

Stroke-associated pneumonia: pathophysiology, diagnosis and management strategies

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Abstract

English:

Stroke-associated pneumonia (SAP) is a common and serious complication occurring within 7 days after acute ischemic stroke, significantly impacting patient morbidity, mortality and healthcare costs. Its pathogenesis involves both neurological impairment and stroke-induced immunodepression. Risk factors include advanced age, male sex, stroke severity, impaired consciousness, and comorbidities. Diagnosis remains challenging due to non-specific symptoms and overlapping presentations with other post-stroke complications. The Pneumonia in Stroke Consensus (PISCES) group recommends modified centers for disease control and prevention (CDC) criteria to classify SAP as 'probable' or 'definite'. Several risk prediction scores and emerging biomarkers show potential for early detection but lack broad validation. Effective management emphasises early screening for dysphagia, while preventive strategies like oral hygiene and postural adjustments, along with timely initiation of tailored antibiotic therapy, are crucial for managing infections which can improve patient outcomes.

Keywords

pneumonia • stroke • stroke-associated pneumonia

Pneumonia asociată accidentului vascular cerebral: fiziopatologie, diagnostic și strategii de management

Rezumat

Romanian:

Pneumonia asociată accidentului vascular cerebral (SAP) este o complicație frecventă și gravă, care apare în primele 7 zile după un accident vascular cerebral ischemic acut și are un impact semnificativ asupra morbidității, mortalității și costurilor medicale. Patogeneza implică atât afectarea neurologică, cât și imunosupresia indusă de accidentul vascular cerebral. Factorii de risc includ vârsta înaintată, sexul masculin, severitatea accidentului vascular, alterarea stării de conștiență și comorbiditățile asociate. Diagnosticul rămâne dificil din cauza simptomelor nespecifice și a suprapunerii manifestărilor cu alte complicații post-AVC. Grupul Pneumonia in Stroke Consensus (PISCES) recomandă criteriile modificate ale Centers for Disease Control and Prevention (CDC) pentru clasificarea SAP ca „probabilă” sau „certă”. Mai multe scoruri de predicție a riscului și biomarkeri emergenți prezintă potențial pentru detectarea precoce, însă lipsesc validări extinse. Managementul eficient pune accent pe screeningul precoce pentru disfagie, în timp ce strategiile preventive, precum igiena orală și ajustările posturale, împreună cu inițierea promptă a unei terapii antibiotice adaptate, sunt esențiale pentru controlul infecțiilor și pot îmbunătăți prognosticul pacienților.

Cuvinte-cheie

pneumonie • accident vascular cerebral • pneumonia asociata accidentului vascular

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Abbreviation

AIS, acute ischemic stroke; CAP, community-acquired pneumonia; CDC, centers for disease control and prevention; CHF, congestive heart failure; CRP, C-reactive protein; CXR, chest X-ray; GCS, Glasgow Coma Scale; GUSS, Gugging Swallowing Screen; HAP, hospital-acquired pneumonia; HPA, hypothalamic-pituitary-adrenal; ICH, intracerebral haemorrhage; ICU, intensive care unit; INR, international normalized ratio; ISAN, (prestroke) Independence, Sex, Age, National Institutes of Health Stroke Scale; LAR, lactic dehydrogenase to albumin ratio; MeSH, Medical Subject Headings; NIHSS, National Institutes of Health Stroke Scale; NLR, neutrophil-to-lymphocyte ratio; NPV, negative predictive values; PANTHERIS, Preventive Antibacterial Therapy in Acute Ischaemic Stroke; PCT, procalcitonin; PISCES, Pneumonia in Stroke Consensus group; PNA, pneumonia; PNS, parasympathetic nervous system; PPV, positive predictive values; SAI, stroke-associated infection; SAP, stroke-associated pneumonia; SIDS, Stroke-Induced Immunodepression Syndrome; SNS, sympathetic nervous system.

