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REVIEW

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Severity assessment tools to guide ICU admission in community-acquired pneumonia: systematic review and meta-analysis

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Abstract *Background:* The aim of this meta-analysis was to determine if severity assessment tools can be used to guide decisions regarding intensive care unit (ICU) admission of patients with community-acquired pneumonia. *Methods:* A search of PUBMED and EMBASE (1980–2009) was conducted to identify studies reporting pneumonia severity scores and prediction of ICU admission. Two reviewers independently collected data and assessed study quality. Performance characteristics were pooled using a random-effects model.
Results: Sufficient data were collected to perform a meta-analysis on five current scoring systems: the Pneumonia Severity Index (PSI), the CURB65 score, the CRB65 score, the American Thoracic Society (ATS) 2001 criteria and the Infectious Disease Society of America/ATS (IDSA/ATS) 2007 criteria. The analysis was limited due to large variations in the ICU admission criteria, ICU admission rates and patient characteristics between different studies and different healthcare systems. In the pooled analysis, PSI, CURB65 and CRB65 performed similarly in terms of sensitivity and specificity across a range of cut-offs. Patients in CURB65 group 0 were at lowest risk of ICU admission (negative likelihood ratio 0.14; 95% confidence interval 0.06–0.34) while the ATS 2001 criteria had the highest positive likelihood ratio (7.05; 95% confidence interval 4.39–11.3). *Conclusion:* Large variations exist in the use of ICU resources between different studies and different healthcare systems. Scoring systems designed to predict 30-day mortality perform less well when ICU admission is taken into account. Further studies of dedicated ICU admission scores are required.

Keywords Intensive care unit · Meta-analysis · Pneumonia · Severity assessment

Abbreviations

ATS	American Thoracic Society
CAP	Community-acquired pneumonia
COPD	Chronic obstructive pulmonary disease
CRB65	Confusion, respiratory rate, blood pressure, age ≥65 years
CURB65	Confusion, urea, respiratory rate, blood pressure and age ≥65 years
DOR	Diagnostic odds ratio
ICU	Intensive care unit
IDSA/ATS	Infectious Disease Society of America/American Thoracic Society

NLR	Negative likelihood ratio	PaO_2FiO_2	Partial pressure of oxygen divided by the fraction of inspired oxygen	PSI	Pneumonia Severity Index
		PLR	Positive likelihood ratio		

Introduction

Severity assessment tools are a key component of national strategies to improve the management of community-acquired pneumonia (CAP) [1–3]. They have been promoted to determine the suitability for hospital admission, guide antibiotic prescribing and identify patients requiring admission to an intensive care unit (ICU) [1–3].

Recent studies have identified delayed admission to the ICU for patients with severe CAP as a risk factor for short-term mortality [4]. An objective scoring system that could accurately identify patients requiring ICU admission and therefore allow earlier intensive management of severely ill patients is potentially desirable. The Infectious Disease Society of America/American Thoracic Society (IDSA/ATS) in their 2001 [5] and 2007 guidelines recommended major and minor criteria that are designed to identify patients requiring ICU management [1]. The major criteria recommend ICU management for patients requiring mechanical ventilation and/or vasopressor support and are universally accepted as indications for ICU care. The minor criteria consist of a number of physiological variables known to be associated with poor outcome (Table 1). The value of these criteria have not been firmly established.

The British Thoracic Society guidelines recommend the CURB65/CRB65 (confusion, urea, respiratory rate, blood pressure and age $\geq$65 years/confusion, respiratory rate, blood pressure, age $\geq$65 years) scores for admission severity assessment [6] while other international guidelines recommend the use of the Pneumonia Severity Index (PSI) [7]. These scores are the most extensively validated in the literature and are widely used in research. Each of these severity scores was originally designed to predict 30-day mortality, but they have also been recommended to identify patients for consideration of ICU care [2, 8]. The value of these scores for ICU admission is still being debated, with some studies suggesting moderate–good accuracy for predicting ICU [9, 10] and others suggesting poor predictive accuracy [11–13]. Additional scoring systems have recently been developed aimed at improving the guidance of ICU admission for CAP patients [14, 15]. The role of scoring systems to guide ICU admission is therefore unknown [16].

The aim of this systematic review and meta-analysis was to determine the accuracy of current CAP severity scores for predicting the requirement for ICU admission in patients hospitalised with CAP.

Methods

This study was a systematic review and meta-analysis conducted according to meta-analysis of observational studies in epidemiology (MOOSE) guidelines [17].

Search criteria

A search of PUBMED for articles published between 1980 and October 2010 was conducted using the following search strategy:

> ("ICU" or "ITU" or "intensive care" or "mechanical ventilation" or "vasopressor" or "severe" or "predict*") and ("pneumonia" or "community-acquired pneumonia" or "CAP").

Full articles of all potentially appropriate abstracts were retrieved and reviewed by investigators. The search strategy was subsequently repeated in EMBASE to identify any references not identified in the original search. Only peer-reviewed data were included; therefore, conference abstracts were excluded. The search strategy was supplemented by a review of reference lists, bibliographies and the investigators' files.

Study inclusion and study quality assessment

All studies were considered eligible if they fulfilled the following criteria: original publications; inclusion of patients with CAP; radiographic confirmation of CAP and exclusion of non-CAP diagnoses, such as non-pneumonic exacerbation of chronic obstructive pulmonary disease (COPD); calculation of severity score based on admission data. We only evaluated studies of patients presenting to hospital with CAP; therefore, studies involving only outpatients were excluded.

