〈Regular Article〉

Radiological Patterns and Clinical Characteristics of Pneumococcal Pneumonia in Older Adults: A Retrospective Cohort Study

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ABSTRACT **Background**: Pneumococcal pneumonia is a major cause of mortality among the older adult population. Chest computed tomography (CT) findings can be broadly classified into three radiological types: alveolar, bronchopneumonia, and ground glass opacity (GGO) types. However, the clinical differences between these phenotypes remain poorly understood. This study aimed to clarify the clinical characteristics associated with each radiological type in patients aged 65 years and older.

Methods: We retrospectively analyzed 184 patients hospitalized with pneumonia between April 1, 2011, and December 31, 2021, who tested positive for *Streptococcus pneumoniae* urinary antigen. Patients were classified into three groups based on chest CT findings: alveolar (n = 84), bronchopneumonia (n = 71), and ground-glass opacity type (n = 29). We compared the clinical features of these groups, including demographic characteristics, activities of daily living (ADL), inflammatory markers, and nutritional indicators.

Results: ADL significantly deteriorated in all groups (Bowker's test: alveolar, $p = 0.046$; bronchopneumonia, $p < 0.001$; GGO, $p = 0.0498$). Although the extent of decline did not differ significantly among the groups (Kruskal-Wallis test, $p = 0.53$), the pattern of changes in ADL tended to be different among the three types. The mortality rate was higher in the alveolar group (7 / 84, 8.3%) compared with the non-alveolar group (5 / 100, 5.0%) (Fisher's exact test, $p = 0.024$). Procalcitonin (PCT) levels were significantly higher in the alveolar group than in the bronchopneumonia group ($p = 0.04$), while there was no significant difference in the nutritional findings.

Conclusion: Among the three types of pneumococcal pneumonia, the alveolar type exhibited distinct clinical features, characterized by a higher frequency of COPD, increased mortality, and

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elevated PCT levels, compared with the other two types. In contrast, no significant differences were observed between the bronchopneumonia and ground-glass opacity patterns in the clinical findings investigated in this study.
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Key words：Pneumococcal pneumonia, Older adults, CT imaging, activities of daily living, Procalcitonin

INTRODUCTION

In Japan, pneumonia is the fifth leading cause of death according to the 2020 Vital Statistics issued by the Ministry of Health, Labour, and Welfare[1]. When aspiration pneumonia, which has been classified separately since 2017[2], is included with pneumonia, the combined total becomes the fourth leading cause of death and makes a substantial contribution to mortality. Over 96% of pneumonia-related deaths occur in individuals aged 65 years or older, and *Streptococcus pneumoniae* is known as one of the most common causative organisms[3]. Preventing pneumococcal pneumonia in older adults is a pressing public health issue, and pneumococcal vaccination is recommended for individuals aged 65 years and older[4].

Respiratory diseases exhibit a wide variety of clinical manifestations and understanding this diversity has become increasingly important for determining appropriate treatment strategies. For example, chronic obstructive pulmonary disease (COPD) can be broadly classified into emphysematous and non-emphysematous types based on computed tomography (CT) imaging findings, whereas bronchial asthma can be divided into type 2 and non-type 2 inflammation according to the underlying inflammatory profile[5, 6]. Furthermore, pulmonary tuberculosis and a wide range of radiological patterns have been reported, including typical findings, such as infiltrates and cavities, pleurisy, miliary tuberculosis, and atypical opacities[7].

This diversity in disease presentation is associated not only with internal factors such as the host's immunity, nutritional status, and genetics but also with external factors such as lifestyle and living environment. It is also associated with clinical heterogeneity[8, 9]. In pneumococcal infections, immunocompromised hosts develop a range of conditions beyond pneumonia, including bacteremia, otitis media, and meningitis[10]. Thus, understanding both the pathological diversity and clinical characteristics is crucial for the development of appropriate treatment strategies.

