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Development and validation of a risk score to predict community-acquired pneumonia occurrence in the adult population

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ABSTRACT

Background: Community-acquired pneumonia (CAP) preventive strategies can benefit from a quantification of individual CAP risk. This study develops and validates a CAP Risk Score (CAP-RS) for the adult population to predict CAP occurrence in the next five years.

Methods: The development phase was as follows: a population-based case-control study to identify potential CAP risk factors for inclusion in the CAP-RS after weighting according to odds ratios; development of a numerical scoring system for weighted risk factors; and establishment of cut-off points to discriminate between different risk levels. The validation phase consisted of a population-based case-control study and a retrospective cohort study (with 47 836 adults aged ≥18 years corresponding to three Maresme (Barcelona) primary care centres) followed up over a five-year period (2015–2019).

Results: 786 new CAP cases were identified. 15 factors were included in the CAP-RS. Risk was higher in subjects with CAP than without CAP (4.5 vs 1.9; $p < 0.001$), and the association (OR) between the CAP-RS and the occurrence of CAP increased as the CAP-RS value increased. AUC-ROC was 0.67 ($p < 0.001$). Cut-offs were established at <1, <5, and <10 points as best discriminating between risk groups. Annual CAP incidence was 1.9, 3.1, 6.2, and 12.4 new cases/10^3 inhabitants for the no, moderately, severely, and very severely increased risk groups, respectively. Significant differences in CAP-free survival were observed between the four CAR-RS categories.

Conclusions: The 15-item CAP-RS, which stratifies risk with good validity, can aid in the design and implementation of preventive CAP strategies for adult populations.

Abbreviations: AUC-ROC, area under the receiver operating characteristics curve; CAP, community-acquired pneumonia; CAP-RS, CAP Risk Score; CB, chronic bronchitis; CI, confidence interval; COPD, chronic obstructive pulmonary disease; DALY, disability-adjusted life-year; DM, diabetes mellitus; CHF, congestive heart failure; CKD, chronic kidney disease; CLD, chronic liver disease; HIS, health information system; HIV, human immunodeficiency virus; OR, odds ratio; PPI, proton pump inhibitor; PPSV23, 23-valent pneumococcal polysaccharide vaccine; RR, relative risk.

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1. Introduction

Community-acquired pneumonia (CAP), which affects the distal part of the lung parenchyma, is an acute and frequent respiratory infectious disease acquired outside hospital. In the general adult population worldwide, CAP incidence, associated with high mortality, morbidity, and health costs, varies widely, ranging from 1.1 to 29.0 cases per 1000 person-years [1]. Global Burden of Disease study data indicate that lower respiratory tract infections, including pneumonia, are the fourth most common global cause of disability-adjusted life-years (DALYs) in all age groups [2]. Knowledge of risk factors for CAP is essential to managing the associated risks through preventive strategies [3], as identifying and acting on modifiable risk factors are of paramount importance to reducing incidence [4,5]. Preventive measures include management of unhealthy lifestyle habits, control of comorbidities and clinical conditions, and appropriate medication. Promoting pneumococcal and influenza vaccination is also important even though the actual vaccination strategy may still be a subject of debate [6,7].

Quantifying the individual risk of developing CAP according to a person's constellation of risk factors can benefit the implementation of preventive strategies, as stratifying individuals according to their CAP risk can enable cost-effective management of prevention. Currently, CAP severity scores validated for clinical management are recommended to predict prognostic outcomes (mortality, hospitalization, intensive care, and mechanical ventilation) and advance high-intensity treatments [8]. However, to our knowledge, there is no risk measurement instrument in the literature that predicts pneumonia occurrence in people living in the community [9,10].

The objective of this study was to develop and validate a CAP Risk Score (CAP-RS), applicable to the general adult population, that individually predicts CAP risk in the next five years.

2. Patients and methods

The study included two main phases: a development phase and a validation phase. The development phase consisted of: a) a literature review to identify well-established and potential risk factors for CAP and b) a case-control study with subsample 1. The validation phase included: a) a case-control study with subsample 2 and b) a retrospective cohort study between 2015 and 2019.

