulmonary oedema (13) and community-acquired pneumonia (15). NIV failure ranged from 8.9% to 59.4% (8, 14).

Risk of bias

Ten studies carried high risk of bias in the reference standard domain because clinicians decided on intubation while aware of the score components (6, 8-16). Four studies derived optimal thresholds from their own data, placing the index test domain at high risk (6, 9, 11, 14). Flow and timing were at high risk in three studies with post-enrolment exclusions or attrition (11, 14, 17).

Accuracy of the original HACOR score

In the derivation study, a score above 5 at 1 hour gave an AUC of 0.88, sensitivity of 72.6% and specificity of 90.2% (Table 3) (6). In COPD, the AUC was 0.90, 0.89 and 0.71 in the derivation, internal and external cohorts (8). In non-COPD hypercapnic failure, the AUC rose from 0.69 at initiation to 0.91 at 1-2 hours (9). In COVID-19, the score showed 82.0% accuracy for CPAP failure, an AUC of 0.742 under helmet CPAP and an AUC rising from 0.79 on day 1 to 0.92 on day 3 (10, 11, 14). In the emergency department, all 48 patients with a 1-hour score above 5 failed NIV, whereas sensitivity was 53.7% in cardiogenic pulmonary oedema (12, 13). AUCs were 0.71 to 0.76 in community-acquired pneumonia and 0.853 in post-tuberculosis obstructive airway disease (15, 16).

Accuracy of the updated HACOR score

In the development cohort, the updated score raised the 1-2-hour AUC from 0.80 to 0.85 in training and from 0.71 to 0.78 in external validation (7). NIV failure rose from 12.4% to 83.7% across updated-score strata from 7 or below to above 14 (7). External Brazilian and Indian cohorts confirmed higher AUCs for the updated version, at 0.78 versus 0.73 and 0.764 versus 0.649 (17, 18). Before or at NIV initiation, the original score discriminated poorly, with AUCs of 0.60 to 0.69 (7, 9, 18).