In pneumococcal pneumonia, CT findings are generally classified into three major types: alveolar type, bronchopneumonia type, and ground-glass opacity type[11]. However, the relationship between radiological diversity and the clinical characteristics of pneumococcal pneumonia remains unclear. In this study, we aimed to clarify the association between radiological patterns and clinical features by classifying older patients (aged ≥ 65 years) with pneumococcal pneumonia into three groups based on CT findings and analyzing differences in their clinical characteristics.

MATERIALS (SUBJECTS) AND METHODS

Study population

We retrospectively reviewed the medical records of patients ≧ 65 years of age who were admitted to our hospital with a diagnosis of pneumonia between April 1, 2011, and December 31, 2021. Among them, only those with positive urinary pneumococcal antigen test results were included in the study.

CT interpretation and radiologic classification

CT images obtained at admission were independently assessed by a board-certified radiologist and two board-certified pulmonologists. Discordant interpretations were resolved by

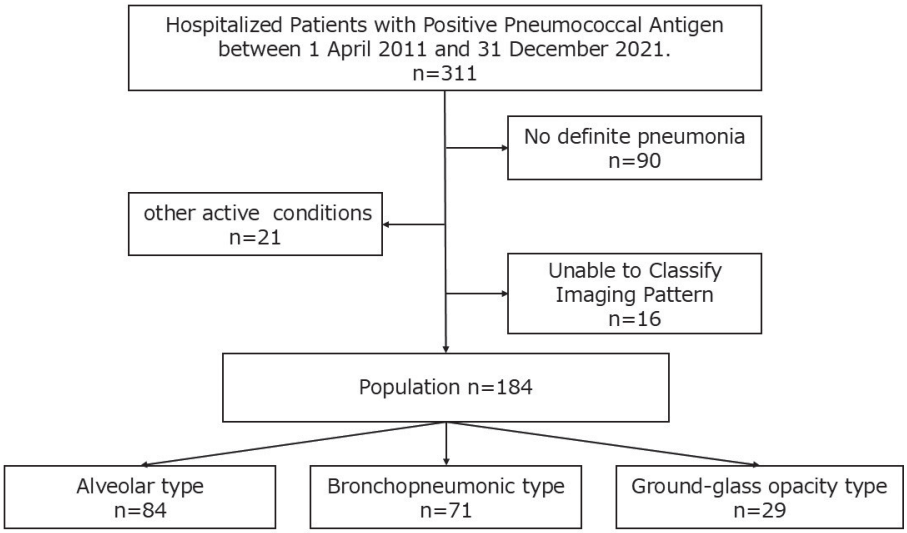

Fig. 1. Study Population
Flow diagram illustrating the inclusion and exclusion criteria for the final study cohort. Of the 311 patients aged ≥ 65 years with pneumococcal pneumonia, 184 were classified into three CT radiological types based on eligibility.

consensus. Based on CT findings, the cases were classified into three radiological patterns:

1. Alveolar pneumonia type - predominantly consolidation.
2. Bronchopneumonia type - predominantly peribronchial / perivascular opacities.
3. Ground-glass opacity (GGO) type - predominantly ground-glass opacities.

Cases were excluded if (ⅰ) no definite pneumonia was observed, (ⅱ) multiple patterns coexisted without a dominant pattern (classified as Unable to Classify Imaging Pattern in Fig. 1), or (ⅲ) other active conditions likely to influence CT findings (e.g., heart failure and acute exacerbation of interstitial lung disease) were present. All chest CT examinations were performed immediately after hospital admission using a multi-detector CT scanner (Aquilion Prime SP, Canon Medical Systems, Japan). Scanning parameters were as follows: tube voltage, 120 kV; tube current, automatic exposure control (range 50-350 mA, SD: 10); rotation time, 0.5 s per rotation; helical pitch, 65 (standard) or 111 (high-speed); and slice thickness, 5 mm. Images were reconstructed with a lung algorithm (FC53 / AIDR 3D Weak).