Introduction

Stroke-associated pneumonia (SAP) encompasses a spectrum of lower respiratory tract infections that develop within 7 days following the onset of acute ischemic stroke (AIS) in patients not requiring mechanical ventilation (1). The incidence of SAP reported in the literature varies widely, ranging from 6.7% to 37.98%, with pooled data indicating that approximately 1 in 10 patients hospitalised with acute stroke experience pneumonia during the early phase of care (2–4). Among stroke-associated infections (SAIs), SAP is typically the most acute and has the worst impact on functional outcome (5). As a prevalent and serious post-stroke complication, SAP is associated with adverse clinical outcomes, including diminished functional recovery, prolonged hospitalisation, increased healthcare expenditure, elevated mortality rates, and a marked deterioration in the overall quality of life (2). Given the impact of SAP on patient outcomes and healthcare resources, this review aims to synthesise recent evidence to enhance the current understanding of SAP and inform evidence-based clinical practice.

Materials and methods

This literature review was designed to consolidate and analyse contemporary evidence on SAP, with a focus on its pathophysiology, risk factors, diagnosis, prevention, and management. A systematic search of the literature was conducted using PubMed and Google Scholar to identify relevant peer-reviewed publications. The search was limited to articles published within the last 10 years to ensure that only the most recent and clinically applicable data were included. Inclusion criteria were: (1) articles published in English, (2) studies involving adult human populations, and (3) peer-reviewed original research, systematic reviews, meta-analyses, or clinical guidelines directly addressing SAP. Studies were excluded if they focused on paediatric populations, animal models, or if full-text access was unavailable. Titles and

abstracts were initially screened for relevance, followed by full-text review of selected articles. Additional references were identified through manual review of the bibliographies of included studies. Data from the selected literature were synthesised and categorised thematically based on the primary domains of interest: pathophysiology, risk factors, diagnosis, prevention, and treatment.

Discussion***Pathophysiology and risk factors***

SAP arises from a complex interplay between neurological impairment and post-stroke immune dysregulation. Strokes involving the cerebral cortex, brainstem, or cerebellum frequently disrupt swallowing function (dysphagia) by damaging neural pathways responsible for mastication and bolus transit. Lesions in the precentral gyrus can cause contralateral facial and oropharyngeal motor deficits, while brainstem strokes may delay the swallowing reflex and diminish oral-pharyngeal sensation. These dysfunctions significantly increase the risk of aspiration, allowing food, fluids, or pathogens to enter the lower respiratory tract and lead to pneumonia (6).

Acute stroke also triggers systemic immunosuppression, primarily through stroke-induced immunodepression syndrome (SIDS). In the early phase, immune cells release cytokines in response to tissue injury, activating afferent vagal pathways that signal central immune-regulatory centres such as the hypothalamus. This initiates anti-inflammatory signalling via the efferent vagus nerve to suppress further cytokine production. However, prolonged stimulation leads to immune exhaustion and weakened host defences. SIDS is driven by the coordinated activation of three key systems: the sympathetic nervous system (SNS), the parasympathetic nervous system (PNS) and the hypothalamic-pituitary-adrenal (HPA) axis (7, 8).

SNS activation causes sustained catecholamine release (epinephrine, norepinephrine, and dopamine), which suppresses lymphocyte counts and disrupts early lymphocyte activation. This catecholamine-mediated immunosuppression plays a critical role in the diminished antibacterial immune response observed following stroke (8). Concurrently, the PNS releases acetylcholine, which binds to $\alpha 7$ nicotinic acetylcholine receptors ($\alpha 7$ nAChR) on macrophages, inhibiting the release of pro-inflammatory cytokines and weakening pulmonary immune defences, thereby increasing susceptibility to respiratory infections (8, 9). Meanwhile, the HPA axis releases glucocorticoids in response to stress and inflammation. Excess glucocorticoid production can cause lymphocytopenia and disrupt immune balance, further compromising host immunity (8). Collectively, these neurologic and immunologic alterations undermine host immunity and heighten the risk of pneumonia, forming a central mechanism in the pathogenesis of SAP.