2.1. Development phase

A literature review was first implemented to identify and select well-established and other potential risk factors for CAP [3]. Second, to identify significant risk factors to be included in the CAP-RS, a population-based case-control study was implemented to assess CAP risk factors, for each of which the corresponding odds ratio (OR) was calculated for weighting purposes. Third, a numerical score that reflected the sum of weighted risk factors was developed, and finally, cut-off points were established to discriminate between different risk groups (ranging from no increased risk to very severely increased risk).

The population-based case-control study encompassed the population aged ≥18 years (47 836 persons), assigned to three Maresme region (Barcelona, Spain) primary care centres belonging to the Spanish National Health Service and covering 96.5 % of the resident population. CAP cases identified in the study population between January 1, 2015 and December 31, 2019 (five years) were selected (according to International Classification of Diseases 10th Revision -ICD-10- codes) from computerized primary care and hospital medical records. Randomly selected from the same primary care centre for each CAP case were 10 age- and sex-matched controls who had not experienced CAP during the study period. According to the known annual incidence of CAP in the study population [11], approximately 620 CAP cases were expected over the five-year study period. Cases and controls were randomly assigned to one of two subsamples, consisting of one third and two thirds of the study population. Random allocation was based on assigning each study subject a random number as a Globally Unique Identifier (GUID) using the SQL language [12]. Subsample 1 was used to assess CAP risk factors, for which OR values were calculated so as to establish those to be finally included in the CAP-RS; and subsample 2 was used for validation purposes.

Study variables included 25 risk factors considered as potentially related to CAP occurrence in a previous systematic review of observational studies [3], as follows: sociodemographic and lifestyle factors (age, sex, current or ex-smoker, alcohol abuse, and – for carpentry, construction, and metallurgy workers – chronic past or current dust/-cold exposure); comorbidities and clinical conditions (e.g., malnutrition, frailty or functional disability, chronic bronchitis (CB) or chronic obstructive pulmonary disease (COPD), asthma, previous CAP, periodontitis, dysphagia, diabetes mellitus (DM), congestive heart failure (CHF), chronic kidney disease (CKD), upper respiratory tract infection, chronic liver disease (CLD), chronic neurological disorder, human immunodeficiency virus (HIV) infection, and active cancer – malignant neoplasms of ICD-10 diagnostic codes C00–C97 activated before the start of the study and with an end date not reported or higher than the date of analysis); therapeutic risk factors (immunosuppressors, oral corticosteroid, or proton pump inhibitor (PPI) use) and 23-valent pneumococcal polysaccharide vaccine (PPSV23) anti-pneumococcal vaccination; and CAP during the five-year study period. With the exception of CAP during the study period, all study variables refer to the participant's situation on January 1, 2015. Operative definitions of each study variable and the corresponding ICD-10 and Anatomical Therapeutic Chemical (ATC) codes are included as Supplementary Material. Data sources were computerized primary care medical records, the pharmacy prescription database, and Hospital of Mataró computerized medical records and laboratory database.

The numerical score that reflected the sum of weighted risk factors was developed as follows. CAP association with study variables was measured via ORs calculated using logistic regression, and factors considered for inclusion in the CAP-RS were those whose OR values reached $p < 0.05$ in the bivariate analysis; OR values used to weight the risk factors were as follows: OR<2, 1 point, OR = 2–3, 2 points, OR = 3–4, 3 points, and OR >4, 4 points. The final CAP-RS was calculated by summing the weights of the items at a given moment in time. For cases and controls, CAP-RS values were calculated, described, and compared using the *t*-test for independent data, and point-by-point distributions were also described and assessed. Based on this information, cut-off points to discriminate between different CAP prevalence groups were established according to four risk categories with scores as follows: no increased risk (<1), moderately increased risk [1–4], severely increased risk [5–9], and very severely increased risk (≥10).