Clinical variables compared across radiologic groups

- Baseline pulmonary comorbidities, including chronic obstructive pulmonary disease (COPD), interstitial lung disease (ILD), bronchiectasis, lung cancer, and lung abscess, were identified based on medical record review and chest CT findings, and were analyzed as underlying pulmonary diseases.
- Patient characteristics included age, sex, smoking history, comorbidities quantified using the Charlson Comorbidity Index[12] (CCI), and length of hospital stay.
- Activities of daily living (ADL): On admission, patients were categorized as independent ambulation, partial assistance, or total assistance / bedridden. The same assessment was repeated at discharge, including deceased patients. ADL

status at both time points was classified by the authors using this three-level scale, based on the information documented in the medical records.

- Inflammatory markers: Blood tests were obtained within 24 hours of hospital admission. White blood cell count (WBC, /μL), C-reactive protein (CRP, mg/dL), procalcitonin (PCT, ng/mL), and lactate dehydrogenase (LDH, U/L).
- Nutritional status: Body mass index (BMI, kg/m^2), total protein (TP, g/dL), albumin (Alb, g/dL), and cholinesterase (ChE, U/L).

Statistical analysis

Continuous variables are presented as the mean ± standard deviation or median (interquartile range). Comparisons between the three groups were performed using the Kruskal-Wallis test. When significant differences were detected, pairwise comparisons were conducted using Dunn's post-hoc test with the Bonferroni correction. Categorical variables were compared using Fisher's exact test. Changes in ADL status between admission and discharge were assessed using Bowker's test of symmetry. Statistical significance was defined as a two-sided p-value of < 0.05, and the study protocol was reviewed and approved by the Ethics Committee of Kawasaki Medical School (approval No. 5080-01).

RESULTS

Patient characteristics

Among the 311 patients ≧ 65 years of age who were hospitalized with pneumonia and had a positive urinary pneumococcal antigen test, 184 met the radiologic eligibility criteria: 84 with the alveolar pneumonia type, 71 with the bronchopneumonia type, and 29 with the GGO type (Fig. 1).

- **Age**. Mean ages were 81.2 ± 8.5 years (alveolar), 82.2 ± 8.9 years (bronchopneumonia), and 80.8 ± 7.9 years (GGO), with no significant inter-group difference ($p = 0.68$).
- **Demographics and comorbidity burden.** Sex distribution, smoking history, CCI scores, and length of hospital stay based on comorbidity assessments did not differ significantly among the three groups (Table 1).
- **Age distribution by radiologic pattern.** In patients aged < 90 years, the alveolar pattern was the most common, followed by the bronchopneumonia and GGO patterns. In patients ≥ 90 years, the bronchopneumonia pattern accounted for approximately half of cases, whereas, when analyzed by age group, the proportion of GGO patterns decreased in the higher age strata (< 70, 70-79, 80-89, and ≥ 90 years) (Fig. 2).

Table 1. Patient Characteristics

Patient characteristics	Alveolar (n = 84)	Bronchopneumonia (n = 71)	GGO (n = 29)	*P* value
Age (years)	81.2 ± 8.5	82.2 ± 8.9	80.8 ± 7.9	0.68
Sex (Male/Female) n (%)	Male：48 (57.1%) Female：36 (42.9%)	Male：37 (52.1%) Female：34 (47.9%)	Male：15 (51.7%) Female：14 (48.3%)	0.78
Smoking History n(%)	38 (45.2)	28 (39.4)	12 (41.3)	0.76
Charlson comorbidity index (CCI)	5.9 ± 2.0	5.8 ± 1.9	5.3 ± 1.5	0.43
Length of Hospital Stay (days)	14	15	13	0.56