Several additional neurological and medical factors contribute to the risk of SAP. Among these, stroke type is a critical determinant, as patients with haemorrhagic stroke face a higher risk of SAP compared to those with ischemic stroke (6). An altered level of consciousness, especially a Glasgow Coma Scale (GCS) score below 8 on admission, is strongly associated with increased SAP incidence (6). Stroke severity, as indicated by a National Institutes of Health Stroke Scale (NIHSS) score above 15, is also a significant predictor (6, 10). Dysphagia, a common and serious post-stroke complication, markedly elevates SAP risk due to impaired swallowing and the likelihood of silent aspiration. This results from disrupted neural control of the swallowing network, leading to dysfunction in the oropharyngeal, laryngeal and oesophageal muscles. Pharyngeal phase deficits, in particular, can hinder bolus transit and cause secretion pooling near the airway, substantially increasing the risk of aspiration and respiratory infections such as pneumonia (11–13).

From a medical perspective, several demographic and clinical factors have been identified as significant contributors to SAP. Advanced age, particularly in patients over 75 years, and male gender are both recognised as non-modifiable risk factors (10, 11, 14). Ageing increases susceptibility to swallowing dysfunction due to physiological decline, such as reduced tongue strength, impaired pharyngeal constriction and inadequate pharyngeal shortening. These changes compromise swallowing efficiency, heightening the risk of aspiration and subsequent pneumonia (13). Cardiovascular and metabolic conditions such as atrial fibrillation, fasting hyperglycaemia and severe hypertension are consistently linked to increased SAP risk (11, 15). Additional comorbidities, including congestive heart failure (CHF), chronic pulmonary disease, renal failure, anaemia, and diabetes mellitus, also increase the risk of vulnerability. CHF and other disorders

Table 1. Risk factor of SAP.

Modifiable	Non-modifiable
Atrial fibrillation	Age
Hypertension	Gender
CHF	Stroke type
Chronic pulmonary disease	Stroke severity
Renal failure	Brain lesion location
Anaemia	
Diabetes mellitus	
Mechanical ventilation	
Nasogastric tube	

CHF, congestive heart failure; SAP, stroke-associated pneumonia.

affecting pulmonary circulation may predispose patients to infection due to pulmonary oedema and compromised respiratory mechanisms (6, 14, 15). Lower serum iron levels have also been linked to higher SAP risk, with studies suggesting an L-shaped relationship. Although the mechanisms remain unclear, impaired iron homeostasis potentially driven by altered macrophage function and microbial iron uptake may contribute to this association (16). Furthermore, the use of mechanical ventilation and nasogastric tubes significantly increases the risk of SAP (6, 14, 17). Mechanical ventilation impairs mucociliary clearance, facilitating bacterial colonisation of the lower respiratory tract (17). Nasogastric tube insertion increases the risk of pneumonia in stroke patients by promoting gastroesophageal reflux and impairing the natural protective mechanisms of the oropharynx. This can lead to microaspiration of infected gastric contents and facilitate colonisation by pathogenic bacteria, particularly in the absence of normal chewing and swallowing, which otherwise help reduce oral bacterial load (17). These risk factors can be categorised as modifiable or non-modifiable, as outlined in Table 1.

Several risk factors have been independently associated with an increased risk of multidrug-resistant bacterial infections in patients with SAP. According to a multivariate analysis by Xu et al. (18), late-onset SAP, intensive care unit (ICU) admission, presence of an indwelling gastric tube, prolonged hospitalisation, prophylactic antibiotic use, and impaired consciousness significantly elevate the likelihood of Multidrug-Resistant (MDR) pathogen involvement.

Diagnosis

The Pneumonia in Stroke Consensus (PISCES) Group recommends using modified Centres for Disease Control and Prevention (CDC) criteria to classify as either 'probable' or 'definite'. Probable SAP is diagnosed when all CDC criteria are met, but initial chest X-ray (CXR) and serial/repeat CXR are non-confirmatory, and no alternative diagnosis or

Table 2. Components of clinical scoring systems for predicting SAP (20).