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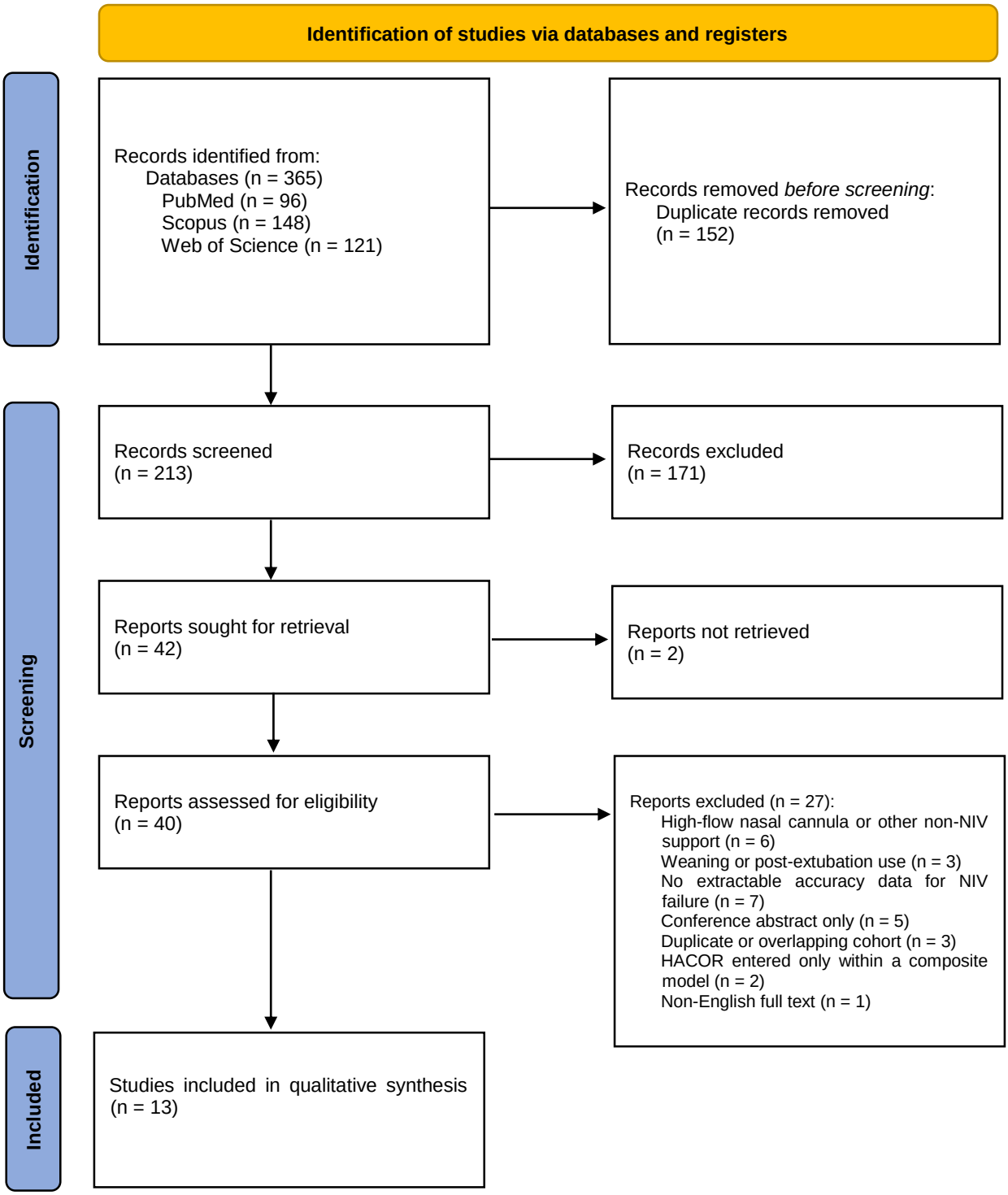


Figure 1: PRISMA flow chart

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Table 1. Risk of bias and applicability concerns (QUADAS-2)

Study	Patient selection	Index test	Reference standard	Flow and timing	Applicability: selection	Applicability: index test	Applicability: reference
Duan 2017	Low	High	High	Low	Low	Low	Low
Duan 2019	Unclear	Low	High	Low	Low	Low	Low
Ding 2021	Low	High	High	Low	Low	Low	Low
Guia 2021	Low	Unclear	High	Low	Low	Low	Unclear
Duan 2022	Low	Low	Unclear	Unclear	Low	Low	Low
Santus 2022	Low	High	High	High	Low	Low	High
Mathen 2022	Low	Low	High	Unclear	Low	Low	Low
Chong 2024	Low	Low	High	Low	Low	Low	Low
Anand 2024	High	High	High	High	Low	Unclear	Low
Watson 2024	Unclear	Low	High	Unclear	Low	Low	Unclear
Waghmare 2024	Unclear	Low	High	Low	High	Low	Low
da Silva 2025	Unclear	Low	Unclear	High	Low	Low	Low
Shekhar 2026	Low	Low	Unclear	Low	Low	Low	Low

Table 2. Characteristics of included studies

Study	Country	Setting	Population and support	n	NIV failure, n (%)	Failure definition
Duan 2017 (6)	China	ICU	Hypoxemic ARF	807	47.8% and 39.4%	Intubation
Duan 2019 (8)	China	RICU	COPD, hypercapnic ARF	1,218	94 (18.8); 61 (18.9); 35 (8.9)	Intubation or death on NIV
Ding 2021 (9)	China	RICU	Non-COPD hypercapnic ARF	148	19 (12.8)	Intubation or death on NIV
Guia 2021 (10)	Three countries	Respiratory units	COVID-19, CPAP	128	35 (27.3)	Intubation or death
Duan 2022 (7)	China, Turkey	18 ICUs	Hypoxemic ARF, CPAP or bilevel	2,179	529 (36.5); 328 (45.1)	Intubation
Santus 2022 (11)	Italy	Respiratory units	COVID-19, helmet CPAP	354	136 (38.4)	Intubation, ICU transfer or death