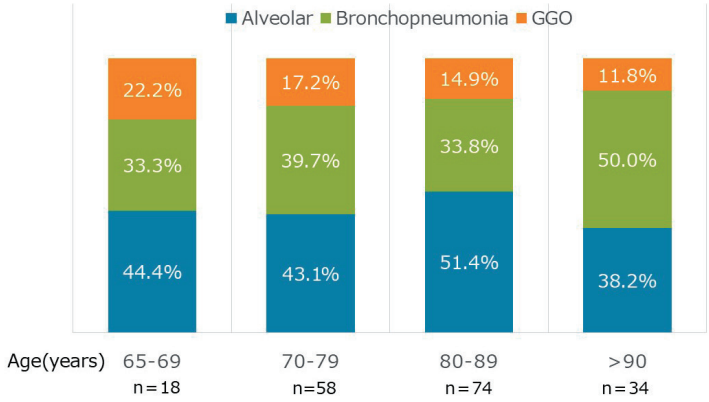

Fig. 2. Age Distribution
Bar graph showing the distribution of alveolar, bronchopneumonia, and GGO types stratified by age.

Table 2. Comorbid Pulmonary Diseases by Imaging Pattern of Pneumococcal Pneumonia

Pulmonary comorbidities	Alveolar (n = 84)	Bronchopneumonia (n = 71)	GGO (n = 29)	Total (n = 184)
COPD	13 (15.5%)	5 (7.0%)	0	18 (9.8%)
COPD + Lung cancer	1 (1.2%)	0	0	1 (0.5%)
COPD + Bronchiectasis	0	1 (1.4%)	0	1 (0.5%)
COPD + Interstitial lung desease	0	0	1 (3.4%)	1 (0.5%)
Interstitial lung desease	1 (1.2%)	0	0	1 (0.5%)
Bronchiectasis	1 (1.2%)	2 (2.8%)	0	3 (1.6%)
Lung abscess + Lung Cancer	1 (1.2%)	0	0	1 (0.5%)
Total	17 (20.2%)	8 (11.3%)	1 (3.4%)	26 (14.1%)

Values are expressed as n(%). Fisher's exact test: overall prevalence was not significant amongg roups(p = 0.055). COPD was more frequent In the alveolar group(p = 0 .048).

• **Underlying pulmonary diseases.** Pre-existing lung disorders were most frequent in the alveolar group: COPD in 13 patients (15.5%), COPD + lung cancer in one patient (1.2%), interstitial lung disease (ILD) in one patient (1.2%), bronchiectasis in one patient (1.2%), and lung abscess + lung cancer in one patient (1.2%). In the bronchopneumonia group, COPD was present in five patients (7.0%), bronchiectasis in two (2.8%), and COPD + bronchiectasis in one (1.4%). In the GGO group, COPD + ILD was present in one patient (3.4%). Thus, the alveolar pattern showed the highest prevalence of preexisting lung diseases, particularly COPD (Table 2). Statistical analysis revealed that the overall prevalence of underlying pulmonary diseases tended to differ among the three radiologic groups (Fisher's exact test, p = 0.055). In particular, COPD was significantly more frequent in the alveolar group compared with the combined non-alveolar group (bronchopneumonia and GGO) (p = 0.048).

ADL

At admission, independent ambulation was least frequent in the bronchopneumonia group (54.9%). The GGO group had the highest proportion of patients who required total assistance or who were bedridden (34.5%) (Table 3). The post-pneumonia ADL scores significantly deteriorated across all

Table 3. Comparison of ADL Among Pneumonia Groups

ADL at admission	Alveolar (n = 84)	Bronchopneumonia (n = 71)	GGO (n = 29)
Independent ambulation	54 (64.3%)	39 (54.9%)	17 (58.6%)
Partial Assistance	10 (11.9%)	16 (22.5%)	2 (6.9%)
Full Assistance	20 (23.8%)	16 (22.5%)	10 (34.5%)

ADL at discharge	Alveolar (n = 84)	Bronchopneumonia (n = 71)	GGO (n = 29)
Independent ambulation	40 (47.6%)	28 (39.4%)	11 (37.9 %)
Partial Assistance	11 (13.1%)	21 (29.6%)	6 (20.7%)
Full Assistance	17 (20.2%)	19 (26.8%)	10 (34.5%)
Death	16 (19.0%)	3 (4.2%)	2 (6.9%)

Values are expressed as n (%). Bowker's test: ADL significantly deteriorated within each group (alveolar, $p = 0.046$; bronchopneumonia, $p < 0.001$; GGO, $p = 0.0498$). Kruskal-Wallis test: no significant difference in the extent of ADL decline among the three groups ($p = 0.53$).