	A2DS2	ISAN	AIS-APS	Kwon	PANTHERIS	Chumbler
Sex (male)	+1	+1		+1		
Age (years)	+1 (≥ 75)	+3 (60–69) +4 (70–79) +6 (80–89) +8 (≥ 90)	+2 (60–69) +5 (70–79) +7 (≥ 80)	+1 (≥ 65)	+1 (60–80) +2 (>80)	+2 (>70)
Mechanical ventilation				+1		
Atrial fibrillation	+1		+1			
CHF			+3			
COPD			+3			
Current smoking			+1			
Dysphagia	+2		+3	+1		+4
Past medical history of pneumonia						+4
NIHSS	+3 (5–15) +5 (≥ 16)	+4 (5–15) +8 (16–20) +10 (≥ 21)	+2 (5–9) +5 (9–14) +8 (≥ 15)	+1 (≥ 11)		+1 (per 3 increase)
Found down at symptom onset						+3
mRS (perstroke)		+2 (2–5)	+2 (≥ 3)			
GCS			+3 (3–8)		+2 (9–12) +5 (3–8) +3 (>11)	
WBC ($\times 10^9/L$)					+2 (>200 mmHg)	
Systolic blood pressure (within 24 h after admission)						
OCSP (TACI/POCI)			+2			
Admission glucose (mmol/L)			+2 (≥ 11.1)			
Total score	0–10	0–21	0–35	0–5	0–12	0–27

A2DS2, age, atrial fibrillation, dysphagia, sex, stroke severity; AIS-APS, acute ischaemic stroke-associated pneumonia score; CHF, congestive heart failure; COPD, chronic obstructive pulmonary disease; GCS, Glasgow Coma Scale; ISAN, prestroke independence, sex, age, National Institutes of Health Stroke Scale; mRS, modified Rankin Scale; NIHSS, National Institutes of Health Stroke Scale; OCSP, Oxfordshire Community Stroke Project; PANTHERIS, preventive antibacterial therapy in acute ischaemic stroke; POCI, Posterior Circulation Infarcts; SAP, stroke-associated pneumonia; TACI, total anterior circulation infarcts; WBC, white blood cell.

explanation is available. Definite SAP requires the presence of typical CXR changes (on at least one) alongside fulfilment of all CDC criteria. This differentiation addresses the challenge that early stage pneumonia in stroke patients may not exhibit typical CXR findings (1). The CDC criteria for the diagnosis of pneumonia are based on a combination of clinical, radiographic and laboratory findings. A diagnosis typically requires the presence of a new or progressive and persistent infiltrate, consolidation, or cavitation on chest radiography, accompanied by at least one of the following: fever ($>38^\circ\text{C}$); leukocytosis or leukopenia; or altered mental status in adults aged ≥ 70 years without another recognised cause. Additionally, at least two of the following signs or symptoms should be present: new onset of purulent sputum or a change in the character of sputum; new or worsening cough, or dyspnoea, or tachypnoea; rales, crackles, or bronchial breath sounds; or worsening gas exchange (1).

Early identification of SAP remains a significant clinical challenge due to the non-specific nature of its early symptoms and their overlap with other post-stroke complications. These overlapping presentations, combined with the limitations of conventional diagnostic tools, such as imaging and laboratory tests, often delay accurate diagnosis. Nevertheless, early and precise detection is crucial for initiating timely antibiotic therapy, which can significantly reduce morbidity, mortality and hospital length of stay (19).