In the case of duplicate publication, only the first study reporting the appropriate data, or the largest study if applicable was included. Where overlap was uncertain, the authors were contacted to clarify this. We included both prospective and retrospective studies where these contained valid data.

There are no widely accepted quality criteria for observational studies. In order to assess quality, we used a modified criteria based on the criteria of Hayden et al. [18].

Table 1 Severity criteria recommended to predict intensive care unit admission or 30-day mortality in patients with community-acquired pneumonia

IDSA/ATS 2007 criteria	Pneumonia Severity Index[a]
Major criteria (any one of)	Age (1 point/year, −10 if female)
Invasive mechanical ventilation	Nursing home resident (10 points)
Septic shock with the need for vasopressors	Neoplastic disease (30 points)
Minor criteria (3 or more)	Liver disease (20 points)
Respiratory rate ≥30 breaths/min	Congestive heart failure (10 points)
PaO_2FiO_2 ≤250	Cerebrovascular disease (10 points)
Multilobar infiltrates	Renal disease (10 points)
Confusion/disorientation	Altered mental status (20 points)
Uremia (BUN level ≥20 mg/dL)	Pulse ≥125/min (10 points)
Leukopenia (WBC count <4,000 cells/mm^3)	Respiratory rate >30/min (20 points)
Thrombocytopenia (<100,000 cells/mm^3)	Systolic blood pressure <90 mmHg (20 points)
Hypothermia (temperature <36°C)	Temperature <35 or ≥40°C (15 points)
Hypotension requiring aggressive fluid resuscitation	Arterial pH <7.35 (30 points)
	Urea ≥30 mg/dl (20 points)
	Sodium <130 mmol/L (20 points)
	Glucose ≥250 mg/dl (10 points)
	Haemtocrit <30% (10 points)
	PaO_2 <60 mmHg (10 points)
	Pleural effusion (10 points)
ATS criteria 2001	CURB65/CRB65
Major criteria (any one of)	Confusion
Invasive mechanical ventilation	Urea >7 mmol/L (excluded in CRB65)
Septic shock with the need for vasopressors	Respiratory rate ≥30/min
Minor criteria (≥2)	Systolic BP <90 mmHg or diastolic BP ≤60 mmHg
Systolic blood pressure <90 mmHg	Age ≥65 years
Multilobar chest X-ray changes	Note: ≥3 of these criteria is regarded as "severe"
PaO_2FiO_2 ≤250	

IDSA The Infectious Disease Society of America; *ATS* American Thoracic Society; *PSI* Pneumonia Severity Index; *CURB65/CRB65* confusion, urea, respiratory rate, blood pressure and age ≥65 years/ confusion, respiratory rate, blood pressure, age ≥65 years; *BUN* blood urea nitrogen; *PaO_2FiO_2* partial pressure of oxygen divided by the fraction of inspired oxygen; *BP* blood pressure

[a] PSI points are added together to give an overall score: age <50 years with no major severity features or co-morbidities = class I (low risk); <70 points = class II (low risk); 71–90 points = class III (intermediate risk); 91–130 points = class IV (high risk); >130 points = class V (highest risk)

Data extraction

Investigators independently assessed articles to determine study eligibility. Non-relevant studies were excluded based on title and abstract review only. Potentially relevant studies were reviewed by two researchers who carried out data extraction and quality assessment. The same two investigators selected the studies and assessed the quality of the study and extracted data for subsequent analyses. Researchers were blinded, meaning that they were unaware of the second reviewer's assessment. All reviewers were researchers in the field of CAP and were experienced in performing clinical CAP studies. Any disagreement between abstractors was resolved independently by a third abstractor who was also blinded to the previous reviewers' assessments. Where appropriate, the authors were contacted to clarify inconsistencies or to obtain missing data.

Severity scores

Details of the severity scores studied in this meta-analysis are shown in Table 1, and further details can be found in the online supplementary material (ESM). Pooled performance characteristics are presented for the "high-risk" groups for each severity score as these are the groups that would be recommended for ICU admission in clinical practice.

Outcomes

The primary outcome was the frequency of ICU admission (during hospitalisation for CAP or within 30 days of diagnosis) in patients meeting severity score criteria. Surrogates of ICU admission, such as the receipt of mechanical ventilation or vasopressor support, were also collected.

Statistical analysis

The frequency of ICU admission for each score was calculated, and these odds ratios (OR) were weighted by the inverse of their variance and pooled across all studies using a Dersimonian/Laird random-effects model. Random-effects models were used to pool all performance characteristics due to expected heterogeneity between studies. For each severity score, pooled sensitivity, specificity, positive and negative likelihood ratios (PLR, NLR) and diagnostic OR were calculated as previously described [19]. It has been suggested that a PLR >10 or a NLR <0.1 provides strong evidence to rule in/rule out diagnoses, respectively, in most circumstances [20]. To display sensitivity and specificity data across a range of cut-offs for each score, we report the area under the receiver operator characteristic curve. Statistical heterogeneity was assessed using Higgins' I^2 test and Cochran's Q test. For interpretation of these values $I^2 < 25\%$ indicates low heterogeneity, 25–50% moderate heterogeneity and >50% severe heterogeneity. A Cochrans Q test p value <0.1 was chosen as indicative of significant heterogeneity.