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Study	Country	Setting	Population and support	n	NIV failure, n (%)	Failure definition
Mathen 2022 (12)	India	ED	Mixed ARF	104	49 (47.1)	Intubation
Chong 2024 (13)	Malaysia	ED	Cardiogenic pulmonary oedema	221	54 (24.4)	Author-defined
Anand 2024 (14)	India	ICU	COVID-19	441	262 (59.4)	Invasive ventilation
Watson 2024 (15)	UK	ICU	Pneumonia	106	43 (40.6)	Invasive ventilation or ICU death
Waghmare 2024 (16)	India	Ward	Post-tuberculosis airway disease	100	38 (38.0)	Author-defined
da Silva 2025 (17)	Brazil	ED	Hypoxemic or mixed ARF	60	18 (30.0)	Invasive ventilation
Shekhar 2026 (18)	India	Tertiary hospital	Hypoxemic ARF	50	20 (40.0)	Intubation

Table 3. Diagnostic accuracy for NIV failure

Study	Score	Timing	Threshold	AUC (95% CI)	Sensitivity, %	Specificity, %
Duan 2017 (6)	HACOR	1 h	>5	0.88	72.6	90.2
Duan 2019 (8)	HACOR	1-2 h	>5	0.90 (0.87-0.92); 0.89 (0.85-0.92); 0.71 (0.67-0.76)	70.2; 77.1; 62.9	92.6; 93.5; 75.8
Ding 2021 (9)	HACOR	Start, 1-2, 12, 24 h	NR	0.69; 0.91; 0.91; 0.94	NR	NR
Guia 2021 (10)	HACOR	1 h	NR	Accuracy 82.0%	NR	NR
Duan 2022 (7)	HACOR vs updated	1-2 h	Updated 7; 10.5; 14	Training 0.80 (0.78-0.82) vs 0.85 (0.84-0.87); validation 0.71 (0.68-0.74) vs 0.78 (0.75-0.81)	NR	NR
Santus 2022 (11)	HACOR	1 h	4.5	0.742	53	87
Mathen 2022 (12)	HACOR	1 h	>5	NR	98.0*	100*
Chong 2024 (13)	HACOR	1 h	>5	0.73	53.7	83.2
Anand 2024 (14)	HACOR	Day 1 to 3	NR	0.79 to 0.92	NR	NR

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Study	Score	Timing	Threshold	AUC (95% CI)	Sensitivity, %	Specificity, %
Watson 2024 (15)	HACOR	2 h	≤5†	0.71 to 0.76	53†	85†
Waghmare 2024 (16)	HACOR	1 h	>5	0.853	89.5	87.1
da Silva 2025 (17)	HACOR vs updated	1 h	Optimal	0.73 (0.57-0.89) vs 0.78 (0.64-0.91)	92 vs 92	63 vs 55
Shekhar 2026 (18)	HACOR vs updated	1-2 h	Updated 7; 10.5; 14	0.649 (0.482-0.816) vs 0.764 (0.636-0.896)	79; 62; 25	36; 69; 92
*Calculated from reported counts. †Threshold, sensitivity and specificity refer to prediction of NIV success. NR, not reported.						

Discussion

This review identified 13 cohorts that tested the HACOR scores against NIV failure in 5,916 adults (6-18). After 1-2 hours of NIV, the original score discriminated failure with AUCs from 0.65 to 0.91, and the updated score reached 0.76 to 0.85 (6-18). The updated score outperformed the original version in each cohort that measured both, including two external cohorts (7, 17, 18). Performance was highest in the developers' derivation cohorts and fell in external samples, from 0.90 to 0.71 in COPD (6, 8).