Potential scoring system tools

Several clinical scoring systems have been developed to aid in risk stratification as outlined in Table 2. These tools aim to predict SAP risk based on clinical and demographic parameters and are primarily intended to assist clinicians in identifying high-risk patients for closer monitoring or prophylactic treatment (19). However, the clinical utility of these scores

remains uncertain. Most have not been evaluated for their impact on clinical decision making, such as their ease of use, the time required for completion, or their influence on clinician behaviour. Moreover, none have been robustly validated in terms of improving patient outcomes, such as reducing SAP incidence or mortality. Sensitivity and specificity at commonly used cut-offs vary widely and may not meet the thresholds required for routine clinical implementation (19).

A study by Tu et al. (21) demonstrated that all evaluated scoring algorithms, specifically Kwon (cutoff = 3), Chumbler (cutoff = 2), acute ischaemic stroke-associated pneumonia score (AIS-APS) (cutoff = 11), age, atrial fibrillation, dysphagia, sex, stroke severity (A2DS2) (cutoff = 7), and prestroke independence, sex, age, National Institutes of Health Stroke Scale (ISAN) (cutoff = 11) exhibited low positive predictive values (PPV) for SAP at their respective optimal thresholds. This highlights their limited utility in reliably identifying high-risk patients. In contrast, all scores consistently achieved very high negative predictive values (NPV), ranging from 98% to 100%, indicating strong performance in excluding individuals unlikely to develop SAP. These findings suggest that such scoring systems may be more useful for excluding low-risk patients than for definitively identifying high-risk individuals.

The A2DS2 scoring system demonstrates a practical advantage in predicting SAP, with most studies consistently applying a cutoff score of ≥ 5 , yielding moderate sensitivity and specificity (22). In a study by Zhang et al. (23), patients with high A2DS2 scores (5–10) had nearly ninefold increased odds of developing SAP compared to those with lower scores (0–4). Additionally, the risk of in-hospital death was more than seven times higher in the high-score group. These findings underscore a strong association between elevated A2DS2 scores, increased susceptibility to SAP and poorer clinical outcomes.

The AIS-APS has been consistently recognised as one of the most reliable tools for predicting SAP. A systematic review by Ni et al. (22) reported that AIS-APS demonstrated a pooled sensitivity of 79% and specificity of 74%, outperforming other commonly used models such as A2DS2 and ISAN. Furthermore, Zhang et al. (20) found that AIS-APS achieved an area under the curve (AUC) of 0.79, reflecting strong diagnostic accuracy, in comparison to lower AUCs for A2DS2 (0.74) and ISAN (0.76). Despite its strong performance, a standardised cutoff for AIS-APS has not been established (22).

A systematic review by Ni et al. (22) reported that the ISAN score demonstrated a pooled sensitivity of 76% and specificity of 74% in predicting SAP. The diagnostic odds ratio (DOR) was 9, indicating that patients classified as high risk were nine times more likely to develop SAP compared to those at low risk. However, the ISAN scoring system lacks a standardised

cutoff value, with different studies reporting a wide range of optimal thresholds. This variability may limit its consistency and applicability in clinical practice.

A study by Wang et al. (24) compared six internationally recognised scoring systems for predicting SAP in patients with AIS. Among these, the Preventive Antibacterial Therapy in Acute Ischaemic Stroke (PANTHERIS) score demonstrated the weakest discriminatory ability, with the lowest Area Under the Receiver Operating Characteristic curve (AUROC) of 0.660. Despite a high sensitivity of 86.0% at a cutoff value of 1, suggesting it effectively identifies most SAP cases, it had a low specificity of 36.6% leading to a high rate of false positives. Its PPV and NPV were 0.067 and 0.020, respectively, indicating limited precision. This score may be useful in clinical contexts where minimising missed SAP cases is prioritised over reducing false alarms. In contrast, the Kwon Pneumonia score showed a more balanced performance, with an AUROC of 0.703, sensitivity of 63.4% and specificity of 68.9% at a cutoff of 2. It achieved a PPV of 0.097 and an NPV of 0.027, supporting its role as a moderately effective tool for both identifying and excluding SAP cases.