Analyses were conducted using Meta-DiSc software (Barcelona, Spain) and Graphpad Prism ver. 5 (Graphpad software, San Diego, CA, USA).

Results

A total of 7,976 abstracts were reviewed and 212 papers were potentially eligible and reviewed in depth. The majority of studies reviewed in depth were not included because they did not report data for any of the severity scores under investigation or did not consider ICU admission as an outcome. The literature review process is summarised in Fig. 1.

A further 52 studies were excluded because they did not meet the inclusion criteria even though they did report data on one of the severity scores considered for inclusion. A total of 28 studies were ultimately included in the meta-analysis [9–11, 13, 14, 21–43]. Two papers reported results from two separate cohorts in a single manuscript, and these cohorts were considered as separate studies for the purposes of the meta-analysis [13, 35].

Characteristics of each of the reviewed studies are shown in Table E1 of the ESM. Seventeen studies were described as prospective cohort studies [10–14, 21, 22, 24, 25, 28–30, 33–36, 40, 41], 10 studies were described as retrospective [9, 23, 26, 27, 31, 37–39, 42, 43] and one was described as a population-based cohort study [32]. Sample size varied from 114 patients [23] to 3,675 patients [32]. The majority of studies provided data on ICU admission as an outcome, while other studies used surrogate outcomes of ICU, such as requirement for mechanical ventilation and/or inotropic support [10] or the requirement for intensive respiratory or vasopressor support [14].

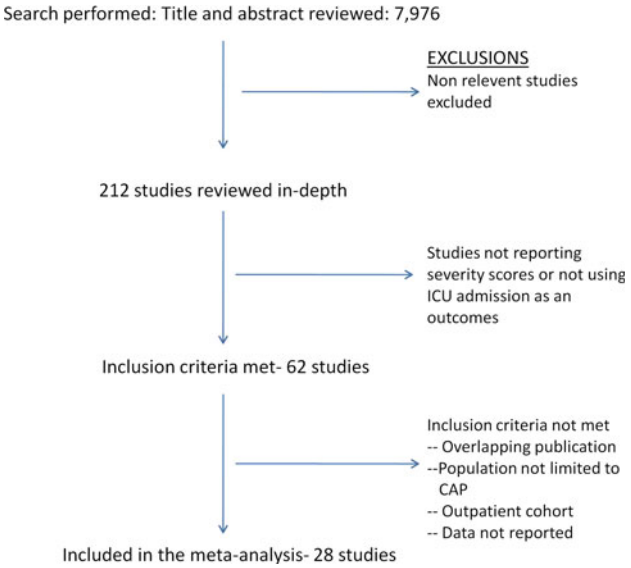

Fig. 1 The literature review process and study selection. *ICU* Intensive care unit, *CAP* community-acquired pneumonia

Severity scores included

Sufficient studies to conduct a meta-analysis were only available for the PSI, the CURB65 score, CRB65, the 2001 ATS severity prediction rule and the 2007 IDSA/ATS criteria for ICU admission.

Meta-analysis

Pooled performance characteristics for each of the cut-offs for each severity score included in the meta-analysis are shown in Table 2. Each score is discussed individually below.

Pneumonia Severity Index

Twenty-six papers reported data on PSI and the prediction of ICU admission, reporting cohorts comprising 25,609 patients with 2,410 ICU admissions, giving a cumulative ICU admission rate of 9.4% [9–11, 13, 14, 22–42].

Using a PSI ≥ IV to determine ICU admission, the pooled sensitivity was 74.1% [95% confidence interval (CI) 72.3–75.8%], pooled specificity 47.9% (47.3–48.6%) with a PLR of 1.48 (1.38–1.59) and NLR of 0.53 (0.47–0.60). The diagnostic odds ratio (DOR) was 2.83 (2.34–3.42). The forest plots of sensitivity and specificity using this cut-off are shown in Fig. 2.

Table 2 Pooled performance characteristics for each score for prediction of ICU admission in community-acquired pneumonia