Accuracy rose once the score was measured during treatment rather than before it (7, 9, 18). Persistent tachypnoea and hypoxaemia under NIV reflect high inspiratory drive, which favours patient self-inflicted lung injury (19). An expired tidal volume above 9.5 mL/kg of predicted body weight predicted NIV failure in de novo hypoxemic respiratory failure (20). A reduction in oesophageal pressure swings of at least 10 cmH2O after 2 hours of NIV predicted success with an AUC of 0.97 (21). HACOR captures the clinical expression of these mechanisms without invasive monitoring (6).

Diagnostic performance varied with case mix (8, 13, 16). In an external COPD cohort with an 8.9% failure rate, a score above 5 gave an NPV of 95.5% and a PPV of 20.2%, so a low score was more informative than a high one (8). In cardiogenic pulmonary oedema, sensitivity fell to 53.7%, and neither heart rate nor respiratory rate predicted failure (13). The ROX index, built from oxygen saturation, inspired oxygen fraction and respiratory rate, was designed for high-flow nasal cannula (22). On high-flow therapy, HACOR reached an AUC of 0.733 at 1 hour in emergency patients, below the ROX index, and 0.71 in COVID-19 pneumonia (23, 24). In hospitalised COVID-19 patients, a 1-hour HACOR above 5 predicted failure of noninvasive respiratory support with a hazard ratio of 2.6 (25).

The updated score adds diagnostic categories and the SOFA score, raising discrimination at the cost of extra laboratory data (7, 17). Score choice also depends on the target outcome, since the NIVO score predicts in-hospital mortality rather than NIV failure in COPD exacerbations (26). A machine learning tool recently outperformed the updated HACOR score, with AUCs of 0.793 versus 0.717 in internal cross-validation (27). Lung and diaphragm ultrasound add information on aeration and respiratory muscle function that HACOR does not capture (28).

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Several limitations apply to this evidence base (6-18). In ten studies, clinicians who decided on intubation had access to the variables that form the score, which introduces incorporation bias and tends to inflate accuracy (6, 8-16). Thresholds ranged from 4.5 to above 5 for the original score and from 7 to 14 for the updated score, which prevented bivariate pooling (7, 11, 12, 18). Eight of the 13 cohorts came from China or India (6-9, 12, 14, 16, 18). Five cohorts enrolled 110 patients or fewer (12, 15-18). Outcome definitions also differed, as some studies counted death during NIV or intensive care transfer as failure (8-11, 15).

Conclusion

The original HACOR score showed acceptable to excellent discrimination for NIV failure once measured after 1-2 hours of treatment, with high specificity and variable sensitivity at the conventional threshold above 5. The updated HACOR score, which adds baseline diagnoses and organ failure, discriminated better in every cohort that compared both versions. The original score measured at NIV initiation performed poorly. The evidence is limited by incorporation bias, heterogeneous thresholds and a predominance of single-centre Asian cohorts. Clinicians are advised to use either score as a structured reassessment aid after the first hours of NIV rather than as a stand-alone trigger for intubation.

List of Abbreviations

ARDS: acute respiratory distress syndrome; ARF: acute respiratory failure; AUC: area under the receiver operating characteristic curve; CI: confidence interval; COPD: chronic obstructive pulmonary disease; COVID-19: coronavirus disease 2019; CPAP: continuous positive airway pressure; ED: emergency department; HACOR: heart rate, acidosis, consciousness, oxygenation and respiratory rate; ICU: intensive care unit; NIV: noninvasive ventilation; NIVO: Noninvasive Ventilation Outcomes; NPV: negative predictive value; PPV: positive predictive value; PRISMA: Preferred Reporting Items for Systematic Reviews and Meta-Analyses; PRISMA-DTA: PRISMA extension for diagnostic test accuracy; QUADAS-2: Quality Assessment of Diagnostic Accuracy Studies 2; RICU: respiratory intensive care unit; ROX: respiratory rate-oxygenation index; SOFA: Sequential Organ Failure Assessment.

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