A study by Gong et al. (25) identified an optimal cutoff value of 1 for the Chumbler score in SAP. At this threshold, the score demonstrated a sensitivity of 71.49% and a specificity of 52.93%, with a PPV of 21.66% and an NPV of 91.07%. These findings suggest that the Chumbler score is relatively effective in excluding SAP in low-risk patients, as indicated by its high NPV. However, its ability to accurately identify high-risk individuals is limited due to a low PPV. Among the models evaluated, the Chumbler score exhibited the lowest overall discriminatory performance.

Predictive and prognostic biomarkers of SAP

In light of the challenges associated with diagnosing SAP, recent research has increasingly focused on the exploration of biological markers as promising tools for its early detection. Several biomarkers including international normalised ratio (INR) (26), procalcitonin (PCT) (27), C-reactive protein (CRP) (28), neutrophil-to-lymphocyte ratio (NLR) (29), lactic dehydrogenase to albumin ratio (LAR) (30) have been found to be significantly elevated in patients who develop SAP. These markers reflect systemic inflammation, infection and tissue injury, suggesting a potential role in the early identification and risk prediction of SAP. While promising, these findings require further validation in large, prospective studies to determine their predictive accuracy and practical applicability in clinical settings.

Elevated INR at admission in patients with AIS exemplifies the link between coagulation abnormalities and inflammatory processes underlying SAP. Higher INR reflects enhanced coagulation activation and consumption of clotting factors triggered by brain injury and immune dysregulation after

stroke. This heightened inflammatory and pro-coagulant state not only increases susceptibility to infections such as SAP but is also commonly observed in patients with more severe strokes, who face greater risks of mortality and poor recovery due to complications like impaired consciousness and respiratory compromise. Thus, INR serves as an important early marker connecting stroke severity with SAP development and prognosis (26).

Complementing INR's reflection of coagulation and inflammation, PCT offers a more direct measure of bacterial infection and systemic inflammatory burden. Produced by epithelial cells in response to infection, elevated PCT levels in AIS patients signify an active inflammatory response that exacerbates neuronal damage, endothelial dysfunction and blood-brain barrier breakdown. These pathophysiological changes contribute to worse clinical outcomes and higher mortality in SAP patients. Therefore, PCT not only predicts the risk and severity of SAP but also indicates a poor prognosis linked to amplified inflammation and coagulation abnormalities following stroke (27).

In a similar vein, CRP, an acute-phase protein synthesised in response to pro-inflammatory cytokines, provides valuable prognostic information regarding SAP. Elevated CRP levels on admission and during the early post-stroke phase correlate with greater diagnostic accuracy and increased severity of pneumonia. Moreover, CRP levels have been shown to independently predict worse functional outcomes and higher mortality rates. CRP levels exceeding 25 mg/L demonstrate high sensitivity, while levels above 65 mg/L show excellent specificity for early SAP diagnosis in severe stroke patients. Furthermore, elevated CRP independently predicts worse functional outcomes and higher mortality, with each 10 mg/L increase significantly raising the risk of developing SAP. These findings underscore CRP's utility in early detection and as a prognostic marker of poor SAP outcomes (31).

NLR further expands our understanding of SAP by integrating cellular immune changes after stroke. Elevated NLR reflects the combined effects of post-stroke immunosuppression and systemic inflammation, characterised by neutrophil proliferation and lymphocyte apoptosis that predispose patients to infections like SAP. Additionally, higher NLR correlates with stroke severity and infarct size, both of which are established predictors of SAP and adverse clinical outcomes. Importantly, NLR may also reveal early, subclinical pneumonia not yet clinically apparent, highlighting its role in the timely identification of high-risk patients. Thus, NLR serves as a comprehensive marker linking immune dysregulation, stroke severity and SAP prognosis (29).