2.2. Validation phase

The validation phase included two population-based studies: a case-control study with subsample 2; and a retrospective cohort study with all inhabitants aged ≥18 years corresponding to the participating primary care centres (47 836 persons) followed up over the five-year period 2015–2019. For the subsample 2 case-control study, the CAP-RS (as a continuous and as a categorical variable) was compared between cases and controls using the Mann-Whitney *U* test and the chi-square test, respectively. The analysis also included an assessment of the predictive value of the CAP-RS, performed as follows: (a) logistic regression estimates of ORs for the CAP-RS (as a continuous variable and as a categorical variable) and determination coefficients (R^2) for the models; and (b) calculation of the area under the receiver operating characteristics curve (AUC-ROC) for the CAP-RS. For the cohort study, CAP-RS values were calculated for all included subjects on January 1, 2015 and data was recorded for all newly occurred CAP cases in the following five years. The cohort analysis included: (a) for each CAP-RS value, calculation of the mean annual accumulated CAP incidence and the 95 %

confidence interval (CI) for the five-year study period; (b) analysis of five-year CAP-free survival comparing CAP risk categories (log rank test); and (c) calculation of hazard ratio (HR) values for each CAP risk category (Cox regression).

2.3. Ethical and legal issues

The study protocol was approved by the Consorci Sanitari del Maresme Ethics Committee (reference 39/21, June 30, 2021). An exemption from obtaining informed consent was granted, given that, as an observational study with retrospective data collection, there was no risk for participants, and that strict data confidentiality was guaranteed. Created from the databases used as information sources was a new isolated repository to contain the study information; this data mart was completely detached from any data that could identify the participants (pseudo-anonymization). Only the minimum essential information to respond to the objectives of the study was obtained from each participant.

3. Results

For the period 2015–2019, 786 new CAP cases were identified in the study population, for which 7860 controls without CAP were randomly selected in the primary care census. One third of this sample (8646 cases + controls) was randomly assigned to subsample 1 (2871 persons) and two thirds to subsample 2 (5775 persons). Fig. 1 depicts the study flowchart.

3.1. CAP-RS development

The subsample 1 case-control study included 261 CAP cases and 2610 controls. Of the 25 risk factors initially considered, 15 were included in the CAP-RS, 14 that showed a statistically significant association with CAP (Table 1), and, as the 15th item, smoking, which was included even though it did not reach statistical significance because of the extensive literature on the subject [13] : [14]. Clinical conditions added points as follows to the CAP-RS: COPD, CB, dysphagia, chronic neurological diseases, and HIV infection (4 points); age ≥70 years, functional disability, and previous CAP (3 points); asthma, PPI use, CHF, DM, and severe CKD (2 points); age 50–69 years, active cancer, and smoking (1 point). After point-by-point score analysis, cut-offs were established at <1, <5, and <10 points, as best discriminating between risk categories. Table 2, which compares scores and distributions for the four CAP-RS categories for subsample 1 cases and controls, shows significant differences in the CAP-RS for subjects with and without CAP, and greater associations for higher CAP-RS values (from OR = 1 for the no increased risk category to OR = 9.8 for the very severely increased risk category).

3.2. CAP-RS validation

Table 2 additionally reports results for the subsample 2 case-control study, pointing to similar results as for subsample 1, i.e., the CAP-RS was significantly higher in participants with compared to without CAP, and the association with CAP increased as the CAP-RS value increased. The AUC-ROC values for CAP prediction were 0.67 ($p < 0.001$) for subsample 1 and 0.65 ($p < 0.001$) for subsample 2.