Scoring systems/ severity assessment tools	Sensitivity	Specificity	PLR	NLR	DOR
PSI					
≥I	95.7% (94.6–96.7%)	9.8% (9.3–10.3%)	1.08 (1.03–1.12)	0.47 (0.31–0.73)	2.32 (1.45–3.71)
≥III	87.7% (86.0–89.3%)	25.3% (24.6–26.0%)	1.19 (1.12–1.25)	0.48 (0.38–0.61)	2.53 (1.90–3.37)
≥IV	74.1% (72.3–75.8%)	47.9% (47.3–48.6%)	1.48 (1.38–1.59)	0.53 (0.47–0.60)	2.83 (2.34–3.42)
=V	34.4% (32.2−36.6%)	84.2% (83.7–84.7%)	2.38 (2.04–2.77)	0.79 (0.75–0.83)	3.09 (2.55–3.75)
CURB65					
≥1	98.2% (95.4−99.5%)	15.5% (14.2–16.9%)	1.20 (1.09–1.32)	0.14 (0.06–0.34)	8.33 (3.41–20.4)
≥2	85.0% (80.1−89.1%)	44.0% (42.4–45.7%)	1.58 (1.32–1.90)	0.37 (0.24–0.56)	4.35 (2.40–7.87)
≥3	50.0% (45.5−54.5%)	72.1% (71.0–73.2%)	1.70 (1.36–2.11)	0.72 (0.60–0.86)	2.40 (1.63–3.53)
≥4	28.9% (22.5−35.9%)	89.9% (88.6–91.0%)	2.09 (1.12–3.90)	0.86 (0.68–1.09)	2.42 (1.04–5.64)
=5	7.4% (4.0−12.3%)	99.0% (98.5–99.3%)	6.95 (3.49–13.9)	0.95 (0.88–1.02)	7.48 (3.60–15.5)
CRB65[a]					
≥1	94.7% (89.9−97.7%)	17.7% (16.1–19.4%)	1.13 (0.89–1.42)	0.36 (0.04–3.44)	3.18 (0.29–35.1)
≥2	61.2% (51.1−70.6%)	60.3 (58.4–62.2%)	1.62 (1.03–2.54)	0.64 (0.39–1.05)	2.78 (0.99–7.77)
=3	41.7 (35.8−47.8%)	85.1% (83.8−86.4%)	3.0 (1.44–6.25)	0.69 (0.57–0.84)	5.72 (3.79–8.63)
2001 ATS criteria[b]					
≥Criteria met	66.7% (63.3−70.0%)	84.6% (83.5−85.7%)	7.05 (4.39–11.3)	0.34 (0.26–0.44)	25.8 (13.4–49.9)
2007 ATS criteria					
≥Major or minor criteria met	61.2% (58.0−64.3)	88.6 (87.7−89.4%)	6.2 (3.3–11.7)	0.43 (0.35–0.53)	15.2 (10.3–22.2)
≥Minor criteria only	55.7% (51.5−59.9%)	91.7 (90.9−92.5%)	6.22 (4.09–9.46)	0.51 (0.38–0.67)	12.4 (6.38–24.0)

ICU Intensive care unit, *DOR* diagnostic odds ratio, *NLR* negative likelihood ratio, *PLR* positive likelihood ratio

Data presented in parenthesis are the 95% confidence interval (CI)

[a] Insufficient data were available for CRB65 = 4 alone

[b] Insufficient data were available to perform analysis for the 2001 ATS minor criteria

Using PSI class V to determine ICU admission, pooled sensitivity was 34% (32–37%), pooled specificity was 84% (83–85%). The PLR was 2.38 (2.04–2.77) and the NLR was 0.79 (0.75–0.83). The diagnostic odds ratio was 3.09 (2.55–3.75). There was significant heterogeneity in all of these analyses ($I^2 > 50\%$). Data for additional cut-offs are shown in Table 2.

CURB65

Eleven papers reported data for CURB65 and the prediction of ICU admission. These studies reported data on 11,602 patients with an event rate of 9.9% overall [9–11, 13, 14, 29, 30, 33, 39, 41, 43]. One study reported mechanical ventilation and/or inotropic support as a surrogate of ICU admission [10]. One study reported the requirement for intensive respiratory and vasopressor support (an outcome that included non-invasive ventilation) as a surrogate of ICU admission [14].

Using CURB65 ≥ 3 to determine ICU admission, the pooled sensitivity was 48.8% (45.9–51.7%) and the pooled specificity was 74.0% (73.2–74.9%). The PLR was 1.70 (1.36–2.11) and the NLR was 0.72 (0.60–0.86). The DOR was 2.85 (2.17–3.74). The forest plots for sensitivity and specificity using this cut-off are shown in Fig. 2.

Using CURB65 ≥ 4 to determine ICU admission, the pooled sensitivity was 28.9 (22.5–35.9%) and pooled specificity was 89.9 (88.6–91.0%). The PLR was 2.09 (1.12–3.90) and the NLR was 0.86 (0.68–1.09). The DOR was 2.42 (1.04–5.64). There was significant heterogeneity in all analyses ($I^2 > 50\%$).

CRB65

Four studies reported data for CRB65 and ICU admission [10, 11, 33, 41]. Data were only available for 3,096 patients with 271 events, giving a cumulative ICU admission rate of 8.8%.

Using a score of ≥3 to determine ICU admission, the pooled sensitivity was 41.7% (35.8–47.8%) and pooled specificity was 85.1% (83.8–86.4%). The PLR was 3.0 (1.44–6.25) and the NLR was 0.69 (0.57–0.84). The DOR was 5.72 (3.79–8.63). Forest plots for sensitivity and specificity are shown in the ESM. There was significant heterogeneity in the analyses for sensitivity and specificity ($I^2 > 80\%$); however, the DOR showed no significant heterogeneity ($I^2 > 39\%$).

Data for additional cut-offs are shown in Table 2.

2001 ATS criteria for severe CAP

Nine studies reported data on the 2001 ATS criteria [11, 12, 21, 27, 28, 30, 37, 41, 42]. These studies contained 4,833 patients with an ICU admission rate of 16.4%.