Building upon these inflammatory and immune biomarkers, LAR integrates systemic inflammation with nutritional

status, two critical determinants of SAP risk and recovery potential. Elevated Lactate Dehydrogenase (LDH) levels reflect ongoing inflammation and immune suppression, while low albumin indicates poor nutritional reserves and weakened host defences. The combined LAR thus offers a superior predictive value for SAP development, severity and outcomes compared to either marker alone. Moreover, both LDH and albumin influence neuroinflammatory pathways and stroke severity, indirectly modulating SAP risk and patient prognosis. Therefore, LAR not only predicts SAP occurrence but also serves as a marker for poor clinical outcomes, including increased mortality and impaired functional recovery (30).

Management

Non-pharmacologic

Managing SAP effectively requires early detection, prevention and targeted interventions, with prompt treatment helping to reduce morbidity and mortality. Prevention focuses on identifying high-risk patients and addressing key factors like dysphagia and aspiration. Dysphagia significantly increases the risk of pneumonia in stroke patients. Early screening using standardised tools, such as the Gugging Swallowing Screen (GUSS), has been associated with a reduced incidence of SAP. Timely identification of dysphagia and implementation of appropriate dietary modifications can effectively lower this risk (32). High-risk patients should receive individualised dysphagia management, including modified food consistencies, adequate nutritional management and swallowing rehabilitation (13).

Postural modification may prevent aspiration in patients with dysphagia and thus play an important role in the prevention of SAP. Head and neck positioning can significantly influence swallowing efficiency, either hindering or facilitating it, thereby affecting the likelihood of aspiration. In particular, a reclining posture can assist food passage through the use of gravity and is commonly employed to help prevent aspiration (15, 33). Moreover, systemic oral hygiene care is associated

Table 3. Main pathogenic microorganism (35–37).

Early-Onset SAP	Late-Onset SAP
<i>Staphylococcus aureus</i>	<i>Staphylococcus aureus</i>
<i>Streptococcal pneumoniae</i>	<i>Streptococcal pneumoniae</i>
<i>Haemophilus influenzae</i>	<i>Enterobacter cloacae</i>
<i>Moraxella catarrhalis</i>	<i>Escherichia coli</i>
	<i>Klebsiella pneumoniae</i>
	<i>Pseudomonas aeruginosa</i>
	<i>Acinetobacter baumannii</i>

SAP, stroke-associated pneumonia.

with a decreased risk of SAP, likely due to its role in reducing the colonisation of pathogenic oral bacteria, a key factor in the pathogenesis of SAP. This reduction may, in turn, help prevent aspiration and infection (34).

Pharmacologic

The management of SAP requires a carefully individualised approach to antibiotic therapy, with particular attention to the timing of initiation, spectrum of microbial coverage and patient-specific risk factors. Antibiotic therapy should be initiated as soon as possible after confirming SAP, ideally within 4 hr, or within 1 hr if the patient is in sepsis or septic shock (35).

The temporal relationship between stroke onset and pneumonia development should primarily guide antimicrobial selection, as the timing of SAP onset closely correlates with the microbial profile outlined in Table 3. It may be postulated that pathogens typically associated with community-acquired pneumonia (CAP) are more likely to cause early onset SAP (≤ 72 hr), whereas hospital-acquired pneumonia (HAP) pathogens predominate in cases occurring beyond 72 hr (late-onset SAP) (36).

For early onset SAP (occurring within 72 hr post-stroke), antibiotic regimens should target pathogens typically implicated in CAP, including Gram-positive cocci and respiratory organisms such as *Haemophilus influenzae* and *Moraxella catarrhalis*. Recommended agents may include β -lactams in combination with macrolides or respiratory fluoroquinolones. In contrast, late-onset SAP (≥ 72 hr to ≤ 7 days post-stroke) warrants broader antimicrobial coverage to include coliform bacteria, with consideration for anti-*Pseudomonas* agents in patients with prior antibiotic exposure or immunocompromised states. Suitable empirical options may include extended-spectrum β -lactams (e.g. penicillins with β -lactamase inhibitors, third- or fourth-generation cephalosporins, or monobactams), fluoroquinolones, or aminoglycosides. In cases where aspiration is suspected or confirmed, no additional antimicrobial coverage is required beyond that recommended for the timing of pneumonia onset (35).