The cohort study identified 786 CAP cases in the overall study population during the five-year study period, representing a mean (95 % CI) annual incidence of 3.3 (3.06–3.51) CAP cases/10^3 adult inhabitants. Fig. 1, the flowchart of the study, shows how the study population was distributed according to the four CAP-RS categories. Fig. 2 depicts mean (95 % CI) annual CAP incidence per 10^3 inhabitants

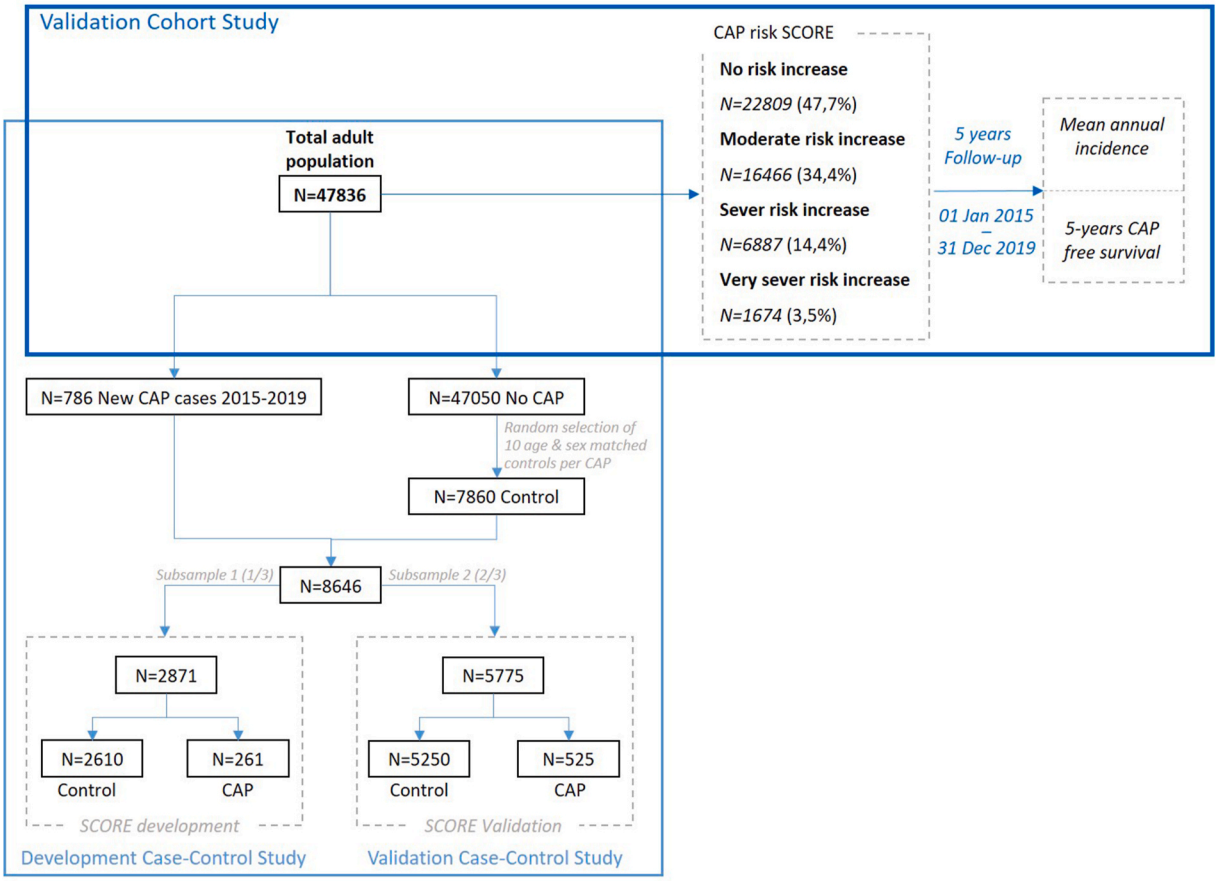

Fig. 1. Study flowchart.

Table 1
Potential risk factors for inclusion in the CAP-RS.