Table 4. Laboratory Findings in Each Pneumonia Group

Inflammatory markers	Alveolar	Bronchopneumonia	GGO	*P* value
WBC (/μL)	10775 [6580 - 14978]	11260 [7215 - 15745]	10540 [8520 - 13930]	0.88
CRP (mg/dL)	7.8 [2.9 - 15.6]	7.6 [3.6 - 13.9]	5.6 [1.6 - 13.6]	0.41
LDH (U/L)	241 [198 - 300]	243 [206 - 293]	250 [211 - 320]	0.85
PCT (ng/mL)	1.09 [0.18 - 6.45]	0.20 [0.08 - 2.02]	0.53 [0.14 - 0.79]	0.04

Nutritional markers	Alveolar	Bronchopneumonia	GGO	*P* value
TP (g/dL)	6.5 [6.0 - 7.0]	6.7 [6.2 - 7.1]	6.8 [6.5 - 7.1]	0.21
Alb (g/dL)	3.0 [2.6 - 3.6]	3.2 [2.8 - 3.7]	3.3 [3.1 - 3.6]	0.13
ChE (U/L)	178 [127 - 250]	193 [150 - 232]	197 [164 - 266]	0.35
BMI (kg/m^2)	19.5 [17.0 - 21.4]	19.5 [17.0 - 21.9]	19.5 [17.0 - 21.4]	0.99

three groups (Bowker's test: alveolar, $p = 0.046$; bronchopneumonia, $p < 0.001$; GGO, $p = 0.0498$), although the extent of decline did not differ significantly among the groups (Kruskal-Wallis test, $p = 0.53$). The mortality rate was higher in the alveolar group (7 / 84, 8.3%) compared with the non-alveolar group (5 / 100, 5.0%) (Fisher's exact test, $p = 0.024$). However, pairwise comparisons among the three groups revealed no statistically significant differences (all $p > 0.05$).

Inflammatory markers

Among the inflammatory markers, no significant differences were observed in WBC, CRP, or LDH levels among the three groups. However, PCT levels differed significantly ($p = 0.04$), with post-hoc analysis (Dunn's test with Bonferroni correction) revealing a significant difference between the alveolar and bronchopneumonia groups (adjusted $p = 0.04$). No significant differences were observed in the other pairwise comparisons (Table 4). Notably, several alveolar-type cases exhibited markedly elevated PCT levels. WBC count and CRP levels also tended to be higher in the alveolar group, although the difference was not significant.

Nutritional indices

No significant differences were observed among the three groups in terms of nutritional parameters (TP, Alb, ChE, and BMI) (Table 4). However, the alveolar group showed a tendency toward lower values for all nutritional indicators except for BMI,

suggesting possible malnutrition.

DISCUSSION

In this study, we classified pneumococcal pneumonia in older patients into three categories—alveolar type, bronchopneumonia type, and GGO type—based on chest CT findings, and investigated the differences in clinical characteristics among these groups.

Among patients aged < 90 years, the alveolar type was most frequently observed, although non-alveolar types collectively accounted for approximately half of the cases. In patients aged 90 years, the bronchopneumonia type represented half of all the cases. This suggests that a variety of radiological patterns, including non-alveolar types, may be observed in older patients with pneumococcal pneumonia, and caution is needed when making diagnoses based on imaging. The high frequency of the non-alveolar types in the elderly may be attributed to age-related changes and underlying lung diseases, potentially resulting in (1) reduced neutrophil chemotaxis and attenuated local immunity[13], (2) microaspiration into the airways due to impaired swallowing function[14], and (3) vaccination[15]. The predominance of the bronchopneumonia type in patients aged ≥ 90 years suggests that dysphagia plays a particularly important role in this subgroup.