The pooled sensitivity was 66.7% (63.3–70.0%) and pooled specificity was 84.6% (83.5–85.7%). The PLR was 7.05 (4.39–11.3) and the NLR was 0.34 (0.26–0.44). The

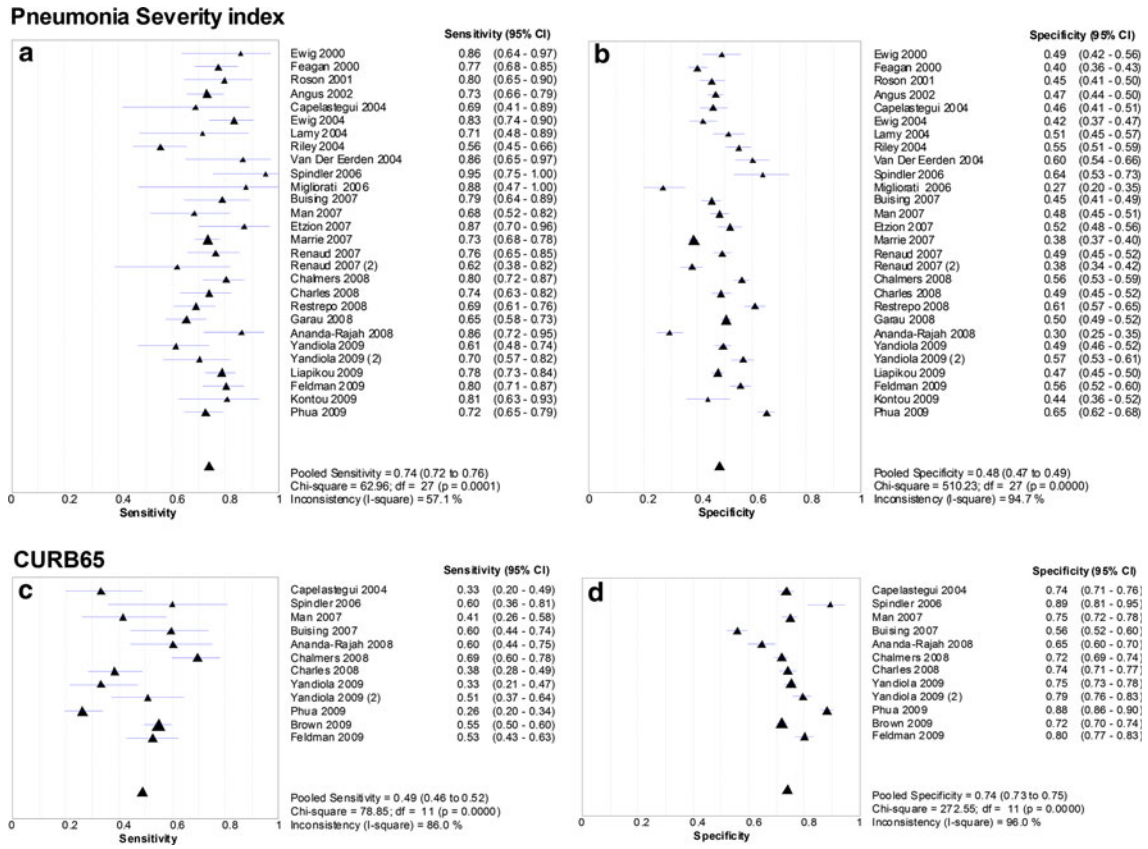

Fig. 2 Pooled sensitivity and specificity forest plots for the Pneumonia Severity Index (PSI; using PSI ≥IV as the selected cut-point) and the CURB65 score (confusion, urea, respiratory rate, blood pressure and age ≥65 years; using CURB65 ≥3 as the selected high-risk cut-off point). **a** Sensitivity for PSI, **b** specificity for PSI, **c** sensitivity for CURB65, **d** specificity for CURB65

DOR was 25.8 (13.4–49.9). Significant heterogeneity was observed in all analyses ($I^2 > 90\%$). There was insufficient data to perform a meaningful analysis of the 2001 ATS minor criteria alone. Forest plots for sensitivity and specificity are shown in Fig. 3.

2007 IDSA/ATS criteria

Five studies reported validation data for the IDSA/ATS criteria 2007. One study examined the minor criteria only, two studies examined pneumococcal pneumonia only while the other studies were of unselected CAP populations.

The validation studies involved 6,488 patients with an ICU admission rate of 14.5%. The pooled sensitivity was 61.2% (58–64.3%), pooled specificity was 88.6% (87.7–89.4%), pooled PLR was 6.2 (3.3–11.7) and pooled NLR was 0.43 (0.35–0.53). The DOR was 15.2 (10.3–22.2). Forest plots for sensitivity and specificity are shown in Fig. 3. There was significant heterogeneity in all analyses ($I^2 > 90\%$).

There were only three studies (8, 39, 42 patients, respectively) reporting data using the minor criteria only. These showed performance criteria for the suggested cut-off of ≥3 minor criteria as follows: pooled sensitivity 55.7% (51.5–59.9%), pooled specificity 91.7% (90.9–92.5%), pooled PLR 6.22 (4.09–9.46) and NLR 0.51 (0.38–0.67), with a DOR of 12.4 (6.38–24.0).

Comparisons between the scoring systems

None of the scoring systems demonstrated a PLR >10 or a NLR <0.1 using any of the recognised cut-offs. Based on the performance characteristics described in Table 2, patients in CURB65 group 0 were at lowest risk of ICU admission (NLR 0.14, 95% CI 0.06–0.34), while the ATS 2001 criteria had the highest PLR (7.05, 95% CI 4.39–11.3).

The data in Table 2 demonstrate that for equivalent "high-risk" cut-offs, there was very little variability in specificity with the ATS 2001 and 2007 criteria showing superior sensitivity using the high-risk definition.