	TOTAL (N = 2871)	No CAP (N = 2610)	CAP (N = 261)	p	OR (95 % CI)
	N (%)	N (%)	N (%)		
Age 18–49 years	1681 (58.6 %)	1571 (60.2 %)	110 (42.1 %)	<0.001	1
Age 50–69 years	792 (27.6 %)	714 (27.4 %)	78 (29.9 %)		1.56 (1.15–2.11)
Age ≥70 years	398 (13.9 %)	325 (12.5 %)	73 (28.0 %)		3.21 (2.33–4.41)
Sex (female)	1419 (49.4 %)	1286 (49.3 %)	133 (51.0 %)	0.603	1.07 (0.83–1.38)
CB/COPD	132 (4.6 %)	96 (3.7 %)	36 (13.8 %)	<0.001	4.19 (2.79–6.29)
Asthma	131 (4.6 %)	104 (4.0 %)	27 (10.3 %)	<0.001	2.78 (1.78–4.33)
Functional disability	54 (1.9 %)	41 (1.6 %)	13 (5.0 %)	<0.001	3.29 (1.74–6.21)
Periodontitis	7 (0.2 %)	6 (0.2 %)	1 (0.4 %)	0.487	1.67 (0.20–13.9)
Immunosuppressors	9 (0.3 %)	8 (0.3 %)	1 (0.4 %)	0.576	1.25 (0.16–10.0)
Oral corticosteroids	60 (2.1 %)	51 (2.0 %)	9 (3.4 %)	0.108	1.79 (0.87–3.68)
PPIs	334 (11.6 %)	278 (10.7 %)	56 (21.5 %)	<0.001	2.29 (1.66–3.16)
Malnutrition	175 (6.1 %)	158 (6.1 %)	17 (6.5 %)	0.767	1.08 (0.65–1.81)
Previous CAP, mean (SD)	0.03 (0.19)	0.02 (0.17)	0.10 (0.34)	<0.001	3.55 (2.30–5.50)
Alcohol abuse	3 (0.1 %)	2 (0.1 %)	1 (0.4 %)	0.249	5.02 (0.45–55.5)
CHF	682 (23.8 %)	572 (21.9 %)	110 (42.1 %)	<0.001	2.60 (2.00–3.38)
Dysphagia	20 (0.7 %)	14 (0.5 %)	6 (2.3 %)	0.007	4.36 (1.66–11.5)
Active cancer	74 (2.6 %)	62 (2.4 %)	12 (4.6 %)	0.031	1.98 (1.05–3.73)
DM	166 (5.8 %)	135 (5.2 %)	31 (11.9 %)	<0.001	2.47 (1.64–3.74)
Upper respiratory tract infection	38 (1.3 %)	33 (1.3 %)	5 (1.9 %)	0.387	1.53 (0.59–3.94)
CLD	32 (1.1 %)	26 (1.0 %)	6 (2.3 %)	0.064	2.34 (0.95–5.73)
Chronic neurological disorder	60 (2.1 %)	42 (1.6 %)	18 (6.9 %)	<0.001	4.53 (2.57–7.99)
HIV infection	7 (0.2 %)	4 (0.2 %)	3 (1.1 %)	0.020	7.58 (1.69–34.0)
Severe CKD	29 (1.0 %)	23 (0.9 %)	6 (2.3 %)	0.042	2.65 (1.07–6.56)
Smoking	173 (6.0 %)	152 (5.8 %)	21 (8.0 %)	0.150	1.42 (0.88–2.28)
Professional contact with dust	58 (2.0 %)	56 (2.1 %)	2 (0.8 %)	0.131	0.35 (0.09–1.45)
Professional contact with cold	48 (1.7 %)	42 (1.6 %)	6 (2.3 %)	0.387	1.44 (0.61–3.42)
PPSV23	204 (7,1 %)	162 (6,2 %)	42 (16,1 %)	<0,001	2,90 (2,01–4,18)

Proportion of pneumonias for each factor. Bivariate OR values and the corresponding scores (OR 1–2: 1 point, OR 2–3: 2 points, OR 3–4: 3 points; OR ≥4: 4 points).
Abbreviations: CAP: community-acquired pneumonia; CAP-RS: CAP Risk Score; CB: chronic bronchitis; CHF: congestive heart failure; CI: confidence interval; CKD: chronic kidney disease; CLD: chronic liver disease; COPD: chronic obstructive pulmonary disease; DM: diabetes mellitus; OR: odds ratio; PPI: proton pump inhibitor; PPSV23: 23-valent pneumococcal polysaccharide vaccine.