Additionally, the alveolar type was associated with a higher prevalence of coexisting pulmonary conditions, especially COPD. This finding indicates that local pulmonary dysfunction, such as impaired mucociliary clearance, may contribute to the development of alveolar-type pneumonia[16]. However, as our study included only patients aged ≥ 65 years, direct comparison with younger populations was not possible, and further studies including younger cohorts will be needed to clarify age-related differences in radiological patterns.

All groups exhibited a decline in ADL following pneumonia. Older patients hospitalized for pneumonia may experience a decline in functional status even if the pneumonia resolves with treatment[17]. The observed decline in ADL during hospitalization may not only reflect the direct impact of pneumonia itself but also the multifactorial influences of prolonged hospitalization, disuse syndrome, and age-related functional decline.

In this study the mortality rate was significantly higher in the alveolar group compared with the non-alveolar groups (Fisher's exact test, $p = 0.024$). The result demonstrated that the alveolar type may predict the poor prognosis of the pneumonia. The extensive lesions observed in the alveolar type may contribute to impaired oxygenation, potentially leading to higher mortality. Although statistical analysis did not demonstrate a significant difference in the overall ADL magnitude of decline among the three groups (Kruskal-Wallis test, $p = 0.53$), the pattern of changes in ADL tended to differ among the three types. The GGO type had a high proportion of patients requiring total assistance or who were bedridden at admission; however, after the illness, fewer patients became bedridden, and many declined only from independent ambulation to partial assistance. Patients with bronchopneumonia type tended to deteriorate to a state of total dependence or bedridden status. In the alveolar type, no remarkable changes in ADL were observed except among patients who died. The relationship between the radiological findings and the patterns of ADL change need to be further investigated, because the number of enrolled subjects in this study was insufficient.

Regarding inflammatory markers, PCT levels were significantly higher in the alveolar group, whereas general markers such as WBC count and CRP did not differ significantly among the groups. PCT is useful for assessing the severity of bacterial pneumonia and diagnosing sepsis[18]. Our findings suggest that in the alveolar type, some cases may

involve a more pronounced host response to *S. pneumoniae*, potentially due to severe bacterial infections such as sepsis.

S. pneumoniae has a wide variety of serotypes, with serotype 3 being associated with a higher risk of severe disease[19]. Serotypes with thick capsules are more capable of evading host immune responses and spreading into the alveolar spaces, thereby forming widespread pulmonary lesions[20]. Some reports have suggested that different serotypes present with distinct radiological findings[21]. These findings indicate the need for further investigation into the relationship between bacterial characteristics and imaging features.

Although we hypothesized that nutritional status might influence radiologic presentation, no significant differences in nutritional indices were observed among the three groups. Therefore, we were unable to identify the specific host factors that determined the radiological phenotypes in this study. Factors, such as impaired pulmonary function, age-related dysphagia, pneumococcal serotype variation, and vaccination status, remain important areas for future research.

Our study has some limitations. Firstly, vaccination status, which is an important host-related factor, could not be confirmed. Secondly, pneumococcal serotyping was not performed, which precluded the assessment of potential associations between serotypes and imaging patterns. Finally, PCT measurements were introduced in the later years of the study period, resulting in a limited number of cases available for PCT analysis. These limitations may affect the generalizability and comprehensiveness of our findings.

CONCLUSIONS

Among the three types of older patients with pneumococcal pneumonia, the alveolar type exhibited distinct clinical features in frequency of COPD, mortality, and PCT level compared with the other two types while there were no significant differences between the bronchopneumonia and GGO patterns in the clinical findings investigated in this study. To gain deeper insights into the determinants of radiological phenotypes in pneumococcal pneumonia, future studies should incorporate both host-related factors, such as swallowing function and local pulmonary status, and pathogen-related factors, including pneumococcal serotypes and vaccination history.

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