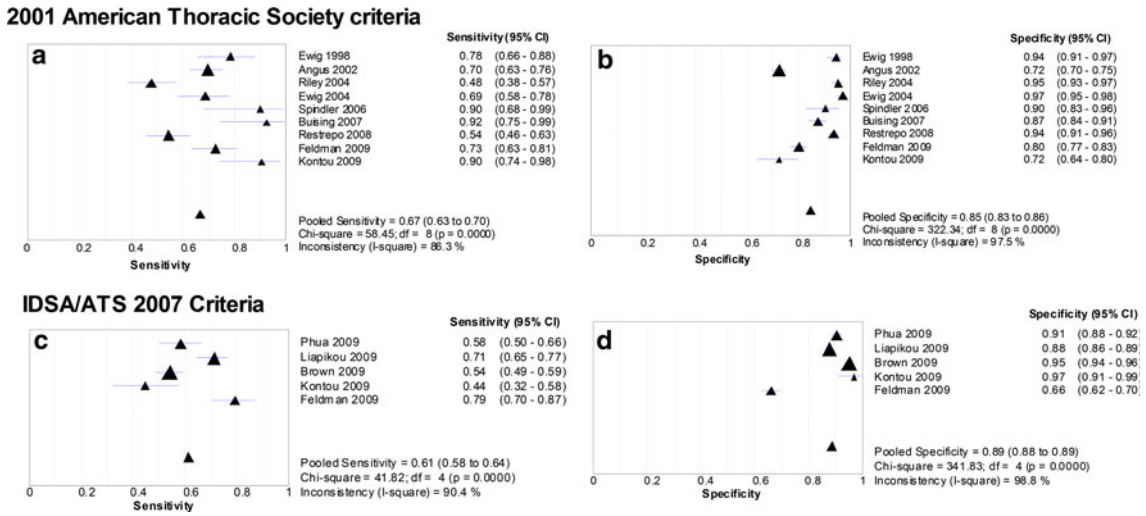

Fig. 3 Pooled sensitivity and specificity for the 2001 American Thoracic Society (ATS) and 2007 Infectious Disease Society of America/ATS (*IDSA/ATS*) criteria. **a** Sensitivity for 2001 ATS criteria, **b** specificity for 2001 ATS criteria, **c** sensitivity for 2007 IDSA/ATS criteria, **d** specificity for 2007 IDSA/ATS criteria

Other severity scores

Four other scoring systems to identify patients requiring ICU admission were identified, but there were insufficient data to perform a useful meta-analysis: the SMART-COP score [14], the SCAP score [15] proposed by Espana et al., CORB proposed by Buising et al. [44] and REA-ICU proposed by Renaud et al. [45] For SMART-COP, the derivation study also contained validation data, but without sufficient information to perform the meta-analysis. This study suggested an area under the receiver operator characteristics (ROC) curve of 0.72–0.87. One study suggested a superior sensitivity for predicting ICU admission in young patients [46]. One further validation study found an area under the curve of 0.83 [43].

Data were available from the derivation study of Espana et al. [13] and from a further validation study by the same authors; these suggested an area under the curve (AUC) for predicting ICU admission of 0.72–0.86. A single independent validation study showed an AUC of 0.83 [43].

CORB and REA-ICU scores have only been examined in a single study and require further validation.

Assessment of source studies and sources of heterogeneity

Intensive care unit admission rates varied substantially between studies, from 2.5 to 19.9% (see the table of included studies in ESM). The mean age of the included patients varied from 59.1 to 78 years. The proportion of patients in PSI class V varied from 8.5 to 31.9%. The use of ICU resources varied markedly in different studies. In some studies, ICU admission was used almost exclusively for patients requiring mechanical ventilation (88.4% of ICU admitted patients in the study by Buising et al. [44] required mechanical ventilation, while 100% of ICU patients in the study by Marrie et al. [32] required either mechanical ventilation or vasopressor support) while in other studies, a minority of ICU admissions received mechanical ventilation (for example, 16.7% in the study of Ewig et al. [22], 40% in the study of Capelastegui et al. [29]). All studies were observational and, therefore, none stated clear criteria for ICU admission locally with the exception of Riley et al. [27] and Brown et al. [43]. Details of the inclusion, exclusion criteria and study characteristics are described in detail in the ESM.

Study quality was assessed as good in 14 studies, moderate in nine studies and poor in six studies.

ICU admissions tools such as the minor criteria or alternatives such as SMART-COP are only likely to be clinically useful in patients not immediately requiring mechanical ventilation or vasopressor support and in patients who are suitable for potential ICU admission; they therefore exclude patients with advanced directives or “do not attempt resuscitation” orders. Only a small number of studies took this into account. Phua et al. [9] and Renaud et al. [45] excluded both patients meeting the major criteria and patients with orders to withhold life-sustained treatment. Liapikou and Brown et al. presented data on the minor criteria in patients not meeting the IDSA/ATS major criteria [40, 43]. The majority of other studies, however, did not exclude these groups of patients and, therefore, the derived performance characteristics may not accurately reflect the population of greatest interest.

Subanalyses

When limited to prospective studies only, PSI and CURB65 showed similar performance to the main analysis. Similarly, limiting the analysis to high-quality studies only did not significantly affect the main conclusions. These results are displayed in the ESM. Among the high-quality studies, there was greater homogeneity regarding inclusion and exclusion criteria in addition to patient demographics and follow-up methodology. Consequently, the results showed less heterogeneity ($I^2 = 38.9\%$, Cochrans Q $p = 0.1$ for the PSI DOR; $I^2 = 20.2\%$, Cochrans Q $p = 0.3$ for CURB65 DOR). For the IDSA/ATS minor criteria, removing the two studies (Kontou et al. [42] and Feldman et al. [41]) involving *Staphylococcus pneumoniae* patients only reduced but did not completely abolish the heterogeneity ($I^2 = 50.7\%$, Cochrans Q $p = 0.1$ for the DOR). Analyses for CRB65 and the ATS 2001 criteria were limited due to the small number of studies and a limited number of high-quality studies, respectively.