Table 2
CAP-RS and categories compared for cases and controls.

	Subsample 1				Subsample 2			
	Control	CAP	p	OR (95 % CI)	Control	CAP	p	OR (95 % CI)
CAP-RS, mean (SD)								
	1.9 (2.9)	4.5 (4.5)	<0.001	1.19 (1.16–1.23)	1.4 (2.5)	3.0 (3.6)	<0.001	1.18 (1.15–1.21)
CAP-RS categories								
0	1258 (48.2 %)	74 (28.4 %)	<0.001	1	3260 (62.1 %)	195 (37.1 %)	<0.001	1
1–4	921 (35.3 %)	76 (29.1 %)		1.40 (1.01–1.95)	1431 (27.3 %)	200 (38.1 %)		2.34 (1.90–2.87)
5–9	355 (13.6 %)	67 (25.7 %)		3.21 (2.26–4.56)	461 (8.8 %)	93 (17.7 %)		3.37 (2.59–4.40)
≥10	76 (2.9 %)	44 (16.9 %)		9.84 (6.34–15.3)	98 (1.9 %)	37 (7.0 %)		6.31 (4.21–9.46)

R^2 subsample 1: 0.039 (continuous)/0.038 (categorical); R^2 subsample 2: 0.023 (continuous)/0.055 (categorical).
Abbreviations: CAP: community-acquired pneumonia; CAP-RS: CAP Risk Score; CI: confidence interval; OR: odds ratio.

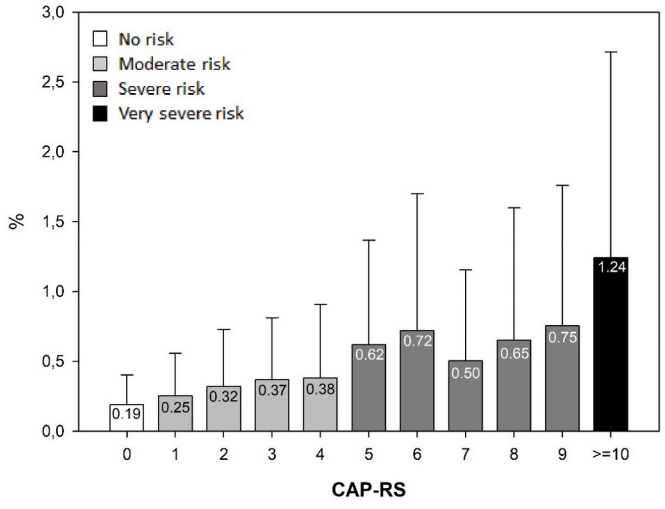

Fig. 2. Mean annual incidence of CAP according to CAP-RS values.

according to CAP-RS values. Annual incidence of CAP was 1.9 (1.16–2.13), 3.1 (2.71–3.46), 6.2 (5.39–7.03), and 12.4 (10.11–14.74) new cases in the no increased, moderately increased, severely increased,

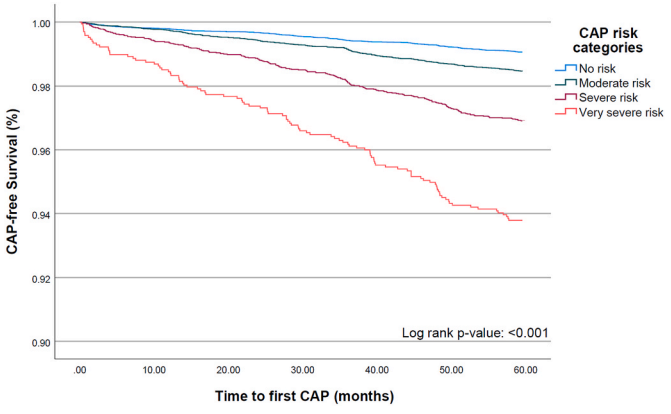

Fig. 3. CAP-free survival by CAP-RS categories.

and very severely increased risk groups, respectively; in relative risk (RR) terms in relation to the no increased risk group, RR (95 % CI) values were 1.67 (1.39–2.00), 3.44 (2.85–4.16), and 6.89 (5.45–8.71), respectively. Fig. 3 depicts CAP-free survival curves for the same four categories, showing significant differences between groups. Cox regression resulted in HR (95 % CI) values of 1.65 (1.38–1.98), 3.35 (2.77–4.05), and 6.82 (5.39–8.62) for the moderately, severely, and very severely increased risk groups, respectively.