Owing to limited data on microbial aetiology and marked regional variability in antimicrobial resistance, definitive recommendations regarding specific antibiotic classes or agents for the treatment of SAP could not be established. The choice of antibiotics should be guided by local antimicrobial resistance patterns and patient-specific factors. Routine prophylactic antibiotic use is not recommended, given the lack of evidence supporting its efficacy in preventing SAP and concerns about promoting antimicrobial resistance. Instead, empirical antibiotic therapy should be initiated promptly upon diagnosis. Treatment duration should be at least 7 days and adjusted based on the patient's clinical response, as no

validated biomarkers currently exist to guide therapy length. Likewise, the available evidence was insufficient to support standardised recommendations on antibiotic dosing (35).

Prognosis

SAP is closely associated with poor clinical outcomes, including a significantly increased risk of mortality (2). Reported mortality among SAP patients reaches approximately 19% at 30 days and 44% at 6 months. A study by Tinker et al. (38) identified several independent predictors of both short- and intermediate-term mortality, including advanced age, haemorrhagic stroke subtype and pre-existing disability. Comorbid conditions such as dementia, lung cancer and a prior history of pneumonia were additionally associated with increased risk of 6-month mortality. Furthermore, elevated levels of inflammatory markers, particularly CRP, were found to correlate with greater functional impairment at discharge, highlighting the prognostic significance of systemic inflammation in SAP (38).

Admission of patients with SAP to the ICU is typically not based solely on the diagnosis of pneumonia itself, but rather on the presence of acute clinical decompensation requiring intensive support. Several precipitating factors beyond general predisposing risks, such as advanced age, dysphagia, or comorbidities, have been identified as significant triggers for ICU admission. These include acute respiratory failure necessitating mechanical ventilation, severe neurological impairment (e.g. NIHSS scores >15), reduced consciousness (GCS ≤ 8) and the development of sepsis or septic shock. Both higher NIHSS and lower GCS on admission were independent predictors of in-hospital mortality – underscoring their role in necessitating ICU-level care (39, 40).

Future directions

Future research on SAP should focus on improving early detection, risk stratification and prevention. Although several biomarkers (e.g. PCT, CRP, NLR, INR, and LAR) show promise, large-scale prospective studies are needed to validate their diagnostic accuracy and clinical utility, particularly when combined with risk scores like A2DS2 or ISAN. Randomised controlled trials are also warranted to assess the efficacy of preventive interventions, including early dysphagia screening, individualised swallowing therapy, postural modification, and oral hygiene protocols. Further investigation is needed into the use of prophylactic antibiotics in high-risk patients and the role of biomarkers in guiding the timing and duration of antibiotic therapy. Additionally, given the contribution of stroke-induced immunodepression to SAP pathogenesis, future studies should explore the therapeutic potential of immunomodulatory and nutritional interventions.

These research efforts are essential to inform clinical practice and reduce the burden of SAP.

Conclusion

SAP is a prevalent and serious complication of AIS, significantly contributing to increased morbidity, mortality and healthcare burden (1, 2). Acute stroke triggers SIDS through activation of the SNS, PNS and HPA axis, resulting in the release of catecholamines and glucocorticoids and a reduction in pro-inflammatory cytokines, which collectively weaken immune defences and increase the risk of pneumonia (7–9). Although diagnostic methods have advanced, early detection of SAP remains challenging, and existing predictive scores and biomarkers require further validation (19, 26–30). Preventive strategies, particularly dysphagia management and oral hygiene, are crucial, while treatment must be prompt and personalised (32, 35). Future research should focus on enhancing risk prediction, validating reliable biomarkers and establishing standardised treatment protocols to reduce the impact of SAP.

Informed Consent Statement

Informed consent was not required for this study.

Conflicts of Interest

The authors declare no conflict of interest.

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