Prediction of mortality

Ideally, a severity score would be able to predict both ICU admission and 30-day mortality. The majority of studies included in this meta-analysis investigated the performance of scores for 30-day mortality and reported ICU admission as a secondary outcome.

Table 3 shows the comparison in the AUC between 30-day mortality and ICU admission in the included studies. Mortality data were not reported in some studies, while others did not provide sufficient data to determine the area under the ROC curve [12, 21, 27, 30, 40–43].

In the majority of studies of PSI, CURB65 and CRB65, the data indicated a lesser performance of the severity scores for predicting ICU admission compared to 30-day mortality (Table 3).

Discussion

National and International guidelines have recommended the use of severity scores, such as PSI and CURB65, to guide a large number of management decisions in CAP, including the selection of patients for admission to the ICU [1, 2, 8]. The 2001 ATS guidelines [5] and the 2007 IDSA/ATS guidelines [1] recommended alternative criteria originally proposed by Ewig [21]. A number of recent studies have attempted to derive new criteria to guide ICU admission in patients with CAP [14, 15, 44, 45].

This study demonstrates inherent difficulties in attempting to use severity scores to predict ICU admission. ICU admission criteria and the characteristics of patients vary significantly between different centres and different healthcare systems. This was reflected in the significant heterogeneity in our analysis even among

Table 3 Comparison between the performance of severity scores for the requirement for ICU admission and mortality prediction using the area under the receiver operator characteristic curve

Study	Mortality	ICU admission	Study	Mortality	ICU admission
CURB65			PSI		
Capelastegui et al. [29]	0.87 (0.84–0.90)	0.60 (0.55–0.64)	Ewig et al. [22]	0.82 (0.75–0.89)	0.72 (0.65–0.78)
Man et al. [33]	0.73 (0.69–0.79)	0.62 (0.55–0.67)	Feagan et al. [23]	0.70 (0.67–0.73)	0.59 (0.56–0.62)
Buising et al. [44]	0.82 (0.76–0.88)	0.66 (0.56–0.76)	Rosón et al. [24]	0.78 (0.75–0.82)	0.71 (0.66–0.75)
Chalmers et al. [10]	0.76 (0.74–0.79)	0.78 (0.75–0.81)	Van der Eerden et al. [25]	0.79 (0.73–0.84)	0.79 (0.73–0.84)
Charles [48]	0.74 (0.70–0.78)	0.62 (0.56–0.67)	Lamy et al. [26]	0.70 (0.59–0.82)	0.56 (0.49–0.63)
Phua et al. [9]	0.82 (0.78–0.85)	0.68 (0.63–0.72)	Ewig et al. [28]	0.71 (0.66–0.76)	0.66 (0.63–0.70)
CRB65			Migliorati et al. [31]	0.80 (0.74–0.87)	0.76 (0.66–0.86)
Man et al. [33]	0.69 (0.63–0.75)	0.57 (0.52–0.61)	Marrie et al. [32]	0.77 (0.75–0.78)	0.59 (0.58–0.61)
Chalmers et al. [10]	0.74 (0.71–0.77)	0.77 (0.74–0.79)	Man et al. [33]	0.74 (0.69–0.79)	0.60 (0.55–0.65)
ATS 2001[a]			Buising et al. [44]	0.82 (0.76–0.87)	0.69 (0.59–0.77)
Ewig et al. [28]	94/93%	69/98%	Renaud et al. [34]	0.85 (0.81–0.88)	0.62 (0.59–0.64)
Spindler and Ortqvist [30]	85/84%	90/85%	Renaud et al. [35]	0.89 (0.85–0.93)	0.58 (0.51–0.64)
Buising et al. [44]	40.5/84.6%	92/87.3%	Etzion et al. [36]	0.79 (0.74–0.84)	0.85 (0.78–0.91)
Kontou et al. [42]	65/71%	90/80%	Restrepo et al. [37]	0.72 (0.68–0.76)	0.70 (0.67–0.73)
IDSA/ATS 2007[b]			Garau et al. [38]	0.77 (0.76–0.79)	0.62 (0.59–0.64)
Phua et al. [9]	81.4/82.9%	58.3/90.6%	Ananda-Rajah et al. [39]	0.72 (0.68–0.76)	0.58 (0.53–0.63)
Kontou et al. [42]	45/75%	77/84%	Charles [48]	0.79 (0.75–0.83)	0.69 (0.63–0.74)
			Phua et al. [9]	0.86 (0.83–0.88)	0.75 (0.71–0.79)
			Kontou et al. [42]	0.77 (0.70–0.83)	0.70 (0.64–0.76)

Area under the receiver operator characteristic curve data are not displayed for the ATS 2001 or IDSA/ATS 2007 criteria since these scores rely (in most reported cases) on a single cut-off point; therefore, sensitivity (%)/specificity (%) for this cut-off are reported

[a] Sensitivity (%)/specificity (%)