4. Discussion

We developed and validated the CAP-RS to evaluate individual risk of developing CAP in the next five years with the aim of aiding the design and implementation of cost-effective strategies and tailored recommendations to prevent CAP in the general adult population.

While the CAP-RS points to increased CAP risk, it does so as a risk score and not as a diagnostic tool, as accuracy in predicting individual CAP cases in the next five years is relatively poor (AUC-ROC values in the development and validation phase case-control subsamples were 0.67 and 0.65, respectively). Each cut-off point reflected an approximate doubling of the CAP risk over the previous cut-off point, ranging from no increased risk (1.9 new CAP cases/10^3 adult inhabitants/year) to very severely increased risk (12.4 new CAP cases/10^3 adult inhabitants/year). Consistent with the above, the CAP-free survival and Cox regression analyses also pointed to an increased risk of CAP in successive risk categories.

The risk factors contributing most (4 points) to the CAP-RS were HIV infection, chronic neurological diseases, dysphagia, and CB and COPD. Since those four disease classes are highly predictive of CAP risk, community dwellers with any of these conditions should be frontline candidates for preventive measures. For patients with HIV, prevention and control measures are fundamental, as CAP is a very common opportunistic infection in these high-risk patients, even if virally suppressed and with high CD4 counts [13,15–17]. Initial measures include pneumonia protection, vaccination, and treatment, and HIV/AIDS protection and treatment. While chronic neurological diseases have been documented merely as potential CAP risk factors [3,18,19], our new evidence would indicate that these diseases represent definitive CAP risk factors. As for dysphagia, whereas a systematic review found this to be a non-conclusive CAP risk factor [3], our study pointed to a strong association with CAP. Finally, CB and COPD are widely recognized as CAP risk factors, as corroborated by our study.

Other important contributory factors (3 points) to the CAP-RS are documented as clear risk factors [3], namely, previous pneumonia, functional disability or dependence in relation to basic activities of daily living, and age over 69 years. Factors contributing moderately to the CAP-RS (2 points) are likewise well-known CAP risk factors, namely, PPI use and asthma, and other less conclusive factors such as CKD, CHF, and DM. Since, in terms of complications and mortality rates, these patients are also at increased risk of poorer post-pneumonia outcomes [20], they should be targeted for CAP preventive interventions. It is well known that PPI treatment is a risk factor for CAP [21–23], so this risk needs to be addressed in terms of benefits versus the potential side effects, strict monitoring of the indication for prescription, and possible alternative treatments to PPIs. Finally, contributing least (1 point) to the CAP-RS are active cancer, age 50–70 years, and smoking. Although smoking in our study was weakly associated with CAP (it did not reach statistical significance), possibly due to underreporting in medical records, it was included in the predictive score due to the extensive literature on the topic and its modifiable nature [14].

Regarding anti-pneumococcal vaccination, our study shows no significant protective effect for PPSV23, whose effectiveness in preventing CAP is the subject of debate and so requires further investigation [7,24–27]. In addition, while more studies are needed to assess PPSV23 effectiveness, other pneumococcal vaccines can be considered, as pneumococcal and influenza vaccines are rated as crucial preventive interventions for CAP [6]. Finally, most of the vaccine strategies focus on decreasing the severity of pneumonia rather than the pneumonia incidence rate.

The coexistence of multiple conditions – many of which are risk factors for CAP – has been shown to have a cumulative effect on the risk of CAP [20,27]. Our study corroborates this cumulative effect, as the CAP-RS reflects an increased risk of CAP as the number of risk factors accumulates.