[b] Feldman et al. [41] did not display error data. Those studies not reporting an area under the curve for 30-day or in-hospital mortality were not included in the table (see text)

studies that were similar in design. While accepting these limitations, based on the ROC curve values shown in Table 3 and the pooled analysis in Table 2, the two most widely used pneumonia severity scores, the PSI and CURB65, demonstrated lower sensitivity and specificity in predicting requirement for ICU admission compared to their prediction of mortality in hospitalised patients with CAP [19]. It would be expected that scores originally derived to predict 30-day mortality would perform less well than dedicated scores for ICU admission. The available data therefore broadly support the IDSA/ATS guideline recommendations to use alternative criteria for guiding ICU admission in patients with CAP [1]. The 2007 IDSA/ATS and the 2001 ATS criteria had a relatively higher sensitivity than equivalent cut-offs of the CURB65, PSI or CRB65 scores. It should be noted that strong objections have been raised to these criteria [47, 48]. The major criteria (either requirement for mechanical ventilation or septic shock) are universally accepted as indicative of the need for ICU admission and are in fact used in some studies as an outcome. The score is therefore not truly "predictive" as a physician must recognise the fact that a patient requires ventilation or vasopressors before the "score" is satisfied [47, 48]. The minor criteria, therefore, have the potential to be more useful in identifying a group of patients at high risk of complications but without an immediately obvious indication for ICU admission. This meta-analysis identified only three studies in which data were presented for the minor criteria [9, 40, 43].

Importantly, none of the scoring systems achieved the NLR of <0.1 and the PLR of >10, which are regarded as strong evidence to reliably exclude or indicate the need for ICU admission [20].

Another important limitation of these scores is the relatively low sensitivity for all of the high risk cut-offs. This means that depending on which score and cut-point is used, 30–70% of patients requiring ICU admission may be "missed". Using lower cut-offs to achieve higher sensitivity may be impractical. For example, hospitalising all patients with a CURB65 score ≥1 or PSI ≥II in the ICU (the only score cut-offs with a sensitivity >90%) would require a huge expansion of ICU resources to cover the majority of hospitalised patients with CAP.

It is unclear to what extent CURB65 and PSI are used in clinical practice to guide ICU admission. A 2004 survey of U.S. hospitals found that 50% of physicians used the 2001 ATS criteria to guide ICU admission; however, 27% used the PSI and a similar number used APACHE II [49]. CURB65 had only recently been derived when the survey was conducted and had not been widely used at that time [49]. Little data are available from the UK, but the British Thoracic Society guidelines recommend consideration of ICU admission for patients with high CURB65 scores, although they also recommend additional criteria [2]. The Australian Guidelines for CAP management recommend using PSI to guide ICU admissions and antibiotic management [8], an approach that has been criticised [50].

"Severe pneumonia" remains a concept without an agreed definition [16]. PSI and CURB65 were originally derived and validated to predict 30-day mortality from CAP, and both scoring systems have been consistently found to have moderate–good predictive value for predicting this outcome [6, 7]. This has led to a presumption that these scores would be equally good in predicting other outcomes. PSI has been used to guide outpatient therapy for low-risk patients, while national guidelines have used both PSI and CURB65 to guide both which patients should receive more aggressive empirical antibiotic therapies and the extent of the diagnostic work-up [1, 2]. It is clear from previous work and from this meta-analysis that the parameters predicting ICU admission may be different to those predicting 30-day mortality and that many factors other than pneumonia "severity" determine the use of ICU care. In some centres, ICU care may be reserved only for those patients requiring mechanical ventilation or vasopressor support. Equally, in some centres, non-invasive ventilation may be performed exclusively in the ICU while in others this may be provided in a high-dependency or ward-based setting. In addition, many studies admitted a significant number of patients to the ICU who did not require either respiratory or circulatory support, suggesting that in many centres, ICU care is provided to patients because of a concern of deterioration.

It is recognised that the majority of mortality from pneumonia occurs in elderly patients with multiple co-morbidities. Many patients who die from pneumonia are treated palliatively and would not be considered in many centres for ICU admission [51, 52]. This is reflected in the fact that the majority of deaths from CAP occur outside the ICU and that as many as 50% of deaths in patients with pneumonia are due to co-morbidities, such as cardiovascular disease, rather than the initial illness [53]. The PSI is particularly heavily weighted by age and co-morbidities, as it is possible to achieve the highest risk score (class V) purely based on age and co-morbid illnesses. This helps to explain why less than 20% of patients in PSI class V are admitted to the ICU [54]. These factors all justify the recommendation of separate severity criteria for ICU admission.

Study limitations

Meta-analyses are entirely dependent on the quality of the source studies. Although the majority of studies were assessed as being of high quality, there was significant heterogeneity in the recruitment of patients and in the exclusion criteria applied. The summary performance characteristics for each score should be treated with caution due to this statistical heterogeneity, although the

results were remarkably consistent in each of the subanalyses. The bias arising from this methodological and statistical heterogeneity may impair the generalisability of the results presented in this manuscript. It has been suggested previously that scoring systems should be validated and recalibrated locally prior to implementation [55], and this suggestion appears to be particularly relevant for scoring systems for ICU admission, given the wide variations in the use of ICU resources demonstrated in this meta-analysis.

Conclusion

Large variations exist in the use of ICU resources between different studies and different healthcare systems. Scoring systems designed to predict 30-day mortality perform less well to predict ICU admission. Further validation of the dedicated ICU admission scores are needed.

Conflict of interest All of the authors declare they have no conflicts of interest.

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