The CAP-RS expressed in terms of four predictive risk categories, and suggestive of several possibilities for CAP prevention in the adult population, should help manage CAP risk by aiding the development of cost-effective and suitably intensive preventive strategies. Ideally, all possible preventive interventions should be applied to persons with any increased risk of CAP. However, considering clinical practice and health system limitations and pragmatic aspects of intervention implementation, a progressive preventive strategy could be established, starting with a recommendation to quit smoking, given its direct and indirect (through CB and COPD) effects on CAP. Recommendations for persons in the severely increased risk group could focus on managing comorbidities and clinical conditions that contribute to risk. Preventive actions could also cover appropriate use of drugs associated with CAP risk, based on intensified monitoring and follow-up with a view to protecting immune systems, controlling pathologies, and avoiding progression, exacerbations, and relapses. Furthermore, for the very severely increased risk group, any change in the acute state of the patient should suggest a pneumonia risk. In such cases, a respiratory examination and chest x-ray should be considered with a view to rapid diagnostic confirmation, and if confirmed, the patient should be treated with early empirical antibiotic treatment. Such measures would be especially indicated for persons with a very severe risk of atypical CAP or for elderly persons with hidden clinical presentations. As for dysphagia, specific recommendations are postural manoeuvres, rehabilitation, and treatments to adapt fluid viscosity (thickeners) and solid food textures [28]. Clearly, regarding those recommendations, further studies are needed to produce evidence to support the best preventive strategies for each CAP risk group and to confirm their cost-effectiveness [29].

The main limitation of the CAP-RS is availability and quality of clinical real-world data in our health information systems (HIS). Each risk factor and its weighting in the CAP-RS is potentially affected by the validity of data recording and coding. Despite efforts in recent years to improve the quality of health records in our setting, misclassification (under-recording or coding errors) of some clinical conditions may have influenced the results of this study. Clearly, since data recording and coding quality may vary between countries and regions we could not use an external cohort to validate the CAP-RS. However, external validation of the CAP-RS for other contexts would be recommended in order to improve its predictive capacity. Certain important risk factors identified in the scientific literature were not included in the CAP-RS, as they did not feature as risk factors or did not achieve statistical significance in our case-control study. Under-recording in the HIS, as mentioned above, may explain the non-inclusion of those risk factors, mainly alcohol abuse, CLD, oral corticosteroid and immunosuppressive treatments, dental/periodontal diseases, poor nutritional status, and environmental exposure. This does not exclude them as risk factors; it merely indicates that they were not included in the CAP-RS, given our study sample, statistical power, the data available in clinical records, and our methodology. Other variables that have also been related to pneumonia risk or protection (e.g., lifestyle factors and excess weight) did not feature in or were not reliably available in our HIS.

As a strength of our study, our CAP-RS, by quantifying the individual risk of developing CAP according to accumulated risk factors, can support the implementation of CAP preventive strategies at the population level. The CAP-RS consists of too many variables to be taken into account in routine clinical practice by physicians. Nevertheless, calculated systematically and automatically by the HIS and recorded in electronic medical records, the CAP-RS can efficiently stratify a population

according to their CAP risk, as was done for the entire adult population in our catchment area.

5. Conclusions

Our 15-item CAP-RS, as far as we are aware, is the first validated instrument for stratifying CAP risk in the adult population, and can prove useful in the implementation of CAP prevention strategies, both at the public health and clinical management levels. More studies are needed, however, to corroborate the validity of the CAP-RS in other contexts.

Author contributions

JA and MSP conceived the study, developed the study plan, and drafted the initial manuscript. JA, IB, and MSP conducted the literature review. AL accessed and verified the underlying data. EP analysed the data and prepared the figures. All authors interpreted the results, revised the manuscript, and gave final approval. Ailish MJ Maher proofread the manuscript, and had no other role in the project.

Suggested reviewers

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Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work the authors did not used generative AI or AI-assisted technologies in the writing process.

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Declaration of competing interest

The authors declare no competing interests.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.resinv.2025.04.